# Humanitarian Engineering

## Advancing Technology for Sustainable Development



# Kevin M. Passino

# Humanitarian Engineering:

## Advancing Technology for Sustainable Development

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$3^{rd}$ Edition

MATLAB and Simulink are trademarks of MathWorks.

In memory of my father, Stan Passino (1933-2013),
my role model for taking action to promote social justice.

To my mother, Mary Dolores Passino, the reason I am an engineer.
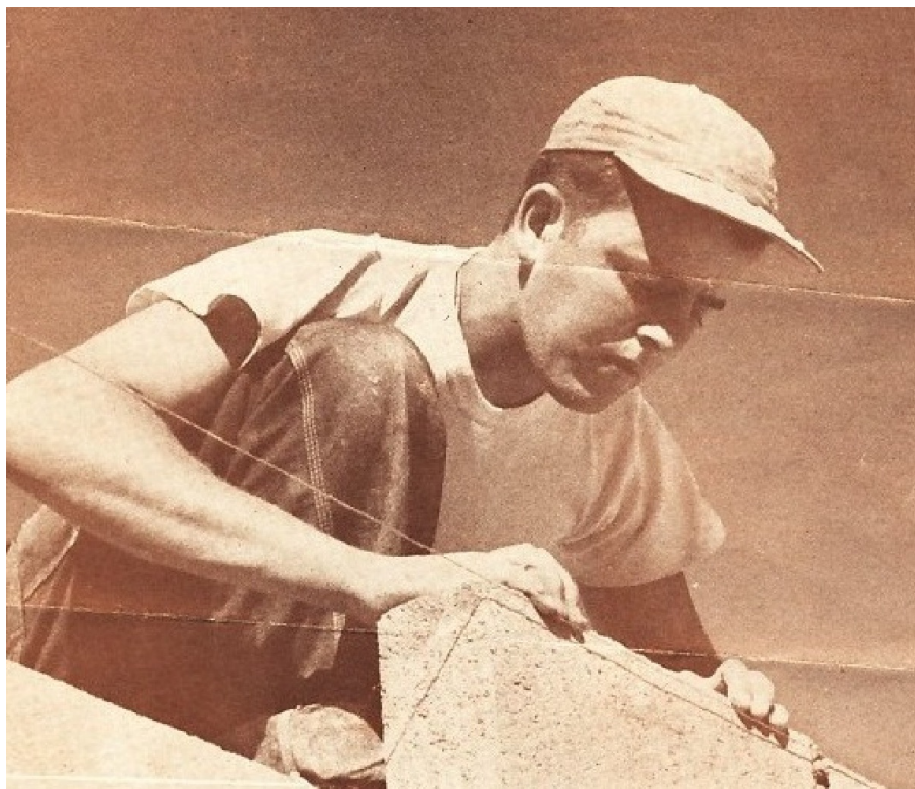


Stan Passino, bricklayer, circa 1956, doing volunteer work (laying block).

*If you want to help fix the mess,*
*you have to be a part of the mess,*
*and learn to love the mess.*

*Unknown origin*

# Preface

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## Preface Contents

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*I shall pass through this world but once. Any good, therefore, that I can do or any kindness I can show to any human being, let me do it now. Let me not defer it or neglect it, for I shall not pass this way again.*

*Stephen Grellet*

*The purpose of human life is to serve, and to show compassion and the will to help others.*

*Albert Schweitzer*

Ending poverty and promoting human development, in a socially inclusive and environmentally sustainable manner, is the greatest challenge of our era. This book examines the role of engineering in humanity's quest to meet this challenge. Social justice is used here to define broad goals, including human dignity, equal rights and social inclusion, along with environmental justice. Development strategies for improving the human condition covered here include approaches from development economics, health, education, and business. Engineering for sustainable community development, here via "participatory development," provides an approach for engineers to cooperatively work with people on location to identify needs and resources, develop technology solutions, and assess impact. For a two-page summary of the key ideas of this book see "The 10 Principles of Humanitarian Engineering" on page .

## Definitions and Focus

The following definitions explain the focus of this book:

- *Technology:* Technology is often thought of as "a tool that extends human capability" or more generally "anything that extends human capability." The New Oxford American Dictionary defines technology as "the application of scientific knowledge for practical purposes." Examples of technology abound (e.g., clothes, shoes, hammers, stoves, fertilizer, medicine, buildings, vehicles, roads, bridges, phones, computers, and the internet).

- *Engineering:* Engineering can be defined as "the use of science and mathematics to invent, create, design, develop, improve, modify, or apply technologies." Or, more simply, "engineering advances technology."

- *Development:* The word "development" in this book means human development and effects on it (e.g., health, education, inequality, and economic). A key issue here is how engineers should advance technology so that it positively affects development.

- *Sustainable development:* The "Brundtland Commission" (BC, 1987) provided the following widely accepted definition: "Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs." The United Nations released 17 "sustainable development goals" (SDGs) for 2016-2030. These goals emphasize ending poverty and promoting development, in a socially inclusive manner, while ensuring environmental sustainability. In this book, there will be an emphasis on "engineering for sustainable community development."

- *Humanitarian:* The word "humanitarian" has been defined as being "concerned with or seeking to promote human welfare" (New Oxford American Dictionary). This is quite a bit broader than typical interpretations of

this word since in addition to (short-term) disaster relief it also applies to long-term development challenges everywhere, from individuals and local communities, to international sites. Here, the meaning of "human welfare" is defined via "social justice" which here is defined as "standards for, and a view on how to promote, human dignity, rights, fulfillment for all of humanity."

The title of this book, *Humanitarian Engineering: Advancing Technology for Sustainable Development*, has a subtitle that defines the focus of the book and the type of humanitarian engineering that is considered. However, there is a problem with the use of the word "humanitarian" that requires some explanation. In spite of the above dictionary definition, the word "humanitarian" is typically reserved for short-term disaster relief ("emergency response" and "humanitarian aid"), and considered inappropriate for describing long-term development work. However, the terms "humanitarian engineering" and "humanitarian technology" are frequently used in engineering (e.g., in the names of journals and conferences, such as those listed starting on page 724) when referring to either disaster relief *or* development and this approach, one consistent with the dictionary definition of "humanitarian," will be used here.

While the focus here is on the advancement of technology for development, specific technologies are discussed in this book only to provide concrete examples; there is no intent to provide an exhaustive "handbook" or "field guide" for humanitarian technology or more specifically, "appropriate technology." I have confidence in people's ingenuity. Given the challenges, goals, methodology, and constraints detailed in this book, individuals can create technologies that fulfill humanitarian needs today and in the future. A book focused on today's technologies would necessarily repeat a significant amount of material that is freely available from a number of sources, and would likely soon be out of date due to the invention of new technologies.

> The type of humanitarian engineering considered here is the advancement of technology for sustainable development.

## Book Organization and Themes

To picture the organization of this book, consider Figure 1. Chapter 1, entitled "Poverty, Sustainability, and Culture," and shown on top left of the diagram, defines *challenges*, and explores the role of the engineer in sustainable development. Chapter 2, "Social Justice," shown on the bottom left of the diagram, specifies local and global *goals* for humanitarian engineering. Chapter 3, "Development Strategies," shown in the center, provides *general methods* to move current conditions (e.g., economic, health, and educational) to improved conditions so that social justice goals are met. Development strategy choice and implementation, which depend on conditions and goals and may need to be dynamically adjusted, are crucial to "convergence" of the development process, where convergence can be defined, for instance, by reduction of inequalities (e.g., economic or participatory), so that social justice is promoted. Chapter 4, "Engineering for Sustainable Community Development," shown on the right side, uses the content of all the previous chapters and, via local, "bottom-up," and

"participatory" development, addresses *community-identified needs* via *community/engineering cooperative* creation of sustainable technological solutions. The first three chapters provide broad background for Chapter 4, which is arguably the most important chapter for engineers who are working "on the ground" with people to promote development in communities. Due to its importance, Chapter 4 is designed so that it can be read independent of the first three chapters. There is quite a bit of material, that is not covered in the chapters, in the homework problems at the ends of the four chapters. The annotated bibliographies at the ends of each of the four chapters provide the references that were used and additional references to explore. There are a number of "Supplements" provided at the end of the book (e.g., questions for discussion, information sources, and recommended further study).
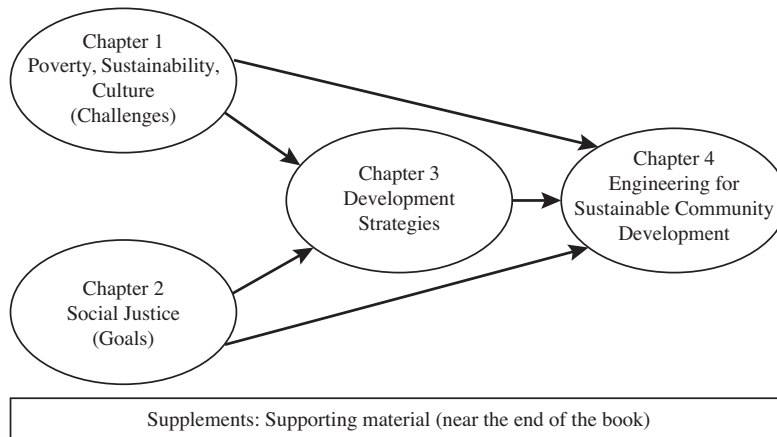


Figure 1: Book organization.

You will see that modeling, dynamics, feedback control, optimization, and cooperation are underlying themes of this book (these are my own areas of technical expertise). At the end of each chapter there is a technical section with material along these lines. In Section 1.6, models, dynamics, and feedback control for a financial advisor for a low-income person are developed and analyzed. Also, there is an analytical study of the "tragedy of the commons" to provide insights into environmental sustainability. In Section 2.4, wealth distribution policies, and democracy, for a community are developed; these are distributed feedback and optimization methods that achieve types of cooperation. Also, an environmental justice policy is discussed in the context of analysis of sustainability. In Section 3.6, modeling and analysis of poverty traps, technology diffusion, and capital investment are studied, and this includes feedback control for spending and capital investment along with wealth distribution and democracy at the higher level. It also includes an approach to feedback control for an environmental policy. In Section 4.12, modeling and analysis of "sociotechnological dynamical systems" are studied and, in particular, cooperative

*Central themes include modeling, dynamics, feedback, and cooperation via participation.*

management of community technologies is studied using a distributed feedback control method. Moreover, modeling and analysis of how technologies affect sustainable community development are studied. Finally, the Matlab code that is provided in conjunction with the topics in the technical sections, and some homework problems, provides a convenient vehicle to explore many technical ideas beyond what homework problems ask for, or the book covers.

## e-Book Navigation

Providing an e-book provides a number of advantages, including: (i) not cutting down trees in order to learn (sustainable education); (ii) easy navigation and electronic search (e.g., for keywords of interest, so there is no need for a book index); and (iii) the potential to view the document on many different devices. A single .pdf file of the book is provided to facilitate (ii) and (iii). For this .pdf file:

Try clicking on any color text to quickly learn how to navigate the book (except in this section).

- In .pdf viewers like Acrobat Reader (free) or Acrobat Pro, there is a "side panel" that can be opened that holds "Bookmarks." These make it easy to move to all major parts of the document.

- Another way to move around the .pdf file of the book is to use "Page Thumbnails" that is a panel on the left side of Adobe Reader and Adobe Acrobat.

The following features have been added to make it easier to navigate the electronic .pdf file of the book by jumping to key referenced entities:

1. Numbers, text, page numbers, or mathematical symbols in red are "clickable" and lead to a page, equation, table, figure, problem, notation and acronyms, chapter, section, or subsection (for these last three, it provides, via the table of contents, and mini-tables of contents at the start of each chapter, another easy way to move around the document).

2. Bibliographic citations are in green and are clickable and take you to the Bibliography at the end of the book. In the Bibliography, at the end of each citation, there is a list of page numbers in red that are clickable and take you to the page where the citation was made (i.e., "back referencing"). In the "Notation and Acronyms" list, at the end of each entry, there is a page number in red that is clickable and it will take you to the page where the reference was made.

3. Text in blue is clickable and takes you *outside* the document to your web browser to see a web site. If, for blue text, rather than clicking you do a "rollover" ("mouseover" where the mouse is moved and the pointer is on top the blue), in many .pdf viewers the web site link (URL) pops up if you hover, during rollover, for a brief time. If a link is broken, as sometimes they are, please try to use your search engine to find the web site by searching on the words describing the link contents.

Colors in this section are *not* clickable, and are only used to illustrate the colors to watch for. Anywhere else in the book, clicking on red text, numbers, or symbols or bibliographic citations takes you to places *internal* to the document, while clicking on blue text and numbers takes you to a web site *external* to the document.

To navigate back to where you were after clicking on red text, numbers, or symbols or bibliographic citations, it is possible to use a simple key stroke (or button, depending on your .pdf viewer) to return to the location or view you were at before the click. For example, if you use Adobe Acrobat, you can go to the "View" menu under "Page Navigation" and click on "Previous View" to go back to where you were (or use the key stroke of "command-left arrow," on the Macintosh). Alternatively, if you are on a PC under Windows, and are using Acrobat Reader, then you use the key stroke "Alt-left arrow" to obtain the "Previous View."

*Click, jump, and use a key-stroke to jump back.*

## Latest Book Edition, On-Line Courses, Extras

At the web site for this book

https://hebook.engineering.osu.edu

there is:

1. Information about how to obtain the book, current/latest, and past editions (download at no cost);

2. Matlab/Simulink code used in this book (in the bodies of chapters and in homework problems);

3. Electronic reports and papers; and

4. Other resources.

At the web site for classes based on this book

https://hecourse.engineering.osu.edu

there are free:

1. Electronic lecture slides;

2. On-line videos of lectures (semester-long course at The Ohio State University (OSU) and short courses);

3. Syllabus and assignments; and

4. Syllabus for a follow-on course called "Computational Humanitarianism" at OSU, that builds on the technical parts of this book.

# Gratitude for Help

I would be grateful for inputs, suggestions, and feedback on this book and the courses via

<div align="center">

[passino.1@osu.edu](mailto:passino.1@osu.edu)

</div>

I have already obtained many people's kind inputs over the years that have, in the spirit of volunteerism, helped me develop and improve this book and the corresponding course. Listed below, in no particular order, are individuals and groups who have helped.

**Individuals:** My PhD students, Luis Felipe Giraldo Trujillo from Colombia, Hugo J. Gonzalez Villasanti from Paraguay, and Isabel Fernandez Puentes from Colombia have helped with some code development, checked the modeling and analysis parts of the book, suggested some homework problems, found relevant literature on technical subjects, and worked with me on research on several of the topics in this book. Felipe Giraldo is now a professor at the Universidad de Los Andes, Bogotá. Maggie McHugh, an OSU student, helped by doing research on several topics that helped with initial course development, and this impacted the book also. Molly Moran, an OSU graduate student, has taught me by working with her on local engineering service projects. Destiny Allen helped me with the sociology perspective by connecting me to some literature and faculty at OSU in sociology; she also helped with some other suggestions. Stephanie DeTillio and Mary Scherer provided helpful suggestions on STEM education issues, and Valerie Hager identified some useful sources on international STEM education for me. Alex Aurand gave inputs on the environmental justice simulations. Lianna Brown, Emily Reed, Mary Lenk, Megan Pearson, and Pallavi Keole either found bad links, helped find parts that were not clearly written, or provided some source material. All these were OSU students. Prof. Bob Gustafson of OSU has given very helpful encouragement, help, and input, especially on the course associated with this book. Betty Lise Anderson, a Professor in the Dept. Electrical and Computer Eng. at OSU has taught me much about STEM education and works with me on STEM education projects (this "iSTEM," program is discussed later in the book). Prof. Andrea Serrani has helped me on nonlinear analysis and control, particularly for the financial advisor. Mr. Roger Dzwonczyk, Dr. John Merrill, and Dr. Howard Greene of OSU have run many courses and international project trips in Honduras, and other countries, for humanitarian engineering (one since 2005) and have provided me with a number of inputs over the years. Prof. Michael Hagenberger has provided me with a very useful Civil Engineering perspective. Dr. Greg Bixler of OSU and the nongovernmental organization (NGO) "Design Outreach" provided some sources and edits. Prof. Lisa Fiorentini, in the Dept. Electrical and Computer Eng., is working a the development of a "basic utility vehicle" and has taught me about that problem, and issues in project management. Dr. Joseph Campbell has worked with me on a paper in humanitarian engineering and provided advice on rural sociology. Dr. Don Hempson

*I welcome feedback that will help improve this book.*

a professor at the Colorado School of Mines helped with aspects of participatory development. Prof. Manuel Betancur, of Universidad Pontificia Bolivariana in Medellín, Colombia helped me learn about issues in Colombia, and hosted me there several times. Prof. Nicanor Quijano, of Universidad de Los Andes, Bogotá, Colombia provided input on global poverty issues and has been an ongoing partner, indeed the leader and originator, of the university development project that will be described later in this book ("weLab"). Prof. Jorge Finke, of Pontificia Universidad Javeriana, Cali, Colombia provided inputs on several issues with the book (e.g., ideas for survey questions to ask students), inputs on STEM education, and good information on corruption. Also, Jorge and Nicanor (both past students of mine) taught me a lot about Colombia, hosted me there several times, worked with me on two humanitarian engineering projects there, and both have worked with me on the weLab/iSTEM projects. Prof. Andrés Pantoja, of the Universidad de Nariño has worked with us on a project for low-cost laboratory experiments, and K-12 STEM education, in Pasto, Colombia. Ms. Margarita Gomez Sarmiento, director of Pequeños Científicos, in Bogotá, Colombia has taught me about STEM education methods and goals in Colombia. Dr. Lee Yee Cheong, from Malaysia, helped me with technology policy and sources on it. Prof. Raúl Ordoñez (past student of mine), from Ecuador and partly educated in México, and now with the University of Dayton, has taught me about Latin America and a bit about Ecuador in particular. Dr. Alvaro Gil and Mr. José Velasquez (past students of mine), both from Venezuela, have taught me some about Latin American politics. Dr. Alejandro J. Piña Ortega, an OSU graduate student, taught me about issues of volunteerism in Venezuela. Ms. Vickie Rush helped me understand issues in Honduras, and the running of an orphanage for HIV/AIDS children in Honduras. Prof. Carlos Juárez of Universidad Centroamericana in San Salvador, El Salvador, and Ms. Mayra Méndez and Mr. Mauricio Quiñonez of the IEEE Section of El Salvador all helped me understand issues in El Salvador. Juan Diaz (my brother-in-law) has helped me understand issues in México. My wife Anne edited one section of the book.

**Groups:** Students in my class "Humanitarian Engineering" at OSU have provided a variety of inputs via discussions and questions in and outside of class, along with their solutions to homework problems and projects and by finding typos in the book. Students in my engineering ethics class that I have taught at OSU since 1991 have provided me a variety of US and international perspectives on ethics in engineering (which has a number of close connections to social justice, discussed later in this book). Students from the OSU student organization "Engineers for Community Service" (ECOS), of which I am the faculty advisor, have provided me many inputs (and pleasant demands) since their formation in Spring 2004. I have obtained useful inputs from the OSU "Humanitarian Engineering Advisory Committee" led by Dr. Howard Greene. Many of the people already mentioned are involved with the OSU Humanitarian Engineering Center. The OSU Muslim Student Association Executive Board helped me with Islamic social justice issues. I have visited, given technical talks, or deliv-

ered short courses, including some on Humanitarian Engineering, in a number of countries where various people (e.g., over lunch or dinner) have given me insights into their countries, including in: Argentina, Colombia (universities in Medellín, Bogotá, and Cali), México (universities in Guadalajara and México City), El Salvador, and Turkey. I have given talks on humanitarian engineering and engineering ethics in a variety of universities and thank the students, faculty, and practicing engineers who gave me a number of insights; these include several US universities, Universidad de El Salvador and Universidad Centroamericana in San Salvador, El Salvador, and Colombia (in Medellín, at Universidad Pont. Bolivariana, Bogotá, at Univiversidad de los Andes, and in Pasto at Universidad de Nariño). Also, I have been involved in some domestic and international humanitarian engineering projects (fieldwork) where I received feedback from locals and learned some valuable lessons of practice: US, Colombia, Honduras, Guatemala, and Paraguay. All these, and other countries I have visited (Argentina, China, Turkey, Greece, Italy, Spain, England, Wales, Sweden, Canada, Japan, Australia, New Zealand, and the Bahamas), have taught me about other cultures and a wide range of perspectives, including how others view the US.

The name of the "publisher" for this book that is used on the title page is a complete fabrication on my part; there is no such publishing company. I use "Bede Publishing" simply to fill the necessary slot for bibliographic referencing of this book. The publisher is simply a computer server at OSU (I assume). This book has never been sold, and there are no plans to ever sell it. The only costs incurred in publishing this book are computer hardware and software costs, and my time, all of which are supported by my employer, The Ohio State University. I gratefully acknowledge this support.

I would like to also thank the LaTeX community for an excellent and free set of word processing tools that I used to create this book.

Finally, I owe many thanks to my wife Anne for taking care of our children while I was out gallivanting around the world; this book would not exist if I did not have her kind, loving, and continuing help (i.e., these days, one of her humanitarian activities). Also, I would like to thank our children Carina, Juliana, Jacob, and Zacarias and our grandchild, Elijah, who have given me wonderful distractions from research and writing.

I am grateful to each and every one of you. It has been fun!

Kevin ☺
Columbus, Ohio, US
2016

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# Notation and Acronyms

| | | |
|---|---|---|
| $s_e^i(k)$ | Total spending by individual $i$ on education at step $k$ | 639 |
| $SCDI$ | Sustainable community development index | 650 |
| TVET | Technical and vocational education and training | 332 |
| $t$ | Time, continuous | 358 |
| UN | United Nations | 9 |
| UNDP | UN Development Program | 19 |
| UNESCO | UN Educational, Scientific, and Cultural Organization | 20 |
| $U(k)$ | Total utilization at step $k$ | 93 |
| $u_i(k)$ | Individual utilization at step $k$ for user $i$ | 93 |
| UDHR | UN Universal Declaration of Human Rights | 120 |
| $u_c(k)$ | Individual utilization limit | 254 |
| $v_w^i(k)$ | Variable income for individual $i$ at step $k$ | 639 |
| $v_h^i(k)$ | Health degradations of individual $i$ at step $k$ | 643 |
| $v_e^i(k)$ | Effects of poor health on getting less education | 644 |
| WHO | UN World Health Organization | 20 |
| WVS | World Values Survey | 47 |
| $w_j$ | Importance (priority) of technology feature $j$ | 511 |
| $w_j^r$ | Relative importance (priority) of technology feature $j$ | 511 |
| $w_j^{min}$ | Minimum value of importance $j$ | 512 |
| $w_j^{max}$ | Maximum value of importance $j$ | 512 |
| $w_j^0$ | Nominal value of importance $j$ | 512 |
| $w^i(k)$ | Wealth of individual $i$ at step $k$ | 639 |
| $w_t^i(k)$ | Total wealth of individual $i$ at step $k$ | 643 |

# Chapter 1

# Poverty, Sustainability, and Culture

## Chapter Contents

*We think sometimes that poverty is only being hungry, naked and homeless. The poverty of being unwanted, unloved and uncared for is the greatest poverty. We must start in our own homes to remedy this kind of poverty.*

*St. Mother Teresa of Kolkata*

*Poverty is the worst form of violence.*

*Mahatma Gandhi*

*The world is very different now. For man holds in his mortal hands the power to abolish all forms of human poverty, and all forms of human life.*

*John F. Kennedy*

*He is now rising from affluence to poverty.*

*Mark Twain*

*Where justice is denied, where poverty is enforced, where ignorance prevails, and where any one class is made to feel that society is an organized conspiracy to oppress, rob and degrade them, neither persons nor property will be safe.*

*Frederick Douglass*

*I thank fate for having made me born poor. Poverty taught me the true value of the gifts useful to life.*

*Anatole France*

*The real tragedy of the poor is the poverty of their aspirations.*

*Adam Smith*

*Walk a mile in my shoes... See what I see, Hear what I hear, Feel what I feel... Then maybe you'll understand Why I do what I do... till then don't judge me.*

*Unknown*

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What is poverty? Does it only refer to having a low income, one that leads to difficult living conditions? Should features of human development include not only income, but also health and education? Where is poverty and under-development most prevalent?

Can our ecosystems sustainably support world-wide socially-inclusive human development and well being? Can the world meet the challenge of sustainable development in the presence of population and resource utilization increases?

What are the features of culture, and challenges of working in cross-cultural settings? Why is it important to be globally competent?

What is the engineer's role in sustainable development? What challenge do you want to take on? What are technologies that can be used to promote human development?

Using analytical approaches, can we learn what is it like for very low-income people to manage finances to survive and avoid risk? Can we learn about the dynamics of resource use, and how development and population size increases impact sustainable resource utilization?

This chapter, which has the theme of "challenges," will answer all these questions.

## 1.1 World Poverty and Development

Some think of poverty as the situation where basic human needs are not being met. What are "needs"? There is a whole array of human needs, with an early quantification given in the 1940s by Maslow in (Maslow, 1943) as:

1. Physiological;

2. Safety;

3. Love/belonging;

4. Esteem; and

5. Self-actualization.

Maslow ordered the needs such that the most basic one is listed first, and so on. Physiological needs include air, water, food, clothing, and shelter. Safety includes security from war, criminal violence, family violence, and child abuse. Some would include economic and health security (protection against ailments and diseases). Love/belonging includes friendship, intimacy, family, etc. Esteem includes the need to be respected, accepted, valued by others, status, recognition, fame, prestige, and attention. It also includes the need for self-respect. Self-actualization needs include the need to realize one's own potential. Sometimes, one need emerges when the one before it is fully satisfied.

There are, however, criticisms to Maslow's view as it is not generally culturally sensitive, is not properly set in the context of specific societies (e.g., individualistic or collectivist societies), and is not welcoming to the individual's own ranking of their needs. For instance, there are some people who rank entertainment, spiritual, or cultural events (e.g., weddings or funerals) very high and indeed will sacrifice some basic physiological needs for these. Such views are to be respected, of course. What right does one human have to say what another human needs? Of course, if a person is not meeting some needs and this adversely affects someone else (e.g., a child) that can be a problem. Also, if someone has a severe mental illness and cannot take care of themselves, that is also another matter. Toyama discusses a number of aspects of Maslow's work in the context of development in (Toyama, 2015).

*Individual needs are defined by individuals, not others.*

In this book, the definition of needs and human well-being arises in a number of contexts. For instance, we will consider standard metrics for whether needs are met such as the "Human Development Index." Or, we will consider in

social justice frameworks the closely related ideas of human rights and human fulfillment. When considering development strategies you will see that different approaches focus on different needs. In Chapter 4, and in particular in Section 4.4, we will discuss strategies to come to understand a community's needs and resources so that technologies can be designed to help meet these needs.

Next, we will take an up-close view of situations in which some basic human needs are not being met.

### 1.1.1 Understanding World Poverty: A Close Up View

There is no substitute for getting up close to poverty in order to learn about it. But, here, the best alternative is to use videos or photos as described next.

*You must get to know the low-income people up close, and in a respectful manner.*

**Living and Talking With People**

There are many documentaries or videos on poverty on the internet. Here, it is suggested that a specific form of documentary be used, the one where someone (or a team): (i) lives with a low-income community and films it; or (ii) visits a low-income community and interviews people about living conditions and challenges. Consider the following three videos, where it is best if you view these with a friend, your family, or class and discuss the issues during or after watching:

**Guatemala:** About 56 minutes long (56:00), at Peña Blanca (west of Guatemala City, near Lake Atitlán and Panajachel), Summer 2010, video entitled

<div align="center">Living on One Dollar</div>

(there is a charge to view the video) and their TED talk. They emphasize the power of "partial solutions." This is related to the old saying "do small things with great love."

**India, Brazil, Bosnia, Uganda, and Mali:** In the World Bank "Voices of the Poor" program there is a video (31:06) called

<div align="center">Hear Our Voices–The Poor on Poverty</div>

and there are several related reports at the World Bank web site here.

**Haiti:** There is a YouTube video (28:29) from Aug. 14, 2012 entitled

<div align="center">Four Guys Live on One Dollar Per Day for 28 Days in Haiti</div>

Their visit was after the earthquake that occurred on Tues. Jan. 12, 2010.

**Emotional Reaction from Close Up**

It is important to reflect on your own reactions to seeing, even if it is only via a video, and learning, even if it is only via a book, about poverty and underdevelopment. Reactions are typically more acute the closer you are to the people and situation (i.e., what I will call in this book the view from "close up," talking to people and seeing where they live and work); it is generally easer to sit in your armchair, read, and study statistics of countries from afar (i.e., what I will call in this book the view "at a distance," which means from an airplane or outer space) with no emotional reaction. Some of my own reactions from up close that I remember most vividly are:

- Surprise, shock.

- A feeling of wonder, and a question of "how can this be?"

- A feeling of confusion, an admission of lack of understanding, and a question of "why?"

- Compassion, empathy.

- A feeling of concern and a question of "how can I (we) fix this"?

- Cry (a number of times).

- Anger (more and more often) that people's dignity is so affronted.

Do you also have such reactions? Do you have different reactions? Sometimes, it is useful to have a "reflection journal" to help yourself think through the issues and the meaning of your own emotional reaction.

The first time I saw poverty up close was when my Dad exposed me to it outside Ft. Wayne, Indiana, United States (US), when I was seven years old while he was trying to help a rural family living in extreme poverty. He did me the great favor of showing via example the importance of respectfully talking to people (husband, wife, two daughters and one son) and developing relationships in a fun and engaging manner, and that via compassion you can actually be effective in helping. It also made concrete what he always told us kids throughout our lives if we were complaining about our own problems: "You think you have problems? Just look around."

It is extremely important for everyone to see or experience poverty, and talk to and develop relationships with people who have low-income, in order to understand poverty. Of course, the best way to do this is by going into low-income community either in your own country or some other country. Visiting at least one location is crucial. Visiting more than one is very useful as you can learn a lot by comparing and contrasting the cases. For example, in my own volunteer work in Harlan County, Kentucky (Appalachia), US, with a woman I was dating in graduate school named "Anne" (now my wife), or in several countries in Latin America, has taught me about the many basic differences in various cases close up. Seeing, however, is very different from experiencing.

I have never experienced serious hunger or thirst so I cannot claim to fully understand those things in a personal way. Per the shocking income data given below, I clearly have no personal understanding of that.

### Developing Solidarity With People

One of the most important aspects you will see in these films is the deep personal understanding that was gained by the persons living with low-income people in Guatemala and Haiti. That understanding is very important. Moreover, you will see the visitors develop "solidarity" with the people. "Solidarity" is defined by the New Oxford American Dictionary as "unity or agreement of feeling or action, especially among individuals with a common interest; mutual support within a group." To develop in the reader a solidarity with low-income people, please consider taking on at least one of the following challenges:

A sense of deep personal connection promotes action.

**Solidarity Challenge, Hunger or Income Poverty:** To gain solidarity with people with a low income, and in particular are hungry, live on bread and water for one full day per week while you are reading this book and/or taking a class out of this book. Limit your daily intake of bread to less than one standard-sized loaf of bread per day (cost range is \$1.50-\$4), but you may choose the type of bread, and drink as much water as you would like[1]. I did this for 4 months back in 2007 and I can attest that you learn some important lessons, such as an appreciation for good basic food. Another approach to this is not to limit the amount of bread, but the amount of money you can spend in one day on food (e.g., \$2 per day). You choose.

**Solidarity Challenge, Diversity:** Spend $N$ hours per week conversing (in person or electronically) with only persons of a race, gender, class, culture, country, or religious/secular view different from your own. Also, ask them questions about the differences from your own case. The more you ask, the more you will learn. One approach to this is to work together with another person (student) on the course projects.

Students/readers may rise to their own solidarity challenge (please, keep yourself and those around you safe and healthy). Be adventurous, keep a sense of humor throughout, reflect, and be sensitive.

### Language and Labels for People and Places

It is important to think about how you talk to people, and about people, communities, and issues in humanitarian engineering. After you develop relationships, work with people, and develop solidarity, you may come to take on the following approaches, ones that I will use in this book:

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[1] I first learned of this idea from persons practicing their religion, classes I had heard of on social justice, and more recently via a similar challenge by Amy Smith at the MIT D-Lab in an engineering context to live on \$2 per day.

- *People and clients:* Use "people with low-income" rather than "people who are poor," or "poor people," and "people who are homeless" rather than "homeless people" (to first emphasize their humanity); however, since many people misinterpret what is meant by poverty or homelessness (indeed there is great disagreement on what "poor," "poverty," or "homeless" even means), it is best not to use these terms with individual people you are working with, especially since they are often terms about the aggregate stereotyped groups, not the individual cases of people. It can simply be offensive to call a person to their face "poor" or "homeless," or say to a person that they live in a "poor community." Labels are sometimes dangerous in the sense that they are offensive and often show a lack of understanding, and a focus on problems rather than assets and resources. Would you call Rosa, from the Living on One Dollar movie, "poor Rosa," to her face? Would you tell Chino he is a "poor kid?" The term "client" or "clients" will be used in this book when talking about an (abstract) individual or group of people you are working with (independent of the assumed issue, and especially when referring to people or groups of people at a distance). This follows the tradition in social work and psychology in the US, two professions focused on helping people. In this book, I will use "poor" or "poor people" when referring to others' work on the subject when they use the term, or whole bodies of thought on poverty when the term is used (e.g., in the religious views on social justice). Sharper terms are sometimes used from a distance (e.g., economically disadvantaged or underprivileged), but it is not a good idea to label people or communities (e.g., you may feel that a community is "disadvantaged" and label it that way, but persons in the community may find that offensive if you refer to their community that way). The term "underserved" community, while still used by some, even in social work, is problematic due to the points made below about the word "service" (see also Section 4.2.2). Often, in this book the term "participant" will be used for a person in a community where a development project is being conducted via a "participatory development" approach (see Chapter 4, Section 4.2.4). Another term that is sometimes used is "stakeholder," as in Section 4.2.4.

> People and communities can label themselves, but others should not.

- *Working together to address issues:* "Helping people" or "working with people," are typically better terms to use than "solving/fixing people's problems" (implying they are not involved and that you think they have a problem that they might not think they have). It is sometimes better to use the terms "challenge," "issue," or "concern" rather than "need" (to be more optimistic and not to imply a type of begging), though at times "need" is natural to use, and it is often used in the literature (e.g., as in "needs assessment"). The terms "serve" and "service" are viewed as problematic by many people as these imply (i) that the helper is giving to the client without their involvement; and (ii) that there is need on the client's part, and your own great facility to help on the other part (i.e., a type of superiority in the relationship, an "asymmetry"), and hence

that the client has nothing to offer when most often that is not the case. I will go ahead and use the terms "serve" and "service" in this book *only* when I am referring to others' work and they use it (e.g., "service-learning," "community service," in Section 1.5.5 on "reasons to serve" by (Davis, 2006), and to contrast development with service in Section 4.2.2 by (Homan, 2011)). I prefer the term "working with people to address issues or promote change" as I feel these are the most accurate descriptions in many cases. Why do I use the word "address" and not "solve"? It can be arrogant or unrealistic to claim you are going to "solve." Your challenge is to understand needs and assets, help address issues, and persistently learn how to be more effective as a humanitarian engineer.

### Other Close-Up Information on Poverty

A useful set of reports were produced by the World Bank under the

<div align="center">Voices of the Poor</div>

program, which is where one of the above videos came from. Two excellent sources for up-close information on how low-income people live are (Banerjee and Duflo, 2012), that will be discussed in Section 3.2.4, and "Portfolios of the Poor" in (Collins et al., 2009) that has a wealth of information on their financial lives (e.g., propensity to give/take loans from each other or use "savings clubs" as in the above Guatemala film). For a sample of more up-close information on poverty, at the web site for (Banerjee and Duflo, 2012),

<div align="center">Poor Economics</div>

the issue of "how the poor spend their day" is discussed and some information on this is provided for a few cases. Listen to Banerjee's lecture on the data ("Part 1: A close-up look at daily life"), but also explore the information on your own. There are a number of interesting features: a lot of time is spent on water and hygiene, time is spent on a diversity of jobs, free time vs. forced-idleness, women shouldering more of the housework than men, and in most cases women sleeping less. You should study their cases and compare to your own daily time budgeting. Also, can you guess how Chino and Rosa from the above Guatemala film spend their time during the day? If you search the internet for "how people spend there time in a day" you obtain a significant amount of information and statistics.

If you go to iTunes and search on "poverty" you will find many items in many categories. There are many documentaries, short and long, on poverty in a range of countries around the world; one site that collects a range of such videos is the

<div align="center">Why Poverty?</div>

web site. Another site that has relevant videos is Top Documentary Films; use the search function at the site for "poverty" and consider

<div align="center">

The End of Poverty?

</div>

which is also at YouTube. Also, there are many videos outside such collections, such as Blood Brother.

An interesting video is the (19:10) TED talk by Josette Sheeran, who is from the United Nations World Food Program, entitled

<div align="center">

Ending Hunger Now

</div>

from July 11, 2011. Also, see the (3:52) video

<div align="center">

United Nations Human Development Report 2013: The Rise of the South

</div>

on YouTube from March 14, 2013; this video provides an overview of the report and talks about many positive signs of human development improvement, and highlights some concerns. In the title of that video, "South" (or "global South") is sometimes used to refer to the developing world as many countries in the developing world are south of the equator (but not all; consider Australia) and the "North" is referred to as the developed world (but, consider North Korea). These terms are used elsewhere in the literature.

## 1.1.2  World Statistics: A View a From a Distance

"From a distance" refers to cases where you study country-level statistics on world poverty and development. Narrowly focusing only on such statistics creates problems. From a distance, it is difficult to think past the clouds that data and statistics make to see clearly specific children, women, and men, and their situations on the ground (e.g., Chino, Rosa, or others in the videos of the last section). Statistics do not typically promote empathy. Yet, the data from the United Nations (UN) or World Bank given below essentially mean that you should amplify your reactions discussed for the close-up case above many-fold (e.g., by a factor of hundreds of millions or billions on some issues). The depth and breadth of the problems described below are truly staggering and hence difficult to understand, but these are the realities of the world we live in.

**Measuring Poverty and Development**

There are 7.3 billion people on Earth (population clock, US Census Bureau, accessed on 1/9/16). Depending on whom you ask, and what country recognizes the existence of other countries, there are about 190-196 countries on Earth. As of Dec. 2013, the US Dept. of State recognized 195 nations. As of 2011 there were 193 "member states" in the United Nations, but this number is also controversial. You will see in the data below on poverty and development that typically a smaller number of countries is included in the studies than the 193 UN member states, even if UN is presenting the data, as it may be that data is difficult to obtain for some countries.

There are several concepts used to define aspects of poverty and development that need to be understood for some statistics. First, the gross domestic

product (GDP) is the market value of the officially recognized goods and services produced by a country in a year. The GDP per capita (per person) is called the gross domestic income, it is not the average income of individuals in a country, and is sometimes thought of as a rough measure of standard of living, but some would dispute that. The gross national product (GNP), also now called the gross national income (GNI), is the market value of the products produced by enterprises owned by a country's citizens. If no enterprises in a country are owned by persons outside the country, and persons in a country do not own any enterprises outside the country, the GDP is the same as the GNI.

There is no correct/definitive measure of poverty or underdevelopment. Defining poverty and underdevelopment is difficult, political, value-laden, moral, and has significant policy implications. There are "absolute" definitions (the common use of "less than \$1 or \$1.25 per day" to say that someone is extremely low-income) or "relative" (e.g., an income that is some percentage below the median income of the country they live in, as in some European countries).

Often, definitions are formulated so that they can be measured numerically, and with data that is relatively easy to gather (e.g., from many people or a wide geographic region). Some features related to poverty are simply difficult to define and measure. For instance, security is of very basic importance to humans, but it is difficult to define and measure. Should the murder rate in the country be used in the definition? Rate of theft? Rate of assault? Rate of rape or sexual abuse? Rate of kidnapping? Proximity to a war? While money (e.g., income) has traditionally been used as a sole measure of poverty, it is recognized that other features are critical, like health, education, and inequality. Also, "social exclusion" is often thought of as a measure of poverty (e.g., lack of voice or lack of ability to be heard in a political process, lack of a job even if excellent national unemployment insurance is provided). Sometimes, poverty is thought of as a lack of achieving human rights. Amartya Sen introduces the "capabilities-approach" to define poverty and hence thinks of poverty as "capability deprivation." This approach will be discussed in detail in Chapter 2. With respect to this chapter, Sen has had a major impact on international development, for example, by helping to define the "human development index" that is discussed below. To make decisions about what to do to fix poverty and underdevelopment problems it is likely best to use more than one poverty measure, along with a deep understanding of people and their situations close up ("on the ground").

### Income Measure of Poverty

Traditionally, income has been used as the sole measure of level of poverty as it is thought to be proportional to a person's "standard of living" ("standard of living" is defined by the New Oxford American Dictionary as "the degree of wealth and material comfort available to a person or community"). Income level must be adjusted so that cross-border and cross-currency understanding can be attained. To do this, first, the US dollar is called the "international dollar" and there are conversion factors from all currencies to the international

dollar each year (e.g., click here for the UN information on this). The conversion factors take into account the currency exchange rate from the country to the international dollar and purchasing power in the country and the US (via a "basket of goods" approach). So, if you are considering international data and it says that someone makes \$1 per day that means that they earn \$1 per day "purchasing power parity" (PPP); if they spend all that money there, and if you live in the US you interpret that as "if the person lived in the US they could buy \$1 US dollar worth of goods per day." So, in much of the data, all that is stated is that the person earns \$1 per day without explanation, but sometimes "PPP" is added.

As an example, some UN poverty data is based on PPP, such as that found via their UN Public Data Explorer. As another example, the World Bank data visualization shows poverty data based on PPP.

**Income Inequality: The Gini Index**

To measure income inequality, the "Gini index" (or "Gini coefficient") is often used (another inequality index, the Atkinson inequality index, of the entropy measure type, is used below and in Section 4.12.2). Consider a distribution of income across a population such as individuals in a country. A Gini index of zero represents perfect equality of income across the population. A Gini index of one represents perfect inequality where one person has all the income and everyone else has no income. The Gini index lies between zero and one, with a higher value of the index representing greater inequality. Some think of the Gini index as a gross measure of the "fairness" of a country.

To define the Gini index mathematically, first define the mean (average) and variance. If $X_i$ and $X_j$ are, for instance, incomes of individuals $i$ and $j$, the (sample) *mean* income across $N$ individuals is

$$\bar{X} = \frac{1}{N} \sum_{i=1}^{N} X_i \tag{1.1}$$

The (sample) *standard deviation* of the $X_i$, $i = 1, ..., N$, is $\sigma$, where

$$\sigma^2 = \frac{1}{N-1} \sum_{i=1}^{N} (X_i - \bar{X})^2 \tag{1.2}$$

This is the "corrected" sample standard deviation that produces an unbiased estimate. The standard deviation is a measure of the "spread" of the $X_i$ data about the mean, or inequality of data from the mean. The *variance* is $\sigma^2$, and is also a measure of spread of the data. The $X_i$, $i = 1, ..., N$, can be any real numbers, positive, negative, or zero.

According to the World Bank, the Gini index, $G_{index}$, is

$$G_{index} = \frac{\sum_{i=1}^{N} \sum_{j=1}^{N} |X_i - X_j|}{2N(N-1)\bar{X}} \tag{1.3}$$

For $G_{index}$ to be well-defined it must be that $\bar{X} \neq 0$. To ensure this, normally it is assumed that $X_i \geq 0$, for $i = 1, ..., N$, and at least one $X_j > 0$, for some $j = 1, ..., N$. Notice that if for pairs of people, $|X_i - X_j|$ in the numerator is higher (lower), then inequality is higher (lower, respectively). Clearly, if all incomes are the same, $|X_i - X_j| = 0$ for all $i$ and $j$, and so $G_{index} = 0$; this is the complete equality case. If one person $i$ has all the income, call it $X_i$, and all others indexed with $j \neq i$ have $X_j = 0$, then the $X_j$ all drop out of the numerator in Equation (1.3) and the numerator is equal to $2(N-1)X_i$. Substituting this and $\bar{X}$ into Equation (1.3), we get $G_{index} = 1$, representing total inequality. To better understand how $G_{index}$ measures inequality, run the program `SCDIplotter.m` that plots $G_{index}$ for a simple example.

Strictly speaking, $0 \leq G_{index} \leq 1$, but sometimes in reported data $G_{index}$ is multiplied by 100 to give values $0 \leq G_{index} \leq 100$. This is how the World Bank provides their data in their Data Visualizer that shows the Gini index for many countries over a number of years, or versus a number of possible variables.

### Human Development Index

There are many ways to specify numeric measures of the well being of a population. Some have advocated measures that go beyond including just income, wealth, production, and exports. One such approach, is the human development index (HDI), an index of "potential" for human development, a measure of both social and economic development, invented by Mahbubul Haq, Amartya Sen, and others. The HDI uses three "dimensions," a long and healthy life, knowledge, and a decent standard of living (HDR, 2013). An "indicator" of life expectancy at birth is used for the long and healthy life dimension. Indicators of mean years of schooling and expected years of schooling are used for the knowledge dimension. GNI per capita (PPP$) is used as an indicator for a decent standard of living. There are minimum and maximum values set for each of the indicators to convert them to "dimension indices" with values between zero and one. The maximum values are the highest indicator numbers over the time range that data has been gathered. The minimum indicator numbers are "subsistence values," set at 20 years for life expectancy, zero years for the education indicators (expected and actual number of years of schooling), and \$100 for per capita GNI (HDR, 2013). Next, the dimension indices are computed by (i) taking the actual measured value of the indicator and subtracting the minimum value of the indictor, and then (ii) dividing by the maximum value minus the minimum value of the indicator. For the income dimension, the natural logarithm is taken of the actual, minimum, and maximum values for this computation; the natural logarithm is a concave function and hence it weights increases from the minimum value heavily (as these increase capability), but increases less for greater values of income (Anand and Sen, 2000; HDR, 2013). For the education case, the two indicators are computed according to (i) and (ii), then the "geometric mean" of the two is computed using zero as the minimum and the highest geometric mean of the resulting indices for the time period considered as the maximum. The three dimension indices are the life expectancy

Key components of measuring human development include income, health, education, and inequality.

index that will be called $I_{Life}$, the education index, called $I_{Education}$, and the GNI index, called $I_{Income}$.

The three dimension indices are combined to form the HDI using the geometric mean. The geometric mean of $n$ indices, $X_i \geq 0$, $i = 1, ..., n$, is

$$\left( \prod_{i=1}^{N} X_i \right)^{\frac{1}{N}} = \sqrt[N]{X_1 X_2 \cdots X_N}$$

The large "π-symbol" in the left side parentheses simply denotes the product, as seen on the right side of the equation. The geometric mean represents the "central tendency" or "typical value" of a set of data. The geometric mean is always less than or equal to the arithmetic mean (Equation (1.1)). Hence, for the dimension indices $I_{Life}$, $I_{Education}$, and $I_{Income}$, the human development index, $HDI$, is

$$HDI = (I_{Life})^{\frac{1}{3}} (I_{Education})^{\frac{1}{3}} (I_{Income})^{\frac{1}{3}}$$

which is the same as

$$HDI = (I_{Life} I_{Education} I_{Income})^{\frac{1}{3}} \tag{1.4}$$

Here, $HDI \in [0, 1]$, with higher values meaning more developed, and some people view a country that has $HDI > 0.7$ as "developed." In Equation (1.4), any increase (decrease) in any single dimension index $I_{Life}$, $I_{Education}$, and $I_{Income}$ will result in an increase (decrease, respectively) in the HDI. If some indices increase and others decrease, then HDI can go up or down (these properties are explored further in Section 4.12.2). With the geometric mean, changes in one dimension are weighted similar to changes in other dimensions. This gives *equal* emphasis to the three dimension indices, $I_{Life}$, $I_{Education}$, and $I_{Income}$, which is support for a view that life expectancy (health), education, and income (standard of living) are equally important for human development. This departs from traditional thinking where only income level is used to define poverty, and by implication, human development.

The UN provides HDIs for a number of years, for many countries, via their UN Public Data Explorer.

### Inequality-Adjusted Human Development Index

There is also the "inequality-adjusted human development index" (IHDI) (see, for instance, (HDR, 2013), for an explanation). The IHDI takes into account inequalities in the three HDI dimensions by reducing each dimension's value per its level of inequality as measured by the Atkinson inequality index (see Section 4.12.2 and (HDR, 2013)). In particular,

$$IHDI = ((1 - A_{Life})I_{Life}(1 - A_{Education})I_{Education}(1 - A_{Income})I_{Income})^{\frac{1}{3}} \tag{1.5}$$

where the Atkinson inequality index for life expectancy is $A_{Life}$ and its definition is in Equation (4.25) (similarly for the others). If there is high inequality, $A_{Life} = 1$ and if there is equality $A_{Life} = 0$. The factor that does the reduction is, for instance, $(1 - A_{Life}) \in [0, 1]$, on $I_{Life}$, so that $(1 - A_{Life})I_{Life}$ is reduced compared to the HDI if there is inequality. The IHDI is equal to the HDI "when there is no inequality across people but falls further below the HDI as inequality rises" (HDR, 2013). Hence, the IHDI is sometimes called the "actual" level of human development since it considers inequality; on the other hand, the HDI is sometimes viewed as an index of "potential" human development that may be attained if there was no inequality (HDR, 2013).

The UN provides IHDIs for a number of years, for many countries, via their UN Public Data Explorer.

### Multidimensional Poverty Index

Another measure of poverty that the UN uses is the multidimensional poverty index (MPI). Persons are considered to suffer "multidimensional poverty" if at least 33% of the indicators that are used reflect "acute" deprivation. The indicators used for the composite MPI are as follows:

- Health (child mortality and nutrition),

- Education (years of school and children enrolled), and

- Living standards (cooking fuel, toilet, water, electricity, floor, and assets).

The MPI is based on "micro data" from household surveys, unlike some of the measures above like IHDI. Estimates of the number of people "living in poverty" can be higher if measured by the MPI measure than when only income is considered (e.g., the percentage of people living on less than $1 per day). MPI data can be studied at the UN Public Data Explorer. For another multidimensional approach to measure poverty and development see Problem 1.5, and Problem 1.6, for the "social progress index" (SPI).

### Gender Inequality and Development Indices

The UN also has a gender inequality index (GII) that is an aggregate measure of reproductive health, empowerment, and the labor market; specifically, it uses maternal mortality, adolescent fertility, percentage of women holding seats in national parliament, percent of population with at least a secondary education (compares to men), and labor force participation rate (compares to men). A higher GII means higher inequality. The formulas for computing GII are in (HDR, 2013). The data for many countries are shown at the UN web site here. Also, see data on the GII at the UN Public Data Explorer.

The UN also has a gender development index (GDI) that is an aggregate measure along three dimensions of health (measured by female and male life expectancy at birth); education (measured by female and male expected years of schooling for children and female and male mean years of schooling for adults

ages 25 and older); and "command over economic resources" (measured by female and male estimated earned income). The same approach as for the HDI is used to compute the GDI. Next, "countries are ranked based on the absolute deviation from gender parity in HDI. This means that ranking takes equally into consideration gender gaps hurting females, as well as those hurting males." (for more information, click here for a UN web site). "The GDI reveals that gender gaps in human development are pervasive. On average, at the global level, female HDI value is about 8% lower than male HDI but disparities do exist across countries, human development groups and regions." (again, for more information, click here for a UN web site). Also, see data on the GDI at the UN Public Data Explorer.

### Engineering and Technology Issues

Of particular interest to an engineer, in the UN Public Data Explorer, are plots that have HDI on the $y$-axis, circles for countries with area proportional to population size, and the following variables from the "innovation and technology" category on the $x$-axis:

There are useful data on prevalence of technologies for the world.

- Electrification rate, percentage of population

- Fixed broadband internet subscription per 100 people

- Mobile phone subscriptions

- International total incoming telephone traffic minutes per capita

- International total outgoing telephone traffic minutes per capita

- Internet users per 100 people

- Research and development expenditure as percentage of GDP

- Researchers in research and development per 1 million people

- Royalty and license fees per person

- Total patents granted to residents and nonresidents per 1 million people

Also of interest is to plot "graduates in science and engineering" on the $x$-axis.

It was projected that the number of mobile phone subscriptions in the world would exceed the number of people in the world in 2015, which was 7.2 billion people. For current information on mobile phone subscriptions, see the International Telecommunication Union, UN Public Data Explorer, and the World Bank indicators.

**Exploring the United Nations and World Bank Data**

To study the impact of many indicators on the above measures of human development, see the UN Public Data Explorer. With it you can, for instance, make a movie showing the change in the HDI for a set of countries (indicated by circles with area proportional to country population size), the color of the circles graded according to HDI value of each country, the y-axis the HDI value, and x-axis the country's expenditure on public health as a percentage of GDP. The movie shows a general movement of the circles upward and to the right indicating that as health expenditures go up, the HDI goes up. The UN Public Data Explorer allows you to study relationships between many other variables using other plotting methods (e.g., line and bar charts) including: composite indices, demography, education, gender, health, human security, income, inequality, innovation and technology, poverty, and sustainability. Many composite measures can be studied including HDI, IHDI, MPI, GII, and GDI.

Another excellent source for information on world-wide poverty and development is the World Bank. In particular, they have extensive data on most countries on many indicators here and this includes an ability to create a world-wide map for indicators for easy visualization. The indicators include:

- Agriculture and rural development

- Aid effectiveness

- Climate change

- Economic policy and external debt

- Education

- Energy and mining

- Environment

- Financial sector

- Gender

- Health

- Infrastructure

- Labor and social protection

- Poverty

- Private sector

- Public sector

- Science and technology

The World Bank collects vast information on development issues, and provides many resources for learning.

- Social development

- Urban development

The World Bank web site has significant additional information including publications, research, projects and operations, and information on many countries.

You should be critical of the data, learn about how data is gathered, and how indicators are defined in terms of the data. For all of the above, you should have concerns about the quality of measures (e.g., for poverty), the accuracy of reporting by individuals (e.g., in assessing their own health or poverty) or the accuracy of making estimates found from sampling a subpopulation and making conclusions about a larger population. Some data are simply very difficult to gather (e.g., ability to estimate the number of homeless people in the world). I find that too often only averages are provided, when the standard deviations would also be instructive (of course, these could be computed in many cases by downloading data if it is available).

### Additional World-Wide Problems

Poverty and underdevelopment are often coincident with a range of other problems, some of which are discussed next. Some feel that poverty and underdevelopment lead to these issues, and others that these issues promote poverty and underdevelopment. Clearly, the relations between all the issues are very complicated.

**Crime:** The United Nations Office on Drugs and Crime has information on a wide range of issues including corruption, crime prevention and criminal justice, drug prevention, treatment, and care, drug trafficking, firearms, fraudulent medicines, HIV/AIDS, human trafficking and migrant smuggling, money-laundering, organized crime, piracy, terrorism prevention, and wildlife and forest crime. They have a UN site on statistics (e.g., consider the statistics on crimes such as murders, assaults, sexual violence, robbery, and kidnapping by the UN given here). See Section 4.6.6 and Problem 2.21, and also Problem 4.56.

**Governance, Corruption, and Security:** The World Bank has the topic of public sector, a project

<div align="center">Open Government Data Toolkit</div>

and a project on governance along with the

<div align="center">Worldwide Governance Indicators (WGI)</div>

that include six aspects:

- Voice and accountability

- Political stability and absence of violence

- Government effectiveness

- Regulatory quality

- Rule of law

- Control of corruption

The World Bank has significant data on these indicators including a data mapping site that provides world-wide maps on these indicators.

There is also

Transparency International: The Global Coalition Against Corruption

that has a significant amount of information on a wide range of corruption issues and research that provides information on a corruption perceptions index, a global corruption barometer, a bribe payment index, etc. Particularly interesting are the "Institutions Perceived by Respondents to be Among the Most Affected by Corruption" here. See Problem 4.53, and also Problem 4.54.

The issue of security is of significant importance to people. At the World Bank, under their indicators, you can find information on expenditures on country's military. Above, via the WGI you can find information on "political stability and absence of violence" and "interactive data access" that allows you to see world data on the above issues, country data, and to compare countries. Some of the information gives you a high level view of the security situation in a country. For another high level view on security of the countries of the world that includes country specific information, travel alerts, and travel warnings see the US Dept. of State.

**Homelessness:** The number of homeless people in the world is very difficult to estimate since there are varying definitions of homelessness and data are difficult to gather (e.g., sampling methods often miss many people who are hiding or not readily accessible). Based on the UN Commission on Human Rights, 2005, there was an estimate of 100 million homeless people world-wide and some say most are women and children. Another site estimates 100 million people, and gives estimates for many countries. See Section 1.2.1 and also Section 1.2.2.

**Orphans:** Consider data on the number of orphans in the world. UNICEF says:

> UNICEF and global partners define an orphan as a child who has lost one or both parents. By this definition there were over 132 million orphans in sub-Saharan Africa, Asia, Latin America and the Caribbean in 2005. This large figure represents not only children who have lost both parents, but also those who have lost a father but have a surviving mother or have lost their mother but have a surviving father. Of the more than 132 million children classified as orphans, only 13 million have lost both parents. Evidence clearly

shows that the vast majority of orphans are living with a surviving parent, grandparent, or other family member. 95% of all orphans are over the age of five.

For more information on orphans from UNICEF click here (where, of course, the numbers have changed relative to the above quote).

**Human Trafficking:**   Human trafficking for slavery (forced labor), forced sex ("sex trafficking"), forced soldiering, human trafficking for organs and tissue removal, etc. is shockingly common in the world. The United Nations UN.GIFT "global initiative to fight human trafficking" program says (as of 2014):

- Estimated 2.5 million people in forced labor (slavery) at any one time.

- The majority of trafficking victims are between 18 and 24 years old

- Estimated 1.2 million children are trafficked each year

- 95% of victims experienced physical or sexual violence during trafficking

- 43% of victims are used for forced commercial sexual exploitation, of whom 98 per cent are women and girls

- 32% of victims are used for forced economic exploitation, of whom 56 per cent are women and girls

- 52% of those recruiting victims are men, 42% are women and 6% are both men and women

- In 54% of cases the recruiter was a stranger to the victim, 46% of cases the recruiter was known to victim

For more information, see the International Labor Organization, and in particular, here. See Section 4.6.6 and Problem 4.55.

### Divisions of the United Nations

There is a significant  amount of information and resources at the UN web site. For instance, under Humanitarian Affairs, among others, there are the following:

1. United Nations Development Program (UNDP): Covers poverty, building democracy, preventing crises, enabling recovery, protecting environment, HIV/AIDS, empowering women, growing national capacity.  They also have many publications on these subjects.  An important annual document posted on their web site is the

   Human Development Report

2. UN World Food Program (UNWFP): Fights hunger, see static and interactive hunger maps, and the

There are many UN organizations working on all aspects of development; these can provide good sources for learning about issues.

UN Food and Agriculture Organization (UNFAO)

that works on food security, nutrition, agricultural productivity, with statistics on relevant factors and in particular FAOSTAT for detailed statistical information.

3. UN Educational, Scientific, and Cultural Organization (UNESCO): Intercultural understanding, cultural diversity and preservation, education, scientific cooperation, freedom of expression, and democracy.

4. UN World Health Organization (WHO): World-wide health issues, physical and mental, on many topics, including impact of environment on health, and data to give a broad view of health problems.

5. UN Children's Fund (UNICEF): Covers a wide range of subjects relevant to children, including protection, child development, education, health, HIV/AIDS, nutrition, water, sanitation, and hygiene. UNICEF tracks statistics on both women and children.

6. For additional data and statistics see the UN Statistics Division and the UN Data site.

There are also programs on food, agriculture, population, settlements, and others.

Finally, the International Monetary Fund (IMF) seeks to promote international monetary cooperation, secure financial stability, facilitate international trade, promote high employment and economic growth, and reduce poverty around the world. The IMF also gathers statistics on countries and the world (e.g., the world economic outlook) and you can see these here.

## 1.2   Poverty in the United States

The details on poverty and underdevelopment characteristics are different for every country, and every region within each country. Here, the case of the US is considered since: (i) many of my students and I live here; and (ii) the US is often said to be the "richest country on Earth" (by some measures, if you consider the total wealth and income as the US is a relatively large country) and it is interesting to understand the problems of poverty and development in what is perceived as a rich country. Information on US poverty and development is not always included in UN and World Bank data discussed above so it is treated separately here using other sources.

To set the context, note that there are 323 million people in the US and 7.3 billion people on Earth (population clock, US Census Bureau, accessed 1/10/16), with the US being the third largest country, behind China and India. This means that only 4.4% of the people in the world live in the US. To get an overall picture of the current economic situation in the US, see

Economic Policy Institute: Research and Policy for Shared Prosperity

but there are many other sources for such information.

### 1.2.1   Living in Poverty in America: A Close Up View

Just like for the discussion for the world, it is very important to see or live in poverty in the US in order to understand it and develop solidarity with the people by talking to them, and developing relationships with them. Depending on where you live, there are a number of approaches to "bring people who are low-income into the classroom" or reading about experiences. Here, we take the approach of watching videos to augment reading this book. There are a number of documentaries on poverty in America. "A Place at the Table" is assigned as a homework problem (Problem 1.12) at the end of the chapter; it is about hunger in America.

There is also (ordered per my view of their quality for education on humanitarian engineering):

**The Poverty Line:**   Sojourners 2012 movie, The Line, a video (43:44) about poverty in America. In particular, it is a movie about living above and below the poverty line, going below the poverty line (e.g., the well-off losing a job and ending up at a food pantry), and moving above it.

**invisiblePEOPLE:**   There are a number of videos of talks with homeless people here. For instance, you could consider: Nikki and Scott (3:10) (LA), Norman (6:37) (NYC), Catherine (5:44), and Mark (5:11), though there are many others.

**Tent City:**   YouTube video (21:06) from Feb. 1, 2011, A Year in Tent City discusses a "tent city" for the homeless, the reasons people live there, and the living conditions there.

**Poor America:**   BBC video (29:12), from Dec. 15, 2012, and free to view Poor America Panorama. It discusses poverty, homelessness, politics, and the contrast with the rich. It is good that the video is made by a non-US organization, the BBC, as overall it sets a different, but accurate tone (e.g., it discusses contrasting political views on the issues in a very frank manner).

**Poor Kids:**   PBS Frontline (53:41) from Nov. 20, 2012, Poor Kids, (and free to view) and interviews kids and their parents to explain the conditions they live in.

There are also collections of videos. For instance, there is the PBS 2011 collection called

<div align="center">The Poverty Tour: A Call to Conscience</div>

which also features discussions with experts. There is a collection of

<div align="center">Ten Documentaries About the Haves and Have-Nots</div>

at the PBS web site. You can find many other similar videos on the internet.

Like in many countries, many people in the US do not have an up-close understanding of poverty and its effects in their own countries.

## 1.2.2   Poverty in America: A View From a Distance

How is poverty defined in the US? The government definition is provided next. In the US, often people who are homeless are thought of as being the lowest income. Here, some brief information on homelessness in the US is provided. Both the information on poverty and homelessness complement the videos in the last section that give a close-up view of these issues.

**Official Definition of Poverty**

Some basic poverty statistics from the US Census Bureau (the US Dept. Health and Human Services also measures poverty in the US) are:

- In 2012, the official poverty rate was 15.0 percent. There were 46.5 million people in poverty.

- The poverty rate in 2012 for children under age 18 was 21.8 percent. The poverty rate for people aged 18 to 64 was 13.7 percent, while the rate for people aged 65 and older was 9.1 percent.

To explain this information, the following was taken directly off the

<div align="center">US Census Bureau</div>

web site on poverty:

1. *Income used to compute poverty status (money income):*
   - Includes earnings, unemployment compensation, workers' compensation, Social Security, Supplemental Security Income, public assistance, veterans' payments, survivor benefits, pension or retirement income, interest, dividends, rents, royalties, income from estates, trusts, educational assistance, alimony, child support, assistance from outside the household, and other miscellaneous sources.
   - Noncash benefits (such as food stamps and housing subsidies) do not count.
   - Before taxes
   - Excludes capital gains or losses.
   - If a person lives with a family, add up the income of all family members. (Non-relatives, such as housemates, do not count.)

2. *Measure of need (poverty thresholds):* Poverty thresholds are the dollar amounts used to determine poverty status.
   - Each person or family is assigned one out of 48 possible thresholds, and thresholds vary according to:
   - Size of the family
   - Ages of the members

- The same thresholds are used throughout the United States (do not vary geographically).

- Updated annually for inflation using the Consumer Price Index for All Urban Consumers (CPI-U).

- Although the thresholds in some sense reflect family's needs, they are intended for use as a statistical yardstick, not as a complete description of what people and families need to live.

Some examples include in 2011 poverty thresholds of (these come from a data file you can download off the web site):

- $11,702 for one person under the age of 65 ($36.02 per day)

- $14,657 for two people (no children)

- $18,106 for three people, one being a child

- $22,811 for four people, two being children

3. *Determining if people are in poverty:* If total family income (all earners in household) is less than the threshold appropriate for that family:

- The family is in poverty.

- All family members have the same poverty status.

- For individuals who do not live with family members, their own income is compared with the appropriate threshold.

- If total family income equals or is greater than the threshold, the family (or unrelated individual) is not in poverty.

Note that in 2012 the minimum wage by US law (lowest wage an employer is allowed to pay an employee) was $7.25 per hour. If someone worked 40 hours a week for 52 weeks that corresponds to an annual income of $15,080 or $41.32 per day.

A comprehensive US poverty report is published annually at US Census Bureau, Poverty.

There are studies providing alternative measures of the poverty rate in the US (Meyer and Sullivan, 2012) (e.g., removing the assumption that benefits from the government such as the "earned income tax credit" that results in qualified individuals getting money from the government and "food stamps," vouchers for free food, are not considered in the calculation, or measuring poverty based on consumption rather than income). Different poverty rates are found based on which measure you use.

### Homelessness in the US

People in the US who do not live in a house, apartment, condominium, etc. (i.e., without a roof over their heads), often due to deep poverty so that rent or ownership cannot be afforded, are called "homeless." People are homeless for a wide

variety of reasons including loss of a job, divorce, alcoholism, drug addiction, severe mental illness (e.g., clinical depression, bipolar disorder, or schizophrenia), and/or lack of a safety net (e.g., family or government help). Many people who are homeless are "temporary homeless" (e.g., until they can find a job or get housed in some way) while others are people who are "chronically homeless" (measured in different ways, but sometimes as being homeless for over a year). Some people are homeless for more than ten years. People who are homeless live in cars, on sidewalks, under bridges, in the woods, in tents/make-shift shelters, etc., and sometimes (e.g., in the winter) may spend time in a "homeless shelter" (a building that houses, and sometimes feeds, homeless people, sometimes more than 100 persons). Services for the homeless sometimes also include soup kitchens and food pantries, and sometimes health or job-training services.

A wealth of information on homelessness in the US is at

<div align="center">

National Alliance to End Homelessness

</div>

A report that gives basic information on the state of homelessness in the US each year is

<div align="center">

The State of Homelessness in America

</div>

The distribution of non-chronic, chronic, and persons in families with children across urban–rural locations is given in the

<div align="center">

Geography of Homelessness

</div>

report.

Technologies for helping people who are homeless are discussed in Section 4.6.4. These technologies are meant to help people survive outside, which can be a significant challenge and create great suffering, especially in regions where it gets very cold at times.

## 1.2.3 Comparing US Poverty to Other Countries

Here, we overview some comparative studies in poverty, inequality, and social mobility.

In Problem 1.14, you are asked to read (Milanovic, 2012) and discuss his comparison of poverty in the US to several other countries. The basic conclusion is that the lowest 5% in terms of average income (PPP$) in the US have higher average incomes than about 50% of the people in Brazil, 80% of people in China, and about 95% of the people in India. If income is assumed to be a good measure of poverty, then one could conclude that people who are low-income in the US "have it easy compared with many people in the world–the data also say that people in the lowest 5% in terms of income in the US have more average income than 60% of the people in the world." Or, you can say that this shows how bad things really are in the rest of the world.

Compared to the developed world (the countries in the Organization for Economic Cooperation and Development, OECD), the US has the highest socioeconomic status for its top 10%, greater inequality than others, and the 10% of

The US has many problems found elsewhere in the world, though the depth and frequency of some problems may be less/more compared to some places.

US individuals with the lowest socioeconomic status is higher than all countries (including Switzerland, Britain, Germany, and France) except Canada, Sweden, and Australia (Worstall, 2013). The measure that is used by the Economist is not the US-based measure of poverty rate, but one that is more like ones used in Europe where poverty is defined as being lower than some percentage of the median income of the country. Moreover, the Economist study takes into account a number of indicators to determine "socioeconomic status" including money and social factors. A detailed comparison of the US to its "peers" (OECD countries) is given in (Gould and Wething, 2012) using different measures of poverty; overall quite different conclusions are made compared to the Economist data discussed in (Worstall, 2013). Problem 1.15 focuses on this work.

Social mobility, as measured by, for instance, intergenerational earnings and educational achievement, is measured and compared between OECD countries in (Causa and Johansson, 2010). There are a number of interesting conclusions, and Problem 1.16 focuses on these. If you want your daughter or son to advance themselves further than what you have, which country do you want to live in?

## 1.3   Sustainable Development

The Brundtland Commission provided what has become a widely accepted "intergenerational" definition of sustainable development in the report *Our Common Future* (BC, 1987):

> Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs.

Sachs (Sachs, 2014) promotes a holistic approach to sustainable development along the following dimensions:

1. Economic development;

2. Social inclusion (e.g., reducing inequalities); and

3. Environmental sustainability.

In (Sachs, 2014) he also includes health, education, governance, politics, policy, and other characteristics in his perspective on sustainable development.

In this section, some of the key interactions between humans and ecosystems, and causes and effects of pollution, are overviewed in order to explain the importance of the following topics in the three following chapters:

- A full treatment of what "social inclusion" means, and the motivation for the environment to be considered in social justice and engineering ethics ("environmental justice" and ethics of the environment);

- Aspects of development strategies where there is a concern for sustainable development; and

*How can we simultaneously achieve economic and social development without destroying the environment?*

- Sustainable technology design for community development (design for minimal adverse environmental impact, or the design of technologies to remove pollution, for example, for water or sanitation).

### 1.3.1   The Pollution Problem: Close Up View

The quality of the environment affects us all, creating a need to maintain (sustain) it, yet there have been significant environmental degradations since, for example, the start of the industrial revolution. Significant environmental pollution is due to the use of materials and energy for manufacturing technologies (e.g., concrete, concrete blocks to construct homes, automobiles, computers, and phones). Additional pollution is created by the use or operation of a technology (e.g., automobiles, boats, or airplanes), or its end-of-life disposal (e.g., to a landfill).

You may have seen pollution up close, for instance, smog in a city or trash littering a stream. Pollution is often quite visible in many countries of the developing world, often due to lack of trash and clean up services. Moreover, indoor pollution is often a significant problem in the developing world, for instance, due to indoor cooking with wood fires (recall the scene in the "Living on One Dollar" film that is identified in Section 1.1.1) or the use of kerosene lanterns for indoor lighting in sealed homes in cold climates.

To provide an introduction to the subjects of this section, consider the following videos:

1. *Causes and effects of pollution:* The (7:40) video

   Pollution (Land, Air, and Water Pollution)

   was posted on YouTube on March 8, 2012. It provides an overview of causes and effects of pollution.

2. *Climate change issues and solutions:* The (3:37) video

   Morgan Freeman's Powerful Climate Change Short Film

   was posted on YouTube on Sept. 23, 2014. It gives an overview of issues related to climate change and solutions to avoid it.

3. *Causes and effects of climate change:* The (4:04) video

   Climate Change: The State of the Science

   was posted on YouTube on Nov. 19, 2013. It provides a scientific overview of the causes and effects of climate change.

You could also consider watching the film An Inconvenient Truth, or one of the many documentaries on the environment and climate change here. Also, see Problem 1.19.

### 1.3.2   Ecosystems and Human Well-Being

Humans are intimately coupled with the ecosystems in which they live. Ecosystems impact most aspects of our lives, and, on the other hand, much of human activity affects ecosystems. The

<div align="center">

UN Millennium Ecosystem Assessment program

</div>

has quantified how ecosystems impact human well-being (MEA, 2005). Figure 1.1 illustrates the various ways that ecosystems impact human well-being. On the left, there "supporting services," ones needed for all ecosystem services. The supporting services include soil formation, nutrient cycling, and primary production (e.g., elements like water and air). There are three types of ecosystem services:

1. Provisioned ecosystem services include food, fresh water, etc.

2. Regulation processes in ecosystems provide services, for example by regulating the climate's temperature or by seepage through soils that purifies water.

3. Cultural services are ones that do not use materials from the environment, but provide value in religions, recreation, ecotourism, etc.

All these services, shown on the left of Figure 1.1, determine all types of human well-being shown on the right of the figure. In particular, they provide security, materials to gain a livelihood (e.g., via fishing), affect health via nourishment, clean water, clean air, and energy to regulate a household temperature, and promote good social relations. Ultimately, each of these constituent parts of human well-being affect human freedoms and choice (more discussion on this point will be provided via Amartya Sen's ideas in Section 2.3.2).

In summary, Figure 1.1 shows how ecosystems impact humans (arrows going to the right in the figure). Next, the impact of humans on the ecosystems is discussed (how there are also arrows going to the left in Figure 1.1), and coupled with this, specific pollution-generated adverse human health effects are outlined.

### 1.3.3   Air Pollution and Climate Change

The US Environmental Protection Agency (EPA) sets standards for six common air pollutants called the "National Ambient Air Quality Standards":

1. *Ground level ozone:* Ozone, found at the ground level and in the atmosphere is composed of $O_3$, and at ground level is the main component of smog. It is the result of chemical reactions between nitrogen oxides ($NO_x$) and volatile organic compounds (e.g., combustion in vehicles, industry, and electric utilities). It reaches unhealthy levels on sunny days and in urban areas, and can be transported with wind. Even low levels can cause health problems, especially in people who are active outdoors, children, and older people. Children are the group at greatest risk as

*We depend in critical ways on ecosystems.*

*Human-generated pollution is having significant adverse effects on ecosystems and human health.*

| Ecosystem Services | | Determinants and Constituents of Human Well-Being |
|---|---|---|

**Supporting Services**

*Services necesary for the production of all other ecosystem services*

• Soil formation
• Nutrient cycling
• Primary production

**Provisioning Services**

*Products obtained from ecosystems*

• Food
• Fresh water
• Fuelwood
• Fiber
• Biochemials
• Genetic resources

**Regulating Services**

*Benefits obtained from regulation of ecosystem processes*

• Climate regulation
• Disease regulation
• Water regulation
• Water purification

**Cultural Services**

*Nonmaterial benefits obtained from ecosystems*

• Spiritual and religious
• Recreation and ecotourism
• Aesthetic
• Inspirational
• Educational
• Sense of place
• Cultural heritage

**Security**

• Ability to live in an environmentally clean and safe shelter
• Ability to reduce vulnerability to ecological shocks and stress

**Basic Material for a Good Life**

• Ability to access resources to earn income and gain a livelihood

**Health**

• Ability to be adequately nourished
• Ability to be free from avoidable disease
• Ability to have adequate and clean drinking water
• Ability to have clean air
• Ability to have energy to keep warm and cool

**Good Social Relations**

• Opportunity to express aesthetic and recreational values associated with ecosystems
• Opportunity to express cultural and spiritual values associated with ecosystems
• Opportunity to observe, study, and learn about ecosystems

**Freedoms and Choice**

Figure 1.1: Impacts of ecosystems on human well-being. Adapted from Figure 1, p. 5, in (MEA, 2005)

their lungs are still developing. Ozone also adversely affects a variety of vegetation.

2. *Particulate matter:* Also called "particle pollution," this is a complicated mixture of very small particles and liquid droplets (e.g., acids, organic chemicals, metals, soil, or dust). Smaller particles create more health problems as they can pass through the nose and throat and adversely affect the lungs and heart. There are "annihilable coarse particles" that are found near roads and dusty industries and "fine particles" from smoke or haze (created when the sunlight hits tiny pollution particles and reduces visibility) that are emitted from forest fires, or reactions between gases from power plants, industries, and automobiles.

3. *Carbon monoxide (CO):* This is a colorless and odorless gas let off from combustion processes, such as vehicles in urban areas. It has adverse health effects because it reduces oxygen delivery in the body (e.g., to the brain and heart).

4. *Nitrogen oxide:* There are a number of nitrous oxides, and a common one is $NO_2$, nitrogen dioxide, which is formed from emissions from vehicles and power plants. It can have a number of adverse effects on the respiratory system.

5. *Sulfur dioxide (SO$_2$):* This results from fossil fuel combustion at power plants and industry. It also can have a number of adverse effects on the respiratory system.

6. *Lead:* This is found naturally, and from fuels for vehicles and industry. It can adversely affect health including the creation of problems with the nervous system, kidneys, immune system, reproductive system, and cardiovascular system.

The atmospheric ozone layer serves to protect the Earth from ultraviolet rays from the sun; hence, its depletion can result in adverse health effects including increased incidence of skin cancer and cataracts, along with potential damage to marine organisms and plants. There are international laws about ozone-depleting substances (Montreal Protocol). There are a wide variety of "toxic air pollutants" that have an array of adverse health effects such as cancer or birth defects. Acid rain is a type of air pollution formed when acids (sulfur or nitrogen oxides from burning coal or other industrial fuels) are incorporated into rain, snow, fog, or mist. Acid rain ends up in streams, lakes, and marshes and causes damage when these cannot "buffer" the acid to neutralize it. The resulting acidic water can have adverse effects on aquatic organisms and ecosystems. Acid rain also causes slower growth, injury, or death of forests.

Greenhouse gases trap heat in the atmosphere. The four most important greenhouse gases are carbon dioxide, methane, nitrous oxide, and fluorinated gases. Carbon dioxide is produced by burning coal, natural gas, and oil (fossil fuels) and also solid waste and wood. Methane results from the production and transport of fossil fuels, and from livestock and decay of organic waste in landfills. Nitrous oxide is produced in agriculture and industry and the burning of fossil fuels and solid waste. Fluorinated gases result from a variety of industrial processes. According to the EPA, in the US the largest emitters of greenhouse gases by economic sector are: electricity (32%), transportation (28%), industry (20%), commercial and residential (10%), and agriculture (10%). The EPA also has global greenhouse gas emissions data here.

Human-created greenhouse gas emissions are causing climate change (e.g., see here). Impacts of climate change include increased or decreased rainfall, effects on agricultural crop yields, effects on human health, and changes to ecosystems including adverse effects on biodiversity. See Problem 1.17 and Problem 1.18. Many people argue that climate change is the biggest threat facing the planet Earth (Sachs, 2014).

Indoor air quality is also of concern. For instance, it is very important for persons with Asthma, and poor air quality can cause a number of serious respiratory problems. Indoor air pollution can result from burning wood, carbon monoxide (from kerosene or gas space heaters, wood stoves, gas stoves, etc.), and other sources such as mold.

### 1.3.4   Water Pollution

Water exists in many places, including its visible locations of streams, watersheds, rivers, wetlands, and oceans. A less visible site is "ground water," the water in underground "aquifers." According to Conserve-Energy-Future, sources of water pollution are either "point" or "non-point" depending on whether they come from a single or multiple sources. A point source could be a factory and a non-point source could be contaminated rain that travels through many paths and ends up in a lake. Pollutants are both organic and inorganic. Causes and effects of water pollution include:

- *Industrial, mining, sewage, landfills, and radioactive waste:* Toxic chemicals that are improperly disposed by industry often end up in streams, rivers, lakes, and ultimately the ocean. These present significant hazards for wildlife and ecosystems, not to mention human health. Mining activities result in metal waste and sulfides that contaminate water. Sewage and waste water can result in a number of disease-causing pathogens. Sometimes, there is sewage leakage and this can pool and create breeding grounds for undesirable insects such as mosquitoes. Similarly, there is leakage from landfills that can contaminate water. Accidents at nuclear power plants (e.g., in Japan) result in significant pollution to water. Sometimes there are problems with leakage of underground storage locations.

- *Marine dumping and oil spills:* Waste, by some countries, is dumped directly into lakes, seas, and the ocean. This contaminates the water and harms sea creatures. Oil spills, via transport or deep-sea drilling accidents, causes significant water contamination and harm to water wildlife and ecosystems.

- *Fertilizers, pesticides, and animal waste:* These, whether used in agriculture or near-home lawn-care, are often washed into streams, rivers, and lakes. Animal waste is often washed away into rivers and causes a number of water borne diseases (e.g., diarrhea or cholera).

- *Climate change and global warming:* These can cause a rise in water temperature that adversely affects water wildlife and ecosystems, to mention a few effects.

Of course, acid rain, as it is discussed above, causes significant water pollution.

### 1.3.5 Soil Pollution

According to Conserve-Energy-Future, soil pollution is caused by:

- *Industrial activity:* Mining and manufacturing cause significant soil pollution, for instance, via by-products of mining and industrial waste.

- *Agricultural activity:* Pesticides and fertilizers can ultimately lead to decreased soil fertility and other chemicals can lead to soil composition degradation that leads to erosion.

- *Human waste disposal:* Whether in the form of urine or feces this pollutes, sometimes via ending up at a landfill. Moreover, disposable diapers cause a significant load for landfills.

- *Oil spills:* These occur during storage and transport of oil, and can make soil infertile and pollute the groundwater with implications for safety of drinking water.

Of course, as discussed above, acid rain also pollutes soil.

The effects of soil pollution include:

- Crops and plants absorb pollution from the soil and adversely affect livestock and human health.

- Crop fertility can be adversely affected.

- When fungi and bacteria, that bind soil together, are affected this can result in erosion.

- Emission of toxic gases from landfills causes air pollution and adversely affects human health.

Organic farming methods, along with restrictions on hazardous waste dumping, can help alleviate some of these problems.

There are other types of pollution, including thermal (taking water from a natural source and heating or cooling it and then returning it), noise, and light. Also, there are general concerns about the adverse effects of pollution of all types on biodiversity (Rockstrom and et al., 2009; Sachs, 2014; Steffen et al., 2015).

### 1.3.6 Pollution and Planetary Boundaries

The present levels of pollution raise the question of whether humanity is destroying the "commons" (natural resources under shared human use like air, water, land, and forests). Will continued improper use lead to a "tragedy of the commons" (Hardin, 1968) where the natural resources needed for human survival are destroyed due to over-use that arises from unmalicious actions by many unthinking individuals? Does the free market, and Adam Smith's notion of the "invisible hand" always result in the side effect of over-use of the Earth's

resources to drive the economic engine (Martin and Schinzinger, 2005)? Indeed, can Earth simultaneously support economic growth, population growth, social inclusion, and environmental sustainability (Sachs, 2014)? What are the limits to growth? These questions are addressed in (Rockstrom and et al., 2009; Sachs, 2014) by quantifying "planetary boundaries," limits beyond which the Earth cannot support, as follows:

1. Climate change, global warming, and its many effects, for example on food supply, biodiversity, intense storms, rising ocean levels.

2. Ocean acidification that threatens marine life.

3. Ozone depletion and hence reduction of protection of humans from the sun's ultraviolet radiation.

4. Pollution from nitrogen and phosphorus via chemical fertilizers in agriculture (about 4 billion people in the world are fed as the result of fertilizers).

5. Overuse of freshwater (in agriculture, industry, homes) and groundwater depletion.

6. Land use due to agriculture, forestry, and expansion of cities.

7. Biodiversity, well-functioning of ecosystems, food supply, construction and industrial materials, etc. (scientists are concerned that humans are creating Earth's sixth large extinction wave).

8. Aerosol loading due to burning coal, biomass, and diesel results in small particles called "aerosols" released into the air.

9. Chemical pollution due to industry.

> The humanity's actions are resulting in breaking through some planetary boundaries.

The world has already exceeded limits in biodiversity loss and impact to the nitrogen cycle, and we have begun to seriously push the climate change limit (Rockstrom and et al., 2009). The paper (Rockstrom and et al., 2009) was revised and updated in (Steffen et al., 2015). Updated information on phosphorus, nitrogen, land-system change, and freshwater use are given in Fig. 2 of (Steffen et al., 2015). Also, for seven of the nine variables, the status in terms of planetary boundaries are given in Fig. 3 of (Steffen et al., 2015) where it shows that planetary boundaries have been exceeded for biogeochemical flows (nitrogen and phosphorus) and for biosphere integrity (e.g., biodiversity). In (Sachs, 2014), Sachs projects economic and population growth and concludes that we are already up against some of the boundaries. He asks what will happen in the future? He, and many others, are concerned about energy use (and its impact on climate change), agriculture (which impacts most of the above), population growth, and economic growth, and their combined effects on the environment.

### 1.3.7 Ecological Footprint and the Human Development Index

While the above sections clarify the causes and effects of air, water, and soil pollution, along with climate change, we also need to understand in another way (in addition to the planetary boundaries) the *extent* of the effects of pollution and adverse effects on ecosystem services. One approach to assess humans' effects on the environment is via "footprint analysis." The ecological footprint is discussed next, and the carbon footprint is studied in Problem 1.21.

According to the Global Footprint Network (GFN), the "Ecological Footprint" is a measure of humans' demands on nature in terms of resource consumption and waste production. It seeks to address the question of whether the biocapacity of Earth (e.g., cropland, fisheries, and forests) can support all human activities. The ecological footprint is the productive area, expressed in hectares (or acres), on Earth needed to provide resources and absorb waste. One of their basic findings is that humanity has created an "ecological overshoot" since the 1970's where the Earth cannot meet annual resource demands each year. GFN says: "It now takes Earth one year and six months to regenerate what we use in a year." This implies that resources are being depleted and at the current time it takes about 1.5 planets to provide resources and absorb waste for humanity. The UN predicts that by 2030 we will need 2 planets if all goes as usual. The GFN data show that with the current population and land area "an ecological footprint of 1.8 global hectares per person makes a country's resource demands globally replicable." See Problem 1.20 where you are asked to compute your personal ecological footprint.

Considering the relation between the ecological footprint and the HDI defined in Equation (1.4) discussed above, there is a movie at the GFN on

> Simultaneous Variations of Ecological Footprint and the HDI

The movie plots on the horizontal axis HDI and on the vertical axis ecological footprint in global hectares. An value of $HDI \geq 0.8$ is considered "highly developed" by the UN and is shown as a vertical line in the movie. The ecological footprint value of 1.8 is shown in the movie as a horizontal line. The movie shows each country as a dot with a color coded by region, and the dots move in the $x - y$ plane according to the HDI and ecological footprint data in the time range of 1980-2007. Generally, the dots move to the right indicating that countries are generally developing in a good direction, but the dots also generally move up, indicating that HDI improvements come at a cost in increasing the ecological footprint. Indeed, from 1980-2007 no country reaches the "goal" of simultaneously having a value $HDI \geq 0.8$ and an ecological footprint less than 1.8 global hectares. What are the implications?

### 1.3.8 The UN Sustainable Development Goals

The analyses via planetary boundaries and footprints suggests that the following question is of fundamental importance:

*Ecological footprint analysis shows that humanity is using more resources than the environment can provide.*

### "Can we achieve socially inclusive human development without destroying the environment?"

Or, more simply, "Is it possible to end poverty without destroying the environment?" Return to the above HDI-footprint movie and note that the countries in the developing world with a high HDI value all have high ecological footprints. The low-income countries in the developing world generally have both low ecological footprints and low HDI values. If all countries develop, must they all end up with high ecological footprints? Significant evidence suggests that the *path* to development cannot be the same as the one taken by rich nations as this would lead to an environmental catastrophe (Sachs, 2014). There must be much more concern for the environment than in the past. This produces a significant challenge for the humanitarian engineer and demands an emphasis on *sustainable development*. But, how do we need to proceed in order to try to avoid a catastrophe?

The UN "Millennium Development Goals" (MDGs), adopted in 2000 and that ended in 2015, had to do with a range of issues in poverty and development. Following these, and set for the time range of 2016-2030, there are the UN "Sustainable Development Goals" (SDGs), ones that set goals of ending poverty, improving development, and doing so in a sustainable way so that the environment is not ruined in the process.

The UN Sustainable Development Goals are:

1. *Goal 1:* End poverty in all its forms everywhere

2. *Goal 2:* End hunger, achieve food security and improved nutrition and promote sustainable agriculture

3. *Goal 3:* Ensure healthy lives and promote well-being for all at all ages

4. *Goal 4:* Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all

5. *Goal 5:* Achieve gender equality and empower all women and girls

6. *Goal 6:* Ensure availability and sustainable management of water and sanitation for all

7. *Goal 7:* Ensure access to affordable, reliable, sustainable and modern energy for all

8. *Goal 8:* Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all

9. *Goal 9:* Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation

10. *Goal 10:* Reduce inequality within and among countries

11. *Goal 11:* Make cities and human settlements inclusive, safe, resilient and sustainable

12. *Goal 12:* Ensure sustainable consumption and production patterns

13. *Goal 13:* Take urgent action to combat climate change and its impacts

14. *Goal 14:* Conserve and sustainably use the oceans, seas and marine resources for sustainable development

15. *Goal 15:* Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss

16. *Goal 16:* Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels

17. *Goal 17:* Strengthen the means of implementation and revitalize the global partnership for sustainable development

Each of these goals is explained in more detail at

UN Sustainable Development Goals

In particular, there are "targets" under each goal. For example, under Goal 1, it says

"By 2030, eradicate extreme poverty for all people everywhere, currently measured as people living on less than $1.25 a day."

Also, it says "By 2030, reduce at least by half the proportion of men, women and children of all ages living in poverty in all its dimensions according to national definitions." Under Goal 4, it says "By 2030, ensure that all girls and boys complete free, equitable and quality primary and secondary education leading to relevant and effective learning outcomes." Under Goal 5, it says "End all forms of discrimination against all women and girls everywhere." Under Goal 9, it says "Enhance scientific research, upgrade the technological capabilities of industrial sectors in all countries, in particular developing countries, including, by 2030, encouraging innovation and substantially increasing the number of research and development workers per 1 million people and public and private research and development spending." Under Goal 12, it says "By 2030, achieve the sustainable management and efficient use of natural resources." Also, note that there are many technological dimensions in the targets that underly the 17 goals, and of the "169 targets, 14 targets explicitly refer to "technology" and another 34 targets relate to issues that are most often largely discussed in technology terms" (p. 42 of (Nations, 2016)).

## 1.4   Culture and Global Competence

Michael Agar said on p. 22 of (Agar, 1994):

> Americans have trouble understanding another mentality, suggested my Swiss friend. They have trouble entering into another world that goes with another language, another point of view, another way of doing things. Americans have trouble with culture. That's a stereotype I've heard all over the world.

It is difficult to provide a simple definition of "culture." The New Oxford American Dictionary defines culture as: The arts and other manifestations of human intellectual achievement regarded collectively:

- The customs, arts, social institutions, and achievements of a particular nation, people, or other social group

- The attitudes and behavior characteristics of a particular social group

In (Haviland et al., 2008) the authors define culture as follows:

> Culture consists of the abstract ideas, values, and perceptions of the world that inform and are reflected in people's behavior. Culture is shared by members of a society and produces behavior that is intelligible to other members of that society. Cultures are learned rather than inherited biologically, and all the different parts of a culture function as an integrated whole.

A "global engineer," or an engineer with "global competency," is one who can easily work across international borders. Understanding other languages, cross-cultural communications, how to work in cross-cultural relationships, and how to take into account local "context" are the key skills of a global engineer; however a global engineer sometimes has to understand international business, technology policy, intellectual property, and trade policy. Of course, the global engineer must understand history, politics, economics, religion, etc. of the country/culture they are working with. Studies on global competency of engineers are in (Downey and Lucena, 2006; DeBoer et al., 2013; Jesiek et al., 2014), and it is competency of this sort that is discussed in this section and throughout this book (e.g., communicating and working with people from different cultures or countries, such as via participatory development in Section 4.2). Here, we consider the challenging issue of working as a cross-cultural (humanitarian) engineer.

*Understanding culture is important for cross-cultural collaborative engineering work.*

### 1.4.1  Features of Culture

"Ethnocentrism" is the belief that your own culture is the only right one, or for some that their culture is superior to all others. Some claim that people in every culture are ethnocentric. Learning about other cultures teaches us, however, that "different" is not the same as "worse" or "better" and often that differences are to be celebrated. Culture is learned; for example, the appropriate ways to satisfy basic needs (food, sleep, companionship, etc.) are learned and used in a society. We share culture in the form of ideas, values, how to perceive reality,

and behavioral standards. This sharing guides human interactions and creates a sense of cultural identity. Each individual in a society has a somewhat different culture. For instance, gender is not just the biological distinction between the two sexes. Gender is "the cultural elaborations and meanings assigned to the biological differentiation between the sexes" (Haviland et al., 2008); in different societies, behavior by and toward each sex is a result of culture. Persons of different ages behave and are treated differently (e.g., children, adults, and senior citizens). Other subcultures in a society may include persons who do the same job, social classes, or ethnic groups. Culture is an integrated whole with various features, including a social structure that defines rule-governed relationships (e.g., families and associations and their rules of interactions of members that govern work and economic subsistence), and a shared identity and worldview (e.g., influenced by religion and national ideology). Culture dynamically adjusts to changing circumstances, such as technology, economics, or politics (Haviland et al., 2008).

Aspects of culture, some of which overlap, include:

- Religion/faith, or lack of it.

- Morals, norms, views of justice.

- Values, attitudes, opinions, priorities, etc.

- Behavior with or toward people, men, women, babies, children, senior citizens, etc.

- Customs (e.g., "kiss, bow, shake" upon greeting), celebrations, holidays, etc.

- Arts (painting/drawing, sculpture, literature, dance, singing/music, etc.)

- Traditions in education, healthcare, grass-roots organizations, clubs, etc.

- Differences in socio-economic class.

- Views of the military.

- Food and drink.

- Topics you do not discuss with persons you do not know really well in "polite conversation" (e.g., sex, money, religion, or politics and perhaps others for different countries).

- Marriage, child-rearing, and discipline.

- Sexual customs.

- History, politics, economics.

- Language, mix of languages.

- Hair, make-up, body decorations, clothing, style.

- Philosophy.

- Funeral and burial customs.

## 1.4.2 Why Cross-Cultural Understanding is Important

It is important to understand your own culture (be able to articulate it, not just inherently know it), and the culture of the person or people you aim to work with, to be an effective cross-cultural engineer for the following reasons:

Cross-cultural communication skills greatly facilitate working with other cultures.

1. *Be an ambassador:* It is crucial to understand the importance of personal relationships before you even start work. As you get to know the people you are working with, you will find that the cultural issues in this section are generally very good topics for discussion, especially initially discussing positive aspects of their culture and perhaps negative aspects of your culture–this is both humble and respectful if not overdone–let them bring up the negative aspects of their culture to commiserate with you about your country's problems. It is highly unlikely that you will want to discuss the poverty and underdevelopment statistics/issues discussed above unless you get to know someone very well, and then discuss the statistics from your own country first. You do not want to come across as bragging out your country in any way. Every country has problems. You want to make sure that you do not say offensive comments or behave in a culturally unacceptable manner. When traveling to another country you have to be especially careful how you treat the opposite gender and children as there can be many problems if you behave like you do in your own country. Think of yourself as an ambassador for your country who is trying to build better relationships between your two countries.

2. *Understanding the people you are working with:* Understanding culture helps you better understand the people you are going to work with to identify needs/challenges, resources, design technologies, and test/disseminate them. One of the key lessons of this section is that different people have different values and hence different opinions, attitudes, and priorities. You need to come to understand these so that you work with others to develop a technology that fits *their* priorities and values to the greatest extent possible. Moreover, culture, values, and priorities can change the very technological design constraints you will be working on; you are seeking to design a product that fits the people you are helping, who can be quite different from the people you know in your own country. You will find a number of surprising things when you study the culture of various countries, things that are inconsistent with your view from a distance created by the media. A number of things you will learn are likely to make you more comfortable about traveling to a country, but some may be a cause for concern. Generally, in my experience: (i) people from one country think people from another country are worse than they actually are (due

to the negativity of news); and (ii) I have always very much liked the real people on the ground (close up).

3. *Understanding views on technology:* The rate of technological advance in a society is related to "cultural lag" where "habits, thoughts, values, and social arrangements often fail to change at the same speed as technological innovation" (p. 273, (Volti, 2006)). This can significantly impact your ability to work with people to introduce a new technology. They may say, "well we do not do things that way here."

4. *Understanding context:* Learning about culture, values, and priorities can be as important as learning the history and current events (e.g., via news on the internet for their country to know what the people are currently concerned about) of the country you travel to, or the country of origin of the people you work with. If for no other reasons, it makes for good conversation and is respectful (e.g., do you know what the most popular music or dance is, and can you ask them what their opinion is of those?).

5. *Understanding yourself:* It is important that you understand your own attitudes and how these attitudes might be arrogant (the "we are perfect and you are not" attitude), even though ethnocentrism is natural. It is useful if you are not surprised about their attitudes about you; often, from a distance, people will assume that your attitudes and opinions are the same as your government's (e.g., a number of people I have talked to from other countries thought that everyone in the US supported the invasion of Iraq when at the time it was quite controversial) or what they hear from people on TV, in movies, or the internet.

### 1.4.3 Transitioning Between Cultures: Experience and Approach

When transitioning between two cultures, such as the one you were born and raised in, and another one, the experience of the transition can be described in the following ways:

- *"Culture shock:"* This term is used for transitions from your home culture to another one, or after a (long) stay in another one, to your home culture. The word "shock" is often properly descriptive of the experience, and it comes from the sudden jump from experiencing everything around you in one way, to another.

- *"Feeling like a child again:"* In some respects, this analogy works well as when you transition into a culture/country that you have never experienced, many things around you are completely new or at least different. It is like experiencing the world for the first time, again, at least to some extent. You will not know some of the most basic ways to speak to people and interact. For instance, when and how to say thank you? How to greet

someone, for different types of people (young vs. old, men vs. women)? What you can say, and when? How to behave in different situations?

- *"Getting outside your comfort zone:"* Related to the last two issues, you can feel "awkward," "out of sorts," "off balance," or "out of equilibrium." These can occur for you, socially, cognitively, emotionally, or physiologically due to jet lag, eating new foods, traveling in new ways, sleeping under different conditions, etc. You may "miss the comforts of home."

There are different ways to react to this cultural transition experience, positive, negative, or a mix of these. One approach would be to view it as a learning experience, with a "steep learning curve." Overall, you could approach a cultural transition as follows:

1. Recognize/learn differences,

2. Tolerate differences,

3. Respect differences, and

4. Celebrate differences!

Yet, you may encounter challenges to such an approach to a new culture. For instance, for item 1, it can take a very long time to achieve this for a new culture. For items 2-4, learning can be important, but other issues can arise. For instance, what do you do if you see a pattern of something you think is wrong (e.g., some group being treated unfairly)? Tolerate/respect/celebrate it? Try to change it? Realistically, how? Just try to set an example via what you say and do? Something more? Such issues can create significant challenges for a humanitarian engineer working in a different culture.

### 1.4.4   Culture and Conversation: A Close Up View

One of the most intriguing aspects of international travel is interacting with the local people. Learning the local language, or at least some words from it (e.g., "please," "thank you," "hello," and "goodbye") is very important as it shows respect and is a great asset for your own learning. Communicating with people of other cultures is, however, difficult as human communications come in many forms: oral, written, and body language. As an example of cultural differences in communication, consider the (1:12) YouTube video from Feb. 21, 2012, that explains gestures in Colombia:

<div align="center">Hilarious Colombian Hand Gestures</div>

Each culture seems to have a set of gesticulations that are used in communication, and some cultures share the same types of gesticulations. To learn more, see the (9:07) YouTube video that was posted on Dec. 27, 2008,

<div align="center">Gestures Across Cultures</div>

Suppose you are meeting and working with people of a different culture, either in your native country or abroad. What do you talk about? How do cultural differences impact what you do and say? How can you be respectful, but not unnaturally constrained? How can you have a fun conversation with them? Relationships are built based on face-to-face conversations so it is important to think about how to proceed.

**Small-Talk Conversation and Talking About Culture**

Initially, probably the best choices of what to talk about are as follows:

1. Topics surrounding being there (e.g., the weather, what you are working on, or your travel experience).

2. The food and drink you are consuming, so long as it is positive (do not ask if the water is safe, if you do not think it is, get a bottled drink or bring your own bottle of water and do not discuss why). You should be adventurous with the food; do not refuse their national dish or drink, or act like it is a big deal that you are trying it by showing great hesitation; show enthusiasm.

3. Current news and events from their country (yes, you should have been reading it).

4. History of their country (yes, you should have read at least one history, and start with positive aspects, not wars and conflict).

5. Literature (yes, if it exists, you should read a book that is most popular in their culture as it makes for great conversation).

> In cross-cultural communication, you will be much better at small-talk conversation if you understand their culture.

For this initial small-talk conversation, as my Dad used to say to us kids, "If you do not have something nice to say, keep your mouth shut." During the conversation, try to use at least a few words of their language so be prepared before you travel; realize that the more of their language you know, the more fun and interesting the experience will be (and do not expect them to know your language). Try to get a translator if your language skills are not sufficient, especially for a work or educational site where you will be closely interacting with the people.

While many of the above five areas for conversation have to do with culture, you can go much further in conversation, even initially, if you navigate the issues properly. To do that, you need to know about culture, such as the features of culture discussed in Section 1.4.1. If you review those, and learn about them, most of them can serve to take you to another level of conversation with people. At the outset, however, it is good to have some ideas of how others may view you and your culture, and admit that there will be things that are very difficult to understand about their culture. These two issues are discussed next.

**Views I Have Heard About the US**

It is quite instructive to meet people from other countries, or read news sources from other countries, to learn about your own country. To give you an idea of how the US is perceived by others I give a sampling of perspectives I have heard directly from individuals from other countries:

- An Ecuadoran, when I told him I was going to visit Colombia, as politely as possible told me "Americans are viewed as naive."

- A Colombian told me that "Americans are arrogant, but not as arrogant as the French and that is why I came to study here." A European once told me that American scientists and engineers are arrogant as they always feel as if they can figure anything out, or solve any technological problem. I have heard Americans called "optimistic" many times.

- A Nicaraguan once told me that the first thing he thinks of when he thinks of Americans is "greedy" and similarly a person in El Salvador once told me that "Americans are greedy capitalists."

- A Spaniard woman once told my wife Anne and I that "my son does not behave like American children as they all behave like Bart Simpson." A man from England who I had never met once told my wife and I that American children all behave badly because Americans were all raised badly and hence do not know how to discipline their children.

- A woman from England who I had never met once told me that she was absolutely certain that no American cared about recycling or the environment.

- A Colombian student attending a workshop I was giving in Bogotá, whom I had never met, came up to me at a "tinto" (coffee) break and quite angrily told me it how bad it was that "we," the US, had just invaded Iraq. I responded in Spanish that "I am not my government." He paused, smiled, and walked away. While that happened, I was giving a short course on one side of the main large street ("Septima"), and then crossed it, and gave another short course in the afternoon on the other side. During the second course I could hear the loud and large group of protesters marching down Septima protesting against the US and their invasion of Iraq. The Colombian government decided to have Colombia join the US "coalition of the willing" that invaded Iraq.

- I have had several graduate students from other countries (China, India, Turkey, Latin America, etc.) tell me, after living in the US for a while: "the system here is just efficient and things are easy to do," "I can't understand how your system works, it is all distributed, but everything operates well," "I have seen Americans help me, such as when my car broke down, and that would never have happened in my own country," "I can't believe that your severely disabled people are employed, such as

at the movie theatre, as in my country they would be on the street and extremely poor," "trust me, Americans are loose," "there is no difference between a Republican and a Democrat that I can see," "it is just so safe here," "the undergraduates do not appreciate how good the equipment is in the laboratory, they take it all for granted," or "everyone is just so open-minded."

- I was talking to a very friendly person in El Salvador about the US involvement in their civil war and he quickly said something like "but let's just forget about that."

- In Guatemala someone said to me, when Anne and I were adopting our son Zac, that it was common knowledge that "Americans have adopted our babies and children to harvest body parts and for forced labor–why else would they adopt?" For one of our other adoptions in Colombia, someone said to Anne something like "you must be adopting since, like other American women, you don't want to get overweight, lose your figure/beauty, or go through the pain of birth."

- A man (from an unnamed country) told me emphatically that "Americans deserved 9/11, including all the deaths of civilians no matter what country they were from," and that was a two days after 9/11. A Colombian friend emailed me the day after 9/11 with a sincere heart-felt message of condolences and said he knew how we felt since they "have so much terrorism in their country and for so long."

- A man in México once told me that the problem with American families and children is that they are obsessed with having fun and spend all day every day trying to find fun things to do, or doing fun things.

- A Chinese man, in a conversation with me and a blonde female American, told her that people in his country would consider her to be quite ugly.

- I had a long talk with a person who had quite low income (and as a child, an orphan and very bad off) in El Salvador. I asked him at one point what "the percentage of people who are poor in El Salvador was." He said, and repeated, that he was certain it was "definitely over 90%" (after I returned home, I looked it up on the World Bank website and per their own poverty line, it said the rate was 34.5% in 2012; of course, there are different definitions of poverty).

I understand that some of you, including Americans, may agree with some or all of that. But, should they really have said some of those things, especially with such certainty? Americans who try to self-describe our culture say: "Americans do not respect authority" and feel that is good; "Americans are creative," "Americans have many freedoms," and "Americans are greedy." It seems that all views from a distance are wrong, at least to some extent, and even some views from up close. For instance, with respect to the above statements about

> You should not be offended by others' views of your culture that are gained from understanding at a distance. You may have similarly poor understanding of their culture.

greed, consider the discussion on the "World Giving Index" below where the US ranked in 2012 as the number one country in the world on the percentage of people giving. Greedy? Or, a cynic may just say that Americans are rich enough to be able to easily give their time and money away? What about the studies in the US that have shown that people who are low-income give away a higher percentage of their income that the rich? Do not misinterpret me, I personally find many Americans quite greedy (sometimes me too); but clearly all the dots above do not connect; I conclude that making judgments from a distance is dangerous, especially if you are not wise enough to keep your mouth shut.

### Things I Do Not Understand About Other Cultures

As you might suspect, I am not going to share any negative views on a country or individual from another culture, but I would point out some things I find "confusing" or humorous to highlight that there are real differences between people around the world and that aspects of culture can be difficult to understand:

> There is nothing wrong with admitting that you do not understand things about another culture.

- I find it unusual that Colombians (think tropics, primarily) (i) do not seem to wear short pants unless they are jogging or on the beach, no matter how hot it is (and even when they have been in the US for a number of years and it is summer time and near 100 degrees F), and (ii) in my experience more often than not wear dark colored cloths (e.g., black), and not white or tan pants (darker cloths keep you warmer). The formality of dress I have seen in many countries in Latin America, where I judge "formality" based on US standards (ok, so some view us as way too relaxed), is confusing to me when I have been in what I think of as relaxed situations with people there.

- I have found that when giving short courses in Colombia, México, China, El Salvador, and Turkey that the students in the courses were more respectful or deferential than in the US, perhaps consistent with the view that Americans do not respect authority (maybe good for democracy, but not so good for grandma and grandpa), though I am hesitant to refer to myself as "authority." This is also perhaps due to the students treating their own professors with more respect and they group me with them?

- In giving short courses around the world, I have been surprised a number of times with the formality of those helping run the workshop, towards the individuals in the course. For instance, certificates are often individually presented to each participant in a small ceremony, something I have never seen in all the short courses I have given in the US. Are people in other countries more respectful to each other than in the US? Or, is it just that in many countries people are more formal than in the US? I have seen this formality in dress many places, but perhaps it extends to other issues.

- I have had several Latinos from different countries (Colombia, Ecuador, and El Salvador) sign their email "Un abrazo" (that is, "a hug"). I have had emails for years from males all over the world have never seen anything like that from anyone outside Latin America. I know men in other countries I have been to hug each other more than American men do, but perhaps the lines of "Latino machismo" are not so clear to me?

Assume I tried to raise issues like these in conversation with someone of a different culture that I do not know so well (if you know someone really well, you can discuss just about anything with them, just using your standard judgment, as in that case the cultural difference influence disappears). The tricky part is the initial conversations with people of other cultures and what to talk about. You could start as suggested above. What if you feel you are ready to move on to other subjects?

### Conversations About More Difficult Subjects

If you get to know someone better, note three things about the way I discuss other cultures above:

1. Taking to a single individual in private is very different from talking to a whole group of people.

2. I keep it positive until I know someone very well; however it is not always kept positive because as they get to know you they will start saying what they dislike about their own country. How to react to that? I think it is best to ask them questions about what they mean. Also, it may be good to point out similar problems in your own culture, if they exist (hence, the need to understand your own culture). Never say "oh, that would never happen in my country/culture" as that could convey a bad message that you feel superior.

3. You can always talk about negative aspects of your own culture, however, do not overdo it; be fair. In my experience, doing this always results in a change in the conversation to them saying "oh, we have the same problem" and then a useful and interesting discussion.

4. Know what you know, but more importantly know what you do not know. There is nothing wrong with saying "I am confused" or "I do not understand, please explain." I have always found that people from other cultures are quite happy to explain.

5. Do not be too baffled. Learn to recognize differences, accept them, and if appropriate *celebrate* them (yes, over their national food and drink).

The most important aspects of these are that you are forming relationships, making friends, being an ambassador, and developing solidarity. Do not view this as a difficult and arduous process; it is fun and you should show it!

If you build a good relationship, it is sometimes good to discuss more difficult issues so you can deepen your understanding of the people you are working with.

**Individuals' Extremism, Ideology, and Intolerance**

There seem to be many extreme views, ideological impacts, and intolerance in some humanitarian engineers and the people they work with. These are all set in a cultural context, and impact how you work with people on the ground; hence, they need to be discussed briefly here.

Negative views by people you are working with can cause significant problems for you, and ultimately lead to projects never getting started, never getting completed, or being a failure (e.g., because they are intentionally subverted/obstructed by people on the ground). This points to the need to try to "get everyone on board, to get buy-in from everyone, to get real involvement (time, money, or sweat/work) from everyone being helped" (see Section 4.2). Also, it points to the need to understand their views on your country and culture (if your country's militarily invaded their country in the past, even the distant past, how will they now feel about persons from your country trying to help?). Will they *trust* that you are trying to help, and do not have a hidden agenda where you are trying to exploit them (I have personally experienced this)?

Extremism, ideology, and intolerance are not welcome because they do not lead to effective or productive work in humanitarian engineering. For instance, there are extremely negative and positive views of religious or secular views on social justice, some of which are driven by ideologies (e.g., liberal vs. conservative or secular vs. religious). There is significant controversy in the field of development, for instance on (i) where to lie on the continuum: aid for charity–aid for subsidy–profiting off low-income people; or (ii) on the continuum: overly coercive/invasive methods to solve poverty problems from the outside–supporting internal local efforts–ignoring the low-income people altogether to let them struggle to solve their own problems. Again, ideological viewpoints, like religious/secular, conservative/liberal, etc. unduly impact perspectives on these issues. Attempts to dogmatically apply any one approach to a range of situations or countries is simply not effective (there are always special cases and counterexamples–there is no blanket approach). Or, over-attention to one "level" (e.g., political or economic system) vs. another (e.g., individual or community) does not provide a balanced well-informed perspective that makes you effective. It is a system, and to be effective, you have to understand at least something about the whole system, and a lot about at least one piece and how it interacts with the other pieces.

With respect to project work, practitioners often have significant biases, being over-optimistic about one approach or technology since it worked in one situation (or one low-income person or low-income community). Some try to ignore cultural differences entirely, not respecting individuals' differences. Some ignore gender issues and will not acknowledge the clear and widespread mistreatment of women and girls (in a number of countries and situations, extreme). For both cultural, racial, and gender issues, ideology enters the equation in dangerous ways (e.g., some general religious stances on women). Some are obsessed with environmental issues and do not consider the complex interplay between people, poverty, development, and the environment (to help end extreme poverty

Beware of extreme views, and learn how to cope with them with grace.

in a community, how much should you be willing to pollute?). Some feel that the only way to do humanitarian work is via volunteer work (no pay or other compensation), others seek to profit off their humanitarian work, or work on a paid job that does humanitarian work, or have a paid engineering job and then on nights, weekends, and vacations do humanitarian engineering. Considering individuals' variety of personal constraints (e.g., their own disabilities or family responsibilities), I feel that all these approaches can be valuable and should be respected, including fully respecting people who do no humanitarian work, of course.

### 1.4.5 World-Wide Cultural Differences: A View From a Distance

While above we considered a close-up view of culture, mainly in the context of conversation, here world-wide cultural issues are discussed via the "World Values Survey" (WVS).

**The World Values Survey**

The World Values Survey and the WVS survey data analysis tool are used to study country-level, and inter-country, cultural issues (Inglehart, 2008). You should essentially think of the WVS as providing detailed data on many facets of the people in countries, and the world (well, at least the many surveyed countries), and how these people's views have been changing over time. It provides a broad understanding of many aspects of culture from a distance. The survey has questions broken down into the following categories:

Learning about culture from a distance sets context and informs up-close cross-cultural communication.

- Perceptions of life

- Environment

- Work

- Family

- Politics and society

- Religion and morale

- National identity

- Structure and metadata

- Sociodemographics

- Inglehart's indicators

The WVS survey data analysis tool allows you to learn from their extensive data set. For instance, you can study responses to their question "Feeling of Happiness" (very happy, quite happy, not very happy, not at all happy) per

age, country, educational level, gender, employment status, religious practice, religion, study year (to see changes over time), and others. Or, you can study importance of family, friends, religion, education, money, politics, etc.; the list of survey questions is quite long so there are a great number of ways to study the data per your interests. For instance, you may be interested in the responses to their survey for your own country or a country you are going to visit.

Some of the most general, aggregate, and interesting results are (Inglehart, 2008):

1. *The global cultural map:* This places points representing countries on a two-dimensional plot with the vertical axis a range of "traditional values" to "secular-rational values" and the horizontal axis a range from "survival values" to "self-expression values." Countries are grouped in different ways (region, language, religion/faith, or ex-communist). Distance on the plot between two countries is not geographic distance; it can be thought of as "values-distance" or perhaps "distance between cultures." An earlier version of this culture map was produced and can be used to gain an idea of changes over time. This plot is useful to, for instance, compare the country you live in to a country you plan on visiting. Of course, to get a more fine-grained understanding of two such countries you can use their on-line data analysis tool discussed above.

2. *Conformity, self-expression, and effective rights:* The next plot from (Inglehart, 2008) is a two-dimensional plot with a horizontal axis going from "conformity" to "self-expression" and a vertical axis going from "lack of effective rights" to "fully meeting effective rights." Countries are represented on the plot as dots. The results show an increase in meeting effective rights as self-expression increases (interpreted in (Inglehart, 2008) as implying the future spread of democracy).

Empowerment; globalization, gender, and converging values; culture, diversity, and religion; and rising insecurity and values are also discussed in (Inglehart, 2008). See Problem 1.25.

### Giving, Volunteering, and Helping Strangers

The Charities Aid Foundation (CAF) published the World Giving Index report. For many countries, the three questions at the heart of their report are: Have you done any of the following in the past month?

1. Donated money to a charity?

2. Volunteered you time to an organization?

3. Helped a stranger, or someone you didn't know who needed help?

The "World Giving Index" is based on a ranking based on averaging the scores on these three questions. For 2015, the CAF, had the following main points (quoted from their web site):

It is useful to understand a culture's views on volunteering as this gives context for understanding willingness to work on a collaborative project.

1. Myanmar, which shared first place with the USA in 2014, tops the 2015 CAF World Giving Index. The USA and New Zealand make up the rest of the top three. Some of the world's most generous countries are among the most deprived. The G-20, which represents the world's largest economies, accounts for only 5 of the top 20 countries in the CAF World Giving Index.

2. For the first time since 2008, men are now more likely to give money than women.

3. People from Iraq were most likely to have helped a stranger, replacing the United States which came top last year.

4. There has been a recovery in young people's generosity, helping to reduce the generation gap which sees much more giving among older people.

Per the increased volunteering of youth, there is a national trend in the US that has shown that the generation of "Millennials" (or "Generation Y"), which is generally defined as persons born in the US between the early 1980s and the early 2000s, has 63% who have volunteered for a nonprofit and 75% who have given to a nonprofit, unusually high percentages compared to past generations in the US (MIR, 2012). It seems that this trend is driving the growth of humanitarian engineering in the US. For more information on these issues in the US see

<div align="center">Corporation for National and Community Service</div>

and

<div align="center">National Conference on Citizenship</div>

and the US Census Bureau  and Bureau of Labor Statistics has relevant information.

**Quality of Life, Satisfaction, Happiness, and Affect**

The UN commissioned a project that resulted in the

<div align="center">Columbia University World Happiness Report</div>

This report relies on surveys on a range of questions, and the use of the "Cantril Ladder," an 11 point scale of "quality of life" from 0-10 with 0 meaning the worst and 10 meaning the best; asking about life satisfaction, average happiness, average positive affect (affect means to "touch the feelings of" or "move emotionally," according to the New Oxford American Dictionary), and average negative affect. It studies causes of happiness and misery, like work, social capital, values and religion, mental and physical health, family, education, gender, and age. It also discusses some policy implications. The report shows that (quoting directly from the web page, 12/28/13):

> Understanding happiness for a country provides context for understanding the happiness of individuals, and enriches our view of poverty, taking it beyond just money.

- Happier countries tend to be richer countries. But more important for happiness than income are social factors like the strength of social support, the absence of corruption and the degree of personal freedom.

- Over time as living standards have risen, happiness has increased in some countries, but not in others (like for example, the United States). On average, the world has become a little happier in the last 30 years (by 0.14 times the standard deviation of happiness around the world).

- Unemployment causes as much unhappiness as bereavement or separation. At work, job security and good relationships do more for job satisfaction than high pay and convenient hours.

- Behaving well makes people happier.

- Mental health is the biggest single factor affecting happiness in any country. Yet only a quarter of mentally ill people get treatment for their condition in advanced countries and fewer in low-income countries.

- Stable family life and enduring marriages are important for the happiness of parents and children.

- In advanced countries, women are happier than men, while the position in lower-income countries is mixed.

- Happiness is lowest in middle age.

Several of these issues could make for very good conversation with persons from other cultures.

## World Mood

There are snapshots, real-time data, and reports on long-term data and trends for mood in the world. There are many reports on world mood. For instance, there is the

<div align="center">

2011 Mood of the World Report.

</div>

There are algorithms for tracking world-wide (or country-wide) mood using data from social media or other internet-accessible data. For this, there are a number of sites based on words used in Twitter (see, for example, the YouTube video The Pulse of the Nation).

Why is knowledge about world mood useful? Before you travel, you will want to read the news about a country you are going to visit, and you could also correlate events in the country and world with mood tracking sites, and also obtain some very interesting material for discussion with people in the country you travel to.

**Other Large Polls on Cultural Issues**

Gallup surveys on a wide range of issues, such as well-being and world issues (and data is given via Gallup Analytics). There is the organization

<div align="center">

World Public Opinion

</div>

that polls about a whole range of opinions worldwide. There is the

<div align="center">

Pew Research Global Attitudes Project

</div>

(including favorable/unfavorable views of the US by a range of countries), the question

<div align="center">

"Do you admire the US for its technological and scientific advances or not?,"

</div>

and other views on the US). There is also the

<div align="center">

Banco de Datos ASEP/JDS data

</div>

on confidence in the government, interpersonal trust, and a map of happiness.

## 1.5   The Engineer's Role

After outlining the important role that engineering has in sustainable development, some types of problems engineers typically choose to work on are identified. Next, priorities for what engineers should do are examined using world-level survey data. This is followed by a definition and discussion on what is and is not humanitarian engineering via the notion of "degrees of humanitarian engineering." Finally, the reasons to become a humanitarian engineer are discussed, along with the wide variety of roles that engineers can take in the field.

### 1.5.1   The Important Role of Engineering in Sustainable Development

Amartya Sen, a Nobel-Laureate economist, said (Sen, 1975):

> The gap between understanding how something would work and making it actually work can be quite a substantial one, and some of the major problems of technological advance in developing countries seem to arise from difficulties in the translation of science into technology.

Engineering is the profession that translates science into technology; hence, Sen's statement is inherently an endorsement of the value of engineering in development.

From an historical perspective, it has been noted that "technological advance has been the greatest single source of economic growth" (Volti, 2006), a point also supported by arguments in (Easterly, 2014; Acemoglu, 2009). Also, consider

that Jeffrey Sachs says (Sachs, 2006): "We glimpse the pivotal roles that science and technology play in the development process" and in studying the history of economic development he says "technology has been the main force behind the long-term increases in income in the rich world" and goes on to say that all countries, including developing ones today, can have "a reasonable hope of reaping the benefits of technological advance," and quotes John Maynard Keynes as concurring with this point (considered to be the most influential economist of the 20th century).

Yet, the (spatio-temporal) diffusion of technological innovations "often widens the socioeconomic gap between the higher- and lower-socioeconomic status segments" (p. 130, (Rogers, 2003)) as power, wealth, and information is in the hands of the wealthy who can then gain the benefits of technological innovation more easily than the lower-socioeconomic classes. Humanitarian engineering seeks to spread technological innovations to lower socioeconomic classes in order to promote social inclusion and sustainable development. Indeed, for the lower socioeconomic classes, poverty is often coincident with problems of lack of clean water, inadequate sanitation, food insecurity, no available electricity, inadequate shelter, etc. Each of these presents technological challenges that various disciplines of engineering are well-prepared to deal with: water filtration, sanitation systems, agriculture, energy technology, architecture, etc. Engineers are needed to create practical and sustainable solutions for these development challenges, that is, to help with sustainable development.

*Poverty is coincident with problems that have technological solutions that engineers can help with.*

### 1.5.2 Matching Engineering Expertise to a Development Challenge

For an engineer, understanding poverty and development naturally goes hand in hand with identification of candidate technologies to help people. When engineers see and understand development challenges, they can often see their role, identify technological approaches, and get to work.

**Development Challenges and Technological Solutions**

Confronted with a challenge, engineers naturally think of technological solutions, either off-the-shelf, modified, or via creation of a new technological solution. Engineers typically think of challenges as "problems," are highly oriented toward problem solving, and skilled at problem solving with technologies. I am sure that in reading about poverty and sustainability above, or via the recommended videos, the engineer has already identified a number of candidate technological solutions, probably ones within their own discipline/expertise, such as:

*There is a wide array of technological challenges in development.*

- *Clean water:* Water filtration systems, chemical, solar, distribution, etc.

- *Sanitation:* Infrastructure, chemical treatment, etc.

- *Food/agriculture:* Fertilizers, irrigation, etc.

- *Energy:* Solar, wind, biomass, lighting, heating, cooking, etc.

- *Health/medical:* Telemedicine, diagnostic equipment, etc.

- *Education:* Instructional technologies (e.g., computers and tablets), STEM projects for hands-on learning.

- *Shelter/infrastructure:* Houses, dams, buildings, roads, bridges, etc.

- *Environment:* Pollution management and remediation.

- *Information systems:* Cell/mobile phones/devices, computers, internet, services support, market information, financial services, etc.

Approaches such as these will discussed in Chapter 3 in the broader context of development (e.g., health and education), and in Chapter 4 in discussing specifically how an engineer should go about developing such solutions with a community. Moreover, many information sources on these technologies are provided here, starting on page 718.

Combined with their problem-solving orientation, engineers typically have a sense of urgency to address time-critical problems (such as poverty), that is supported by useful and effective skill sets. As is standard in engineering, engineers are most often *not* highly motivated to "study the problem to death," that is to go gain an extremely large amount of information about the problem over many years. Engineers are pragmatic and clearly understand the sense of urgency to try something now to fix the problem (in traditional engineering, often driven by the need to beat a competitor to market), and know that further improvements are always made to technologies after deployment and information gathering on performance of their solution, just like with standard technological products.

**When Engineering Does Not Work**

Engineers can, of course, be faulted in their approach in at least two ways:

1. *Solutions without technology?* Some engineers tend to think that *everything* has a technological solution and sometimes do not recognize: (i) that some problems do not have technological solutions, and (ii) the importance or effectiveness of other approaches. They do, however, generally accept the difficulty of great technological challenges and will acknowledge that a technological solution is many years off (i.e., "science fiction"); in such cases they generally quickly accept other immediate, partially technological, or near-term solutions. Can you name challenges identified in the UN and World Bank data that you are certain cannot be solved via technology? What about discrimination? What about greed and laziness that are connected to crime and corruption? I can provide four good examples of when technology will not work from my own experience. My wife, Anne, and I adopted three children (Carina, Juliana, and Jacob) in Medellín, Colombia, and one child (Zacarias) from Guatemala City, Guatemala. Love makes a family, not technology. Robotic parents would not work. Technology could not have solved the problem of them being orphans.

*Key development challenges have no technological solution.*

2. *The problem of incrementalism?* Not waiting until all the science (physical or social) is in is a fundamental feature of engineering practice, but it can result in less than optimal solutions. Engineers are sometimes faulted for not seeking perfection the first time, and doing ad hoc constructions before good understanding is achieved. But, even considering their often rational sense of urgency, engineers' patient incrementalism is quite unacceptable to some (e.g., donors who want to know exactly when the problem is going to be solved–engineers are frequently fundamentally opposed to making big unrealistic promises), especially idealists rather than realists/pragmatists, and people who do not know what is happening on the ground. People sometimes say, "can't you do better than that" (e.g., the marketing department trying to compete to sell a product). Good engineers generally know the state-of-the art and how far past it you can realistically push in producing the next version of a technology. Such ideas are highly relevant to humanitarian engineering.

### 1.5.3   Engineering Priorities: A View From a Distance

The data  from the UN and World Bank, and others, generally defines needs, and the depth of a need can be seen as a way to prioritize where to go and what to do, at least from the country perspective. However, you of course need to know what the people want or are interested in doing (see Chapter 4). What people want is generally related to what they need but the matching of peoples' challenges to technological solutions in the last section was based on what other people think people need; it is a principle of humanitarian engineering that you should *never* presume to know what people want or need. This issue will come up several times below, and you need to, close up, talk to people and communities about challenges (again, see Chapter 4). At the same time, it is useful to frame the issue in the context of the view from a distance.

Priorities for what engineering problems should be addressed should be defined by people in communities; however, gaining a view of priorities from a distance helps provide context.

The following survey questions of the World Values Survey may be of high interest to the humanitarian engineer aiming at working with a person or group in a different culture. I cut a list of questions out of their web site, significantly shortened it to the most relevant ones; however, most of the ones I cut out do have some level of relevance to humanitarian engineering.

- **Perceptions of Life:**
  Active/Inactive membership of voluntary organisations
  (V29) Active/Inactive membership of environmental organization
  (V31) Active/Inactive membership of charitable/humanitarian organization
  (V23) Most people can be trusted
  (V47) Do you think most people try to take advantage of you (10 point scale)
  (V80) Schwartz: It is important to this person to think up new ideas and be creative
  (V84) Schwartz: It is important to this person to help the people nearby

(V88) Schwartz: It is important to this person looking after the environment

- **Environment:**
  *(V105) Would give part of my income for the environment*
  *(V106) Increase in taxes if used to prevent environmental pollution*
  *(V107) Government should reduce environmental pollution*
  *(V104) Protecting environment vs. Economic growth*
  *(V108) Environmental problems in your community: Poor water quality.*
  *(V109) Environmental problems in your community: Poor air quality.*
  *(V110) Environmental problems in your community: Poor sewage and sanitation.*
  *(V111) Environmental problems in the world: Global warming or the greenhouse effect.*
  *(V112) Environmental problems in the world: Loss of plant or animal species or biodiversity.*
  *(V113) Environmental problems in the world: Pollution of rivers, lakes and oceans.*

- **Work and Family:**
  (V50) To develop talents you need to have a job
  (V63) Men make better business executives than women do
  (V62) University is more important for a boy than for a girl

- **Politics and Society:**
  *(V77) Future changes: More emphasis on technology*
  *(V90) Opinion about scientific advances*
  *(V177) Be willing to pay higher taxes in order to increase countrys foreign aid*
  *(V91) Science and technology are making our lives healthier, easier, and more comfortable*
  *(V92) Because of science and technology, there will be more opportunities for the next generation*
  *(V93) Science and technology make our way of life change too fast*
  *(V94) We depend too much on science and not enough on faith*
  *(V123) The world is better off, or worse off, because of science and technology*
  *(V166) Most serious problem of the world: 1st choice*
  *(V166 ES) Most serious problem of the world: 1st choice*
  *(V167) Most serious problem of the world: 2nd choice*
  *(V167 ES) Most serious problem of the world: 2nd choice*
  *(V168) Most serious problem for own country: 1st choice*
  *(V168 ES) Most serious problem for own country: 1st choice*
  *(V169) Most serious problem for own country: 2nd choice*

*(V169 ES) Most serious problem for own country: 2nd choice*
*(V170) MDG: Reduce extreme poverty*
*(V171) MDG: Increase primary education*
*(V172) MDG: Reduce child mortality*
*(V173) MDG: Fight HIV*
*(V174) MDG: Improve housing conditions*
*(V178) Priority: Global poverty versus National problems*
*(V230) How often use of PC*

- **National Identity:**
  (V126) Trust: Your neighborhood
  (V127) Trust: People you know personally
  (V128) Trust: People you meet for the first time
  (V129) Trust: People of another religion
  (V130) Trust: People of another nationality
  (V130NZB) Trust: People in general
  (V130NZA) Trust: Relatives

- **Sociodemographics:**
  (V238) Highest educational level attained
  (V244) Nature of tasks: manual vs. Cognitive
  (V245) Nature of tasks: routine vs. Creative

You can use the WVS survey data analysis tool to study the response rates on the above questions for your country and the country you are going to visit. In Section 4.4, for the specific local situation you could encounter, the approach to gather community inputs on needs, resources, assets, and aspirations will be discussed.

### 1.5.4   Degrees of Humanitarian Engineering

To what extent is the work you are doing "humanitarian" or "engineering"? Is tutoring a child in math and science in a rich community humanitarian engineering? What about such tutoring for a high school or college student in a developing country where the science and engineering is directed at solving a local problem (e.g., contaminated water)? There is typically a type of continuum between the extremes of whether a project is or is not humanitarian engineering, and I will call the location on that continuum the "degree" of humanitarian engineering. Most of the value of discussing "degree" lies in thinking about what impact you are having in a more careful manner. There is no intent here to create a numeric quantification of the degree of humanitarian engineering for an activity.

There are a variety of concerns with even trying to define "degrees" of humanitarian engineering. There can be very important features of a humanitarian

engineering project that cannot be quantified easily (except perhaps, in some cases, via a subjective assessment by all involved people):

1. *Emotional factors:* (i) The value of relationships (e.g., friendships) developed on a project; (ii) The level of empowerment, satisfaction, and happiness you have given people and yourself (yes, humanitarian engineering is a lot of fun); and (iii) The level of solidarity achieved.

2. *Educational factors:* Often, the amount of learning that is achieved on a project is neither evaluated nor assessed for learning on non-technical issues: (i) Learning that someone from a culture/country is a normal decent human being; and (ii) Learning that you can do something you did not know you could do. This applies to all persons participating on a project, including community members.

In my own cases, I can say that I have most often walked away feeling that I got more than I gave, and that sometimes the most valuable thing the clients got of lasting value, from what I could tell, was along the lines of these emotional and educational factors. I have in many cases wondered what their assessment is after a number of years. I have never asked about the personal side as I think it would be difficult to discuss in a frank way. For all the discussion below, realize that you do not need to "put numbers to the information" to make it quantitative; you can simply use the information and abstractly combine it in a qualitative assessment.

### Humanitarian *and* Engineering

Engineering is based on science and mathematics, and below when "engineering" is referred to, naturally this includes science and math in addition to traditional aspects of engineering itself, like the design process, and specific applications. Humanitarian engineering is best interpreted as "humanitarian **and** engineering," not "humanitarian **or** engineering." An engineer can do what is only humanitarian work with no engineering content, but just because an engineer is doing it does not mean it is humanitarian engineering. True humanitarian engineering has *significant* components of humanitarianism and engineering. This is depicted in Figure 1.2. On the horizontal axis, "Engineering" (with a capital E) represents very sophisticated engineering (e.g., graduate research or innovation by perhaps an experienced engineer), "engineering" (with a small e) represents less sophisticated engineering (e.g., use of standard off-the-shelf technologies or only minor modifications to technologies), and "−ngineering" is meant to represent the case where there is no engineering at all. On the vertical axis, "Humanitarian" (capital H) represents a highly humanitarian activity (e.g., working with those who are the worse off), "humanitarian" (small h) represents helping people that have clear needs, and "−umanitarian" denotes the case where there is no humanitarianism. The black dot in the upper-right-hand corner, "Humanitarian Engineering," (both capitals) represents the case where there is sophisticated engineering and a high level of humanitarianism. The dashed line,

*Humanitarian engineering requires a significant level of both humanitarianism and engineering.*

$H = E$, represents the theoretical case where there are equal amounts of humanitarianism and engineering. The colored box in the upper-right corner represents valid possibilities for what can be considered humanitarian engineering activities. For the box, there is a lower threshold on the level of humanitarianism ($H-$threshold), and a lower threshold on the sophistication level of engineering ($E-$threshold). In most cases, an activity has to be *above* these two thresholds to be considered humanitarian engineering. Of course, these two thresholds cannot be quantified numerically, and they can be of different sizes so you get a rectangle rather than a box. Also, the thresholds may judged by some people to be different for various cases (e.g., a freshman engineering student vs. a PhD engineering student vs. a novice engineer vs. an experienced engineer) and contexts or locations. The thresholds are only meant to quantify the idea that a satisfactory level of *both* humanitarianism and engineering need to be present for an activity to be considered humanitarian engineering. Of course, there is nothing wrong with pure humanitarianism, or pure engineering; it is, however, important to be clear about the meaning of "humanitarian engineering" at this point in history.
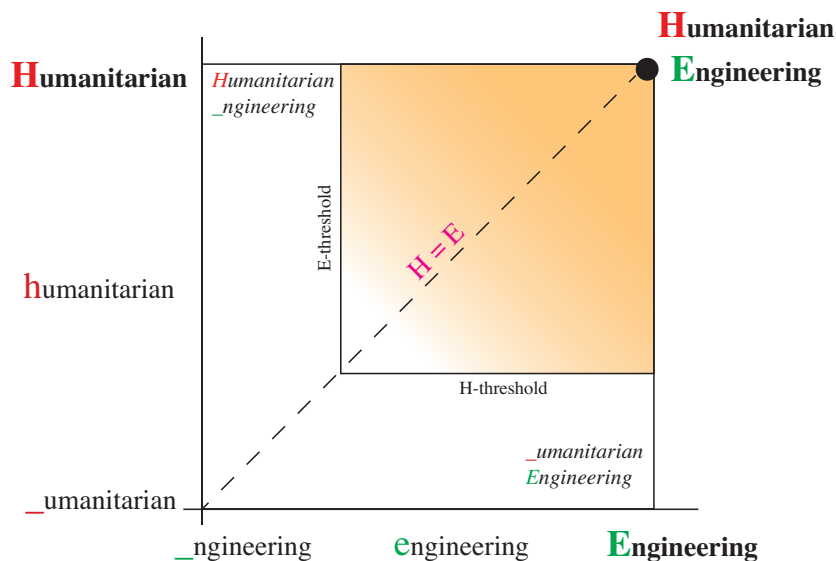


Figure 1.2: Defining humanitarian engineering as having *both* humanitarian and engineering components.

Suppose you use a dot to represent some activity (e.g., project, class, organization, or program). The closer the dot is in the $(H, E)$ plane to the big black dot in the upper-right-hand corner dot in Figure 1.2, the higher the degree of humanitarian engineering. Per Figure 1.2, the extent to which you are doing humanitarian engineering is a matter of "degree" in the sense that you can

qualitatively assess your position on a continuum in the two-dimensional plane from "definitely humanitarian engineering" (upper-right corner) to "definitely not humanitarian engineering" (lower-left corner). Being below the $H = E$ line means the activity has more engineering content than humanitarian content, and being above that line means it has more humanitarian content than engineering content. If your activity is in the upper-left corner, and his highly humanitarian but has no engineering content, it is not humanitarian engineering. On the other hand, if the activity is in the lower-right corner, there is very high engineering content but no humanitarian content so it is not humanitarian engineering.

For some examples, consider two cases. Suppose you travel to an African village and talk to the people and they unanimously say that their biggest problem is clean drinking water. Suppose you voluntarily create (or modify) a technology for water purification for the village, and go there to work with the village to implement it, and make sure there is a community-ran approach to maintenance, and you do assessment to show the project was successful (e.g., via a statistical analysis of reduction in health problems due to unclean water). This is a relatively clear case of doing successful humanitarian engineering, near the upper-right-corner in Figure 1.2. Next, suppose that your project is simply to go paint some walls, and do *nothing* else technical, and no engineering. Clearly, this is not humanitarian engineering, but it may be humanitarian. Per Figure 1.2, this activity lies on vertical axis, perhaps up some way from no humanitarianism, but with no engineering.

> Does helping people always imply humanitarianism?

As another example, in the university, clearly any activity that is *for engineering academic credit*, must have both a sufficient and level-appropriate (e.g., freshman–senior) amount of engineering content, and of course enough humanitarian content, to be considered for-academic-credit humanitarian engineering. While engineering students may want to help their community in activities that have no engineering content (i.e., engineers doing non-engineering service), this is *not* humanitarian engineering. Of course, however, such non-engineering service may be important and praiseworthy, even thought it should not be rewarded with engineering academic credit, which is a quantification of what university-level engineering material is learned (e.g., considering accreditation standards of ABET in the US).

### Degree Definitions in Terms of Poverty and Social Justice

What qualitative (conceptual) or quantitative (numeric) measures can we use for the definition of the degree of humanitarian engineering? There is no single measure; hence, only some key indicators are discussed here. First, you could measure the "initial conditions" (that is, just before your project starts) in terms of the poverty level of the people you are going to help (however you want to define that), and the number of people to be helped. Of course, that must be modified via asking for inputs from the clients; if there is what you think is a need, and they do not think so, then addressing something that is unwanted clearly does not increase the degree of humanitarian engineering (and

may decrease it).

If you try to quantitatively measure poverty (i.e., with numbers), then there is the problem of having multiple "attributes" of poverty/development, each of which must be quantified, and these must be combined, and it is often convenient to get a single numeric measure so often "weights" are assigned to each attribute (e.g., a big weight would indicate that attribute was important) and the "weighted sum" is used as an "aggregate measure of poverty." Such an approach is problematic since it throws out the complicated nature of poverty. Regardless, returning to our issue, one approach is to use an aggregate poverty measure as one indicator for degree (e.g., IHDI or MPI), but for a community as discussed in Section 4.12.2. If this is the only indicator (i.e., degree is equal to aggregate poverty measure), this corresponds to assessing degree in a narrow way (especially if the aggregate poverty measure only included a monetary measure like income).

Amartya Sen qualitatively assesses issues via his "capabilities" approach (Sen, 2011) that we will study in Chapter 2. This raises the issue of qualitative (conceptual) assessment vs. quantitative (numerical) assessment, an issue that creates significant debate since some of his capabilities are difficult or impossible to quantify. Nonetheless, a qualitative (i.e., non-numeric) assessment could be used to define degree of humanitarian engineering in a natural and useful way, and based on this you can have a notion of the extent to which you are doing humanitarian engineering. See more on such issues in Section 4.4 and Section 4.9.

Another approach is to use ideas from social justice (Chapter 2) to define degree (which like in the last section may also use peoples' inputs); a measure of the level of justice/injustice being considered can be a measure of degree. How? There are many approaches, for instance, degree could be equated to an aggregate measure of the extent to which all basic human rights are met (e.g., via a weighted average). But, another measure would consider not just basic human rights, but others like worker rights, economic or political participation, or effect on environment. Another measure motivated by social justice is the degree of human dignity or human fulfillment (or "human welfare"), even though those are clearly difficult to quantify.

### Degree in Terms of Achieved Change

Next, consider the relevance of assessment of solution success, a topic that will repeatedly arise in this book due to its importance (e.g., in Section 4.9). It is difficult to assess success. At what point in time do you assess success (i.e., at what time do you define "final conditions")? Immediately after the project is complete? One year later so that project "maintainability" can be assessed to some extent? Longer? It often makes sense to try to work with people over many years; then you may want to apply metrics over many years to assess trends in success. A reasonable approach to assessing the degree of humanitarian engineering in terms of initial and final conditions is to develop a metric that measures the gap between the two, and perhaps trends in that gap

Humanitarian engineering degree qualitatively assesses the level of helping.

over a long period of time, with the initial condition as a "base line." But, this can be problematic as then it can be difficult to determine what exactly caused the change (see Section 4.9.3).

For specific local problems it may be feasible to assess your solution's success with some metrics. For instance, if you are working on health care technology (e.g., for monitoring or diagnosis), your "outcome" may be the level of health as measured by vital signs, blood samples, prevalence or severity of illness, etc., assuming nothing else affected these. Such attributes have convenient numeric quantifications, but can be difficult to aggregate as discussed above. Moreover, they may not be too difficult to obtain: it may involve getting the clients (patients) to all come back to a clinic later, get all the proper tests, then do this over a region, and gather all the information in a data base for statistical analysis multiple times (e.g., based on means and standard deviations of outcome data). This is the approach in (Banerjee and Duflo, 2012) that is discussed in Section 3.2.4.

Unfortunately, if your solution affects many issues (health, education, political participation) over a large area such as a whole country, then it may be extremely difficult and costly, or impossible, to quantify all outcomes with numeric measures, and aggregate them, in order to do statistical analysis. In this case, though, when economic policy and governance are viewed as solution strategies to poverty and underdevelopment, high-level statistical analysis is possible. This is the "global" approach of Sachs, Easterly, and Collier, all of which will be covered in Chapter 3. Their analysis is, however, sometimes after-the-fact (based on history) so they are not considering the aid strategy, economic policy, or governance fix they implement, but analysis of what succeeded in the past in order to get an idea of how to predict what will happen if they choose a certain solution.

Regardless of whether assessment is local or global, no matter what degree of humanitarian engineering you focus on, it is probably not fair to argue that you have achieved some nonzero degree until you have shown via assessment that you succeeded in doing so! Failed humanitarian engineering is a serious issue that is discussed in Section 4.9; failing at something grand (global) can be much worse than failing at something small (local), but depending on the level of failure in each case, the opposite might be the case. This points to the practical importance of focusing on achievable goals and partial solutions. It also points to the need for a high level of professionalism (expertise) to take on humanitarian engineering problems: if you do not have much expertise, should you even try? Failure can be worse for the people you are trying to help than not trying at all! Failure can destroy their hope and motivation for trying again to fix a problem.

### Long-Term Global Humanitarian Engineering Strategy

From a long-term perspective, why does an assessment of degree of humanitarian engineering matter? One key reason is that it can be used as the basis for a long-term development strategy. People working in humanitarian engineering

have different views on global strategy. Here are some strategies:

1. *Addressing the worst cases: Persistent "raising of the minimum" strategy:* Degree assessment helps determine focus for some: Many people like to focus on the "worst" problems (e.g., extreme poverty rather than moderate poverty) affecting the most people, or alleviating the most suffering by the most people, so that viewing their own efforts as an investment, they get the most return (reduction of suffering) for their investment. Also, the general idea, from a long-term perspective, is that if many engineers persistently focus on the worst case over a long period of time (and always switch to the worst), extreme poverty will be eradicated first, and you will always be "raising the minimum" to seek the average (i.e., close the inequality gap, however you define that).

2. *Addressing difficult cases: Persistent "raising of cases below the mean:"* A narrow focus on the worst cases, however, may place a constraint on what you are doing as an engineer that can potentially limit your effectiveness. For instance, what if you cannot see a way that you personally can help someone in extreme poverty, but have a great technology idea to help with a sizable subset of moderately low-income people–for example, a slightly more expensive technology–and one that they have identified a clear need for? Does it make sense to focus on the moderately low-income cases instead, since you can see a tangible and feasible solution? After developing such a solution you may figure out how to both improve it and lower costs so that it can be used for a more difficult case. Moreover, realize that if you always focused on the cases that are below the average, then this strategy will also close the inequality gap also (but perhaps not end extreme poverty as quickly) so long as someone is also taking care of the worst cases, that are also below the mean.

Of course, there are other concepts for long-term strategies that could work, some of which are related to both of the above ideas (e.g., make the number of engineering projects in progress proportional to the distance below the average, possibly with a nonlinearity that creates significant focus on the bottom). The degree of humanitarian engineering impacts project choice (site and type) and the constraints you can realistically work with (e.g., cost and technology reliability), and ultimately the long-term impact of everyone practicing humanitarian engineering.

### 1.5.5 What Are My Reasons to be a Humanitarian Engineer?

It is important to reflect on *why* you want to have a role in humanitarian engineering. Are your reasons selfless or selfish? Does it "suit you well"? Do you want make a career of it, or just volunteer on weekends and vacations?

**Reasons for Doing Humanitarian Engineering**

The first consideration for an engineer is whether to have a role at all. In my experience, the motivation and rationale for doing humanitarian engineering varies widely among engineers. The following list provides some of reasons that I have directly heard from engineers, or via a survey I gave, where at least one person checked the box:

- Want to use engineering skills to "make a difference"

- Want to use engineering skills to "give back" ("pay back")

- Want to use engineering skills to "pay it forward" (from the New Oxford American Dictionary, "respond to a person's kindness to oneself by being kind to someone else")

- Want to use engineering skills to help people

- Want to use engineering skills to improve society

- Want to use engineering skills to improve the world

- Want to integrate personal values with professional engineering career

- Saw poverty or underdevelopment and am motivated to do something about it

- I had (or have) a role model who has served others and am hence motivated to serve myself

- Am simply intrigued with the intellectual challenge of a very difficult engineering problem

- My religion/faith motivates me to help

- My secular viewpoint motivates me to help

- I am adventurous and simply want to see the world and do something useful at the same time

- Want to get a job for good pay in the area of humanitarian engineering

- Want to be a "global engineer" (e.g., in a multinational corporation) and view humanitarian engineering as a chance to learn about engineering and potential customers around the world

- Want to be a social entrepreneur for technology (i.e., start a business that has some profit and does "social good")

- I have heard that poverty and development is one of the most challenging problems in the world and I want to help solve it as I like big long-term challenges.

> You should reflect on why you are a humanitarian engineer.

- I have seen physically or mentally disabled persons experience terrible conditions or discrimination and I want to use my engineering skills to help solve those problems

- I have seen my gender group treated as unequal and discriminated against and want to help solve that problem as an engineer

- I have seen my race treated as unequal and discriminated against and want to help solve that problem as an engineer

- I have not yet decided on my major interest in engineering, but this is the most interesting engineering topic for me at this point

- I have significant interests outside traditional engineering disciplines and humanitarian engineering seems to require other disciplines combined with engineering skills more than any other area of engineering

- I am involved in humanitarian engineering mostly because my Mom, Dad, or other family or friends want me in it, or are happy that I chose to get involved

- I am involved in humanitarian engineering simply because it makes me feel good to help

- I am involved in humanitarian engineering because it makes me appear to be a good person to others (i.e., it improves my reputation)

- I have done some bad things in the past and am seeking "redemption" to make up for those things by doing good things via humanitarian engineering

What are your reasons? One, or several of the above?

I gave a talk to the second-year OSU Humanitarian Engineering Scholars (typically sophomores) in 2014 entitled "Do I Really Want to Be a Humanitarian Engineer"? To start the talk I asked them to respond to the following request: "Provide a list of your motivations to be a humanitarian engineer." There were 49 students responding, and their reasons were typed in, then Wordle was used to create the word cloud in Figure 1.3. My interpretation of this is that the average student (of course biased by student's interest to be in HES in the first place) wants to "help other people around the world."

**Reasons to Serve**

In (Davis, 2006) the author discusses a range of issues associated with doing service that are relevant to humanitarian engineering, especially when it is "engineering volunteerism" (i.e., unpaid service by engineers). Davis summarizes by saying that there are five basic reasons to serve (quoting): "we are God's children; we share the Earth; I find myself in you; I win praise by serving you; and I suck." He thinks of service being good for the server, the people served,

Figure 1.3: Word cloud of reasons to be a humanitarian engineer provided by OSU Humanitarian Engineering Scholars. Word size in the cloud is proportional to its frequency of occurrence in the set of student responses.

society, God, or objectively good. He says "service might produce goods that are necessary, educational, pleasurable, beautiful, holy, or right." He says that the following types of service might not be good: "ill-conceived or unwanted or badly executed or questionably motivated." Other types might be both good and bad.

Next, he discusses the issue of inequality and service. He points out that people freely serve, but that those being served need it (the realm of freedom and the realm of necessity). By serving, does the server confirm their relative superiority, and the served acknowledge their relative inferiority? Does an apparent act of humility raise the server up? Does the server like inequality? He claims that the statement "all men are created equal" is a "self-evident falsehood." We do not have equal gifts or opportunities. Servers seek to close the inequality gap, but servers do not improve the served, they improve the conditions in which the served find themselves. He asks if service efforts move us toward equality: "Might some acts of service enshrine and even extend the very gap they mean to bridge?" "Where will the server be, five years from any particular service transaction?" "Where will the served be?"

I rephrase the points that he makes in his paper into statements like the ones above (almost all words from his paper, and quotes are from his paper (Davis, 2006)):

- I serve others to serve God.

- I serve others because I love God.

- I serve since God has temporarily given me more than you, and I freely choose to help you.

- I serve because I love others, and hence want to help or share with others.

- I serve because it is a small world so your challenges are my challenges and my goods are your goods.

- I serve because I identify with others (I can imagine being in someone else's shoes).

- I serve because I see your suffering, cannot imagine myself suffering like that, and hence help both you and me (it is good for you but also for me).

- I serve mostly because it makes me look good, and perhaps also helps you.

- I am bad, I am evil, I am a sinner and I know others know this; I serve to mitigate those issues ("I suck, please let me serve you, perhaps I will suck somewhat less").

### 1.5.6   Engineers' Roles: From People to Policy

There is a role for engineers at all "levels" of humanitarianism along the continuum:

People–Community–Region–Economic–Political

Engineers of all disciplines can be involved, of course. An engineer can choose to work close up with the people on the ground, designing technologies to solve problems (specific technologies in all areas of engineering, such as agricultural or health technologies, or education to develop technological capacity). They can provide community-level engineering help (e.g., via a fresh water supply system, sanitation, or a road), and similar comments hold for a region (e.g., an electricity grid). At the economic and political level there are several roles for engineers: (i) enabling market/financial knowledge and access (e.g., via cell phones or the internet pricing information or interface to a bank from a distance); (ii) ensuring fair and open elections (e.g., software for information flow to and from a government, software to promote transparency and fight corruption) or good technology policies (e.g., that promote innovation and seek fair trade). Of course, each of these includes the environment and engineers have a key role to play in sustainable design and solving problems with the environment (especially in "environmental engineering"), and setting environmental policy.

Non-governmental organizations, support services, and institutions need engineers more and more often due to the increasing pervasiveness of technology, either to design new technologies that fit their needs in helping others, or to get advice on how to help people with technologies. Engineers need to be "at the table" at the UN and World Bank. Policy cannot be set on science, engineering,

*Engineers can help with development at all levels, from people to world institutions.*

or technology without someone who is highly knowledgeable about these topics, and far beyond the technological knowledge that everyone has about operating their cell phone or computer. See Problem 3.5.

### 1.5.7 Engineers' Roles: From Charity to Profit

There has been a debate in the development community about whether to provide aid (e.g., to persons making $1 per day) or work with persons in a developing country to create businesses (e.g., manufacturing sites) so that they can sell products to the developed world (i.e., the "aid vs. trade debate"). Many persons are attracted to the idea of developing local talent to have them start their own business to sell locally or globally. Let us consider the debate as occurring along two continua between the developed world and developing world that quantify transfer of goods and people:

*Engineers may provide charity, or seek to profit for their work.*

- *Developed-to-developing transfers (give, sell):*

  Charity–Subsidy–Cost Recovery–Profit

- *Developing-to-developed transfers (give, sell):*

  Loan interest–Low-Cost Commodities–Brain Drain–Profit

Significant debate occurs about what is transferred between developed and developing countries with considerations given to history (e.g., colonialism, slave trade, and infrastructure development), technology/knowledge transfer, exploitation (paying below a fair wage), environment (multinational corporations destroying the environment in many developing countries), low cost commodities, and other aspects. The objective here is not to enter such a debate, or to develop a full balance sheet (clearly, the above list is simplistic, not representing all transfers in each direction), but to argue that no matter what is happening, or what is the best approach, engineers can play a significant role.

The key issues are: who is given what, who sells what, who profits, and where does it all happen? Consider the following sampling of relevant points to the transfers in both directions:

- There is the tired and over-used old saying "give someone a fishing pole, not a fish." A fishing pole is a technology; generally, all technologies take on a similar feature: they enable people, empower people, by extending their capabilities so that they can help themselves.

- The issue of whether you give technologies away or subsidize them is a decision that is often made by others, even if you are in a company (well, one bigger than just yourself). From an engineer's perspective, either it is their own choice of whether to give it away (i.e., individual humanitarianism), they can try to sell their technologies to an aid agency or nongovernmental organization (NGO, defined by the World Bank as "private organizations

that pursue activities to relieve suffering, promote the interests of low-income people, protect the environment, provide basic social services, or undertake community development" (Directive 14.70)) (and they can decide), or the engineer can work in a business that sells the technology (and locate the business in a developed country or developing country, and involve persons from the developing country in either case). See Section 3.5 and Section 4.10.3.

- Can engineering and business skill capacity be grown in the educational system in a developing country (e.g., higher education) so that they can develop and maintain technologies in-country (see Section 3.4), and profitably sell products on the world market? Are there fair trade policies? Intellectual property policies? What is the effect of creating technological capacity in a developing country? Does it only result in brain-drain, a loss of talent to the developed world so that they have even more advantages? What is the effect of capital accumulation in a developing country? Just the transfer/investment in developed countries?

My conclusion is that engineers in both developed and developing countries have significant opportunities to be involved in creating technologies to help people, whether they do it as a volunteer capacity (i.e., free help), an educational mission (e.g., engineering education in a university), or from a profit-seeking approach in a company. Section 3.5 covers the social business approach to development, and "participatory social business" is discussed in Section 4.10.3.

### 1.5.8 Engineers' Roles: From Practice to Theory

There is also a role for engineers at all "levels" of humanitarianism along the continuum:

Practitioner–(Mixed Practice/Theory)–Theorist

The humanitarian engineer who is a "practitioner" only stays competent with respect to relevant technologies, and may help develop some modifications based on observations of what works and does not work, but their central focus is direct-contact helping of people. On the other hand, the theorist seeks to discover problems and create entirely new technological solutions, ones never invented. This typically will involve a significant portion of work "at their desk," using standard science, mathematics, computational, and engineering methodology. Of course, there are people who are both practitioners and theorists, and motivated by their work on the ground, they may invent new solutions. People working only at either end of the spectrum can do useful work, and hence the value of work at any point along this spectrum should be acknowledged. Clearly, there is bad practice, sometimes as it is not informed by theory. There is bad theory, or worthless theory, that is not informed by real problems on the ground and good practice.

These ideas are quite standard in engineering, and simply describe what is typically referred to as the applications–theory spectrum. Some people only

*Humanitarian engineering work is needed across the entire theory–practice spectrum.*

work on technology applications, while others develop theory that may be useful for improvements to technologies, or the invention of new technologies. Of course, the distinctions are not crisp, but mixed. Too often, persons who are too far along the spectrum in either direction, do not respect the value of the work at the other end of the spectrum. A more balanced view, that respects contributions from anyone one in humanitarian engineering working anywhere along this spectrum, is more productive. Of course, this discussion applies to engineers where ever they work, but it is important for the academic community in particular (e.g., to recognize the value and possibility of doing theoretical work that is publishable and potentially useful for a community).

This book has a mixed theory-practice treatment, where although specific technologies are not discussed in detail, there is detailed treatment of many aspects of humanitarian engineering practice (e.g., participatory development in Chapter 4). Also, there is a coverage of theory for mathematical and computational approaches for the study of dynamics (e.g., community dynamics). The treatments in the analytical parts of the book are fully consistent with many person's views on the need of the practitioner for theory (e.g., (Homan, 2011)), the need for understanding community system dynamics (e.g., (Agunga, 1997; Homan, 2011; Ramalingam, 2013; Amadei, 2014; Spaiser et al., 2014)) as studied in Section 2.4 and Section 4.12.2, and the need for new humanitarian technologies (e.g., financial services for low-income people in Section 1.6 or cooperative management of community technology in Section 4.12.1).

## 1.6  Models, Dynamics, and Analysis of Poverty and Sustainability

In this section, models of individual poverty will be provided. These include an influence diagram, a budget, and a dynamical system model of poverty. In each case, a number of principles of modeling and analysis based on the models are highlighted. For the budget and dynamical systems models, parameters are changed and effects are analyzed. Also, a dynamical model of sustainability is provided by giving a mathematical model of the tragedy of the commons, and a computational analysis of when the tragedy occurs is given.

### 1.6.1  Influence Diagrams

Assume you have a set of "nodes" (often represented by some shape like a circle, ellipse, or rectangle) and a set of "directed arcs" that are lines originating at one node and ending with an arrowhead at another node (possibly the same node). The set of all nodes, and arcs pointing between them, is called a "directed graph." Sometimes, directed graphs are called "influence diagrams" if the meaning of the arc is that the entity represented by the node at the origin of the arc ("origin node") influences the entity represented by the node connected to the arrowhead end of the arc ("destination node"). A "topology" of a graph is the pattern of interconnections between the nodes. For instance, it can be

"connected" in that every node has an arc either originating at it or ending at it. The topology could be a "line" in that if you put the nodes on a line, arcs only connect between adjacent nodes. In that case, if you also connect the two endpoint nodes you get a "ring." Sometimes, if there is a "path" (directed sequence of arcs and nodes) with a node at the start and that same node is at the end of the path, this is called "feedback" since the node influences other nodes which end up affecting that same node. If every node in the graph has an arc pointing to every node in the graph (including itself) and an arc pointing to it from every node in the graph, then the topology is "completely" connected. Sometimes, it is said that a topology is "dense," meaning that there are many arcs between nodes, and other times it is "sparse" with relatively few arcs between nodes. You can imagine how a "cluster" or "community" might be defined for human groups if nodes represented persons and an arc represented a verbal communication from one person to another; in this case, clearly the topology might change over time or even the number of nodes. Alternatively, an arc could represent the influence one person has on another, that might not involve, for instance, verbal communication. The number of arcs and nodes can be finite or infinite. Clearly, there are many physical meanings you can associate with nodes and arcs.

For an influence diagram, often there are arcs that (i) originate at a node an point to no node, or (ii) arcs that originate at no node and point to a node. In case (i), the arc arrowhead is labeled with an entity outside the directed graph that it influences. In case (ii), the root of the node is labeled with an entity outside the graph that influences the node in the graph.

### Influence Diagram for Poverty

Influence diagrams are directed graphs with meanings associated with nodes and arcs depending on  what they represent ("model"). As an example, suppose that nodes represent features (aspects) of poverty and arcs represent the influence of one feature on another, or influences from (on) entities outside the model. For instance, consider Figure 1.4. There are three nodes, one representing the individual's accumulated wealth (e.g., number of dollars PPP), one representing health (e.g., as assessed by a medical doctor and the individual), and one representing knowledge (e.g., level of educational attainment). In the diagram, notice that wealth influences both health and education. Having money impacts your ability to attend school, get healthcare, and live in a disease-free environment. At the same time, health affects wealth (e.g., ability to work) and knowledge (e.g., attendance at school). Finally, knowledge can affect income (getting a better paying job) and health (learning good hygiene practices or fixing problems with contaminated water). The diagram is completely connected, representing a full inter-feature coupling between these three features of poverty (the topology is a ring) There is a feedback loop in two directions via two paths that traverse all three nodes. There are also many feedback loops between individual nodes.

> Influence diagrams can provide an understanding of broad relationships between components of a development problem.

There are outside influences: income from a job affects wealth, environ-
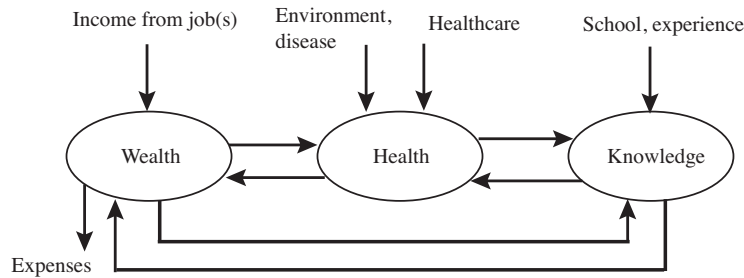
Figure 1.4: Influence diagram model of poverty.

ment/disease prevalence affects health as does healthcare, and school/experience affects level of knowledge attainment. There is one influence noted between the model and outside the model: expenses (e.g., for food). Thinking through the model construction teaches about poverty and development. Indeed, it shows good motivation for using measures of poverty that include more than one feature (e.g., HDI or MPI).

**Adding Expressive Power**

It is also important to note what is *not* included in the model in Figure 1.4. For instance, other features that might indicate poverty are not included (e.g., income inequality) and there is no indication that the individual's three poverty features affect nearby humans (e.g., sharing wealth, catching diseases, and getting an educated person's help with a technical matter). Moreover, arcs only indicate "influence," not the type of influence (e.g., causing an entity to increase or decrease), though that may be clear from the context. Also, there is no quantification of the poverty features by numbers, as in wealth measured by dollars PPP stored, number of years of education, or how fast these change dynamically over time. With respect to all these aspects it is said that the model "lacks expressive power" or simply cannot represent these aspects.

To give one example of how to increase the expressive power of the influence diagram, suppose that a "strength of influence" number is associated with each arc, a number that lies between −1 and +1 (normally a strength of "0" is not used as that would represent that the arc should not have been there in the first place since there is no influence). Using intuition, influence strengths are added to the diagram in Figure 1.4 to get Figure 1.5. For instance, there is a strong influence (+1) of income on wealth, and correspondingly, expenses on wealth (but notice the −1 indicating that expenses decrease wealth). Wealth and knowledge for this person both influence each other strongly since she must pay for her education (it is not free) and her accumulated knowledge will directly influence how well she will be paid. The other strengths represent intuitive guesses at strengths of influence, but for this particular person (not some average of many people). Clearly, even with the addition of strengths, the model's expressive power is limited since it does not represent, for instance, time-varying

behavior (e.g., changes in income, health, or education over time).
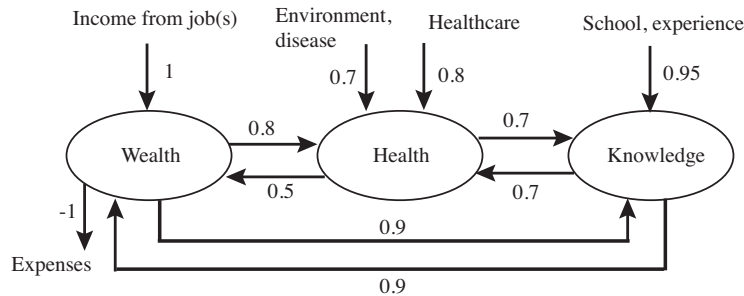


Figure 1.5: Influence diagram model of poverty.

Another common approach, when the actual strengths are not known, but the direction of change is known, is to add, near the arrow heads, "[+]" to represent that if the quantity associated with the root node increases, the quantity associated with the node the arc is pointing to increases. Then, "[−]" is added near the arrowhead if a root node quantity increase causes a decrease in the quantity associated with the node the arc is pointing to. This approach is the "causal loop diagram" that is used in some studies of system dynamics, including in business and the social sciences (e.g., see (Sterman, 2000)).

## 1.6.2 Matlab/Simulink for Simulating Dynamics

In order to quantify poverty in more detail, the expressive power of numbers and dynamics are used. In order to represent these we use mathematical models (e.g., the difference or differential equations) and computational models via computer simulations. Here, we begin work in this direction via a tutorial on Matlab/Simulink for simulating discrete- and continuous-time dynamical systems. Following this, an example of simulating a budget is given.

All computer programs in Matlab/Simulink used in this book are posted at the web site for this book. When referring to the names of these programs, or lines of code or commands, a `text-type face` is used.

**Matlab/Simulink Tutorial: Signals, Systems, and Feedback**

Consider the operation of the following Simulink diagrams ("programs"):

1. `InputsProcessOutputsContinuous.slx`: This program illustrates basic ideas in continuous signals, processing of those signals, and viewing outputs (e.g., including gains, different signal shapes, linear and nonlinear mappings, the integral and derivative, and viewing outputs). The integral is a continuous sum, and the derivative is an instantaneous slope.

2. `InputsProcessOutputsDiscrete.slx`: This is similar to 1., but with sampled signals, changes in simulation configuration, plotting via inter-

polation/steps vs. points at sample times, discrete-time integration and differentiation). The discrete-time integral is a discrete sum (i.e., sum in the usual sense), and the derivative is the slope of the line between the last two points (Euler approximation to the derivative).

3. `ContinuousDynamics.slx`: This illustrates behavior of a first order system, low-pass filtering/high-pass filtering (loudspeaker analogy), a second order system, feedback control (wealth accumulation in a bank), and feedback for automotive cruise control (bad design/tuned design).

4. `DiscreteDynamics.slx`: This illustrates low-pass filtering, and feedback for automotive cruise control (bad design/tuned design).

**Example: Life-Long Budget Simulator**

Using ideas from the above tutorial, items 1. and 2., a simulator of life-long wealth accumulation is given in the program `WealthCalculator.slx`. It is assumed the person lives for 100 years. It is a discrete-time simulation, with a step size of 1 year (this parameter is set under "Model Configuration Parameters" in Simulink). The program has the following features:

- Initial contributions are provided by care-giver, but it is assumed that all such contributions are consumed.

- Income level (dollars per year).

- "Provisioning" from charity, institutions, support services, government and the like (free income).

- Living expenses for the person.

- Living expenses for having one child.

- Healthcare expenses for a family (persons and child).

- Expenses paid for a child's education.

Income minus expenses is put in the bank to accrue 1% interest compounded annually, or another investment (e.g., stock market) which accrues 6% interest compounded annually. The output is the amount of money accumulated over a lifetime, or wealth. The money remaining at death can be given to spouse, children, or other family (inheritance), or a charity. A more standard approach to setting up such a budget is via a spreadsheet; however, the intent here is also to provide instruction on the use of Simulink. In Problem 1.32 you will be asked to modify `WealthCalculator.slx` to fit your own life, for both best and worst cases you can envision.

There is always something that is *not* in a model. What is not in this model? Some problems with the model are seen via Problem 1.32, but others include the lack of coupling between income and health, education and income, etc.

Significant health problems may result in you losing your job or not getting a raise due to substandard performance. Raising your income ensures that you can get better healthcare and hence keep your income high. Such issues were discussed in the influence diagram model in the last section.

### 1.6.3 Poverty Dynamics and a Personal Spending Strategy

Here, to deepen understanding of the discussions on poverty earlier in the chapter, we model the dynamics of personal finance for a single person living in poverty who adopts a certain spending strategy. The model is relatively simple, but presents three features that make it very difficult for the person to decide how to spend:

1. *Dynamics:* Accumulating money is represented by an integrator (in discrete time, a sum), and spending based on what is saved creates a "feedback loop." Both represent dynamics that can present significant challenges and unusual, nonintuitive, or unpredicted behaviors.

2. *Nonlinearities:* The person's savings is assumed to be positive (no loans) and this is represented with a nonlinearity that complicates the dynamics. Also, there is a nonlinearity in that the person cannot spend more than they have, and spending itself is defined as being positive. If a person has very low daily income, then survival is in question and suffering occurs due to lack of sufficient spending on basic necessities (e.g., food). This creates risk.

3. *Nondeterminism:* There are two types of nondeterminism: (i) It is assumed that the person's income is random with a relatively large variance as this is typical for low-income persons (e.g., on one day they may earn nothing, but on the next they may earn several dollars, as in the case of a day-laborer). Stochastic features make it difficult to know how much to save vs. spend, and hence difficult to maintain some savings in case of emergencies (e.g., a health problem that needs attention by a doctor that the person has to pay for); and (ii) It is assumed that periodically there can be "shocks," including major health expenses, loss of income due to bad weather, loss of a job, etc. These uncertainties create significant risk.

The last two features are based on findings in (Banerjee and Duflo, 2012), some of which are described in Section 3.2.4, and (Collins et al., 2009). Next, a Simulink model is introduced that represents all these features. Following that, financial advisors are designed to overcome these financial management problems.

**A Dynamical Model of Poverty**

A Simulink model was developed for simulating an individual's poverty as shown in Figure 1.6. Suppose that the individual's lifetime is 60 years, or 21,600 days.

You can think of the case when time is zero as: (i) the time of birth and in that case the income is provided and managed by a caregiver; or (ii) the first time the person starts to manage their own funds. Here, we will assume the first case in our discussions and assume that the amount of wealth the individual has at that time is zero (i.e., no inheritance). Suppose that an individual makes on average $1 per day PPP. In particular, suppose that their income is a random variable between zero and $2 per day PPP; suppose each day's income is "uniformly distributed" on the range $[0, 2]$ which means each day a randomly chosen number from that range is the daily income, with no tendency to pick any value over another value. The random income values each day are independent of every other day (e.g., yesterday's income does not influence today's income value). This corresponds to the person being a day laborer (or the likes) and some days s/he gets good work and makes $2, some days makes an intermediate amount greater than $0 and less than $2, and other days cannot find work and makes nothing. This variation in income per day causes significant challenges for determining what to spend each day. This random daily income is represented with the top left block in Figure 1.6 that generates a random income for each day (the "raise" block is used to increase the average income above $1 per day–for example if the constant in the raise block is 1, the average income will be $2 per day–this will be used in Problem 1.33).

Modeling and simulating the dynamics of poverty gives us a sophisticated understanding of the challenges of low-income people.
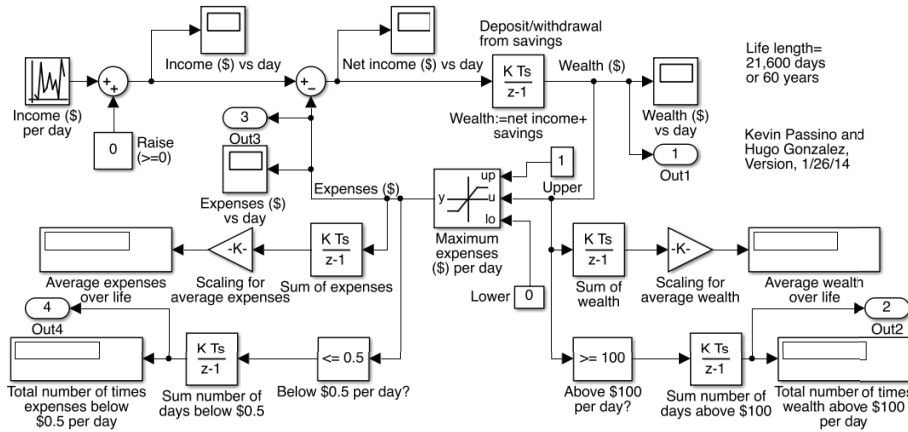


Figure 1.6: Dynamical poverty model, Simulink diagram.

Savings is equal to the income from the day, minus the expenses that day, added to what was in savings from the previous day; the result of that sum is the current wealth (assumed to be stored in the person's pocket or hidden somewhere–they do not have a bank where they could get compounded interest). The individual's "spending strategy" represents her or his approach to budget management and here it is first represented by a "saturation" where if today's wealth is less than the upper limit $E$ then all that wealth is spent (e.g., on food). However, if wealth is greater than or equal to $E$, then only $E$ is spent on food

that day. The lowest amount spent in a day is $0 no matter what $E$ is chosen as. The choice of the value of $E$ is made by the person, supposedly at birth (no small task!) and is assumed to stay constant for a lifetime (of course, adjustment strategies for $E$ can easily be invented as is discussed below). Choosing $E$ amounts to choosing a spending strategy (an approach to managing finances) out of many possible strategies. One more feature of the spending strategy is that spending never exceeds wealth, though it may be on some day equal to it; notice that no matter what the choice of $E$ is the slope of the saturation is unity, meaning that as wealth goes to zero the amount of spending goes to zero.

This completes the description of the dynamics. The remaining pieces of Figure 1.6 are simply for (i) gathering data on income, wealth, expenses, and net income for each day of the person's lifetime; and (ii) computing "performance metrics" that quantify the economic well-being of the individual.

### Computing Metrics for Poverty: Suffering and Risk

There are four performance metrics computed in Figure 1.6:

> Metrics measure how well someone is doing when they are using a particular spending strategy.

1. *Average wealth over a lifetime (bottom right side of diagram):* This is the sum of the wealth over each day of the person's life divided by 21,601 (the number of days they live plus one since time starts at zero). Higher average wealth is considered good as having some savings helps take care of dangerous unexpected events (like a problem with health that required costly medical care).

2. *Total number of days wealth is above $100 (bottom right side of diagram):* This counts the number of days that wealth is considered high enough to cope with unexpected problems in life. This is a second measure of the ability of the person to cope with risks. Higher values of this metric are good.

3. *Average expenses over a lifetime (bottom left side of diagram):* This is the sum of the expenses each day of the person's life divided by 21,601. Higher average expenses is considered good since very low spending indicates that the person did not, for example, eat well.

4. *Total number of days that expenses are below $0.5 (bottom left side of diagram):* This is counts the number of days that expenses (amount spent) are so low that the person did not, for example, eat enough and hence is hungry and suffering. This is a second measure of the spending of the individual; higher values of this metric are bad (in fact, they may lead to death if there are enough consecutive low-spending days as the person will starve–here, however, death is *not* explicitly considered in the simulation).

Since income is random each day, this means that wealth, expenses, and net income are generally random each day of a person's life also (of course when there is enough wealth over some long time period, the person may spend the maximum amount of $E$ over that time period, not a random amount). Moreover,

the performance metrics themselves are *random* variables; that is, they change "each time the person lives their life" (if you consider that the person does not know how they will live their life); alternatively, you can consider that there are multiple individuals who live their lives under the same conditions and due to good/bad luck one person can end up with more wealth than the other. We will consider averages of metrics over multiple hypothetical lives of one individual, or the lives of multiple individuals (either way, the computations are the same–the only difference is in how you think of the results).

To start, consider the effect of spending strategy choice on the performance metrics for one lifetime for each strategy choice. The abstract case where the individual lives many lifetimes is considered after that.

### Effect of Spending Strategy on Metrics: One lifetime

First, consider a spending strategy that is "conservative" in the sense that less than the average income of $1 per day is spent by letting $E = 0.95$ (inherently, it is assumed that the person knows the average income *exactly*). This corresponds to saving on average 5 cents per day so wealth will accumulate as seen in Figure 1.7. The number of days that wealth is over $100 is 20,415 (almost their whole life), and the number of days the person went hungry because they spent less than $0.5 is 9 (quite a low number, and all these times are right at the start before they had accumulated wealth). The plot shows that average wealth is relatively high, and expenses are almost always at $0.95 per day so that is roughly their average spending per day. Was the spending strategy a good choice? The person had to suffer significantly only 9 days of their life, but had some level of suffering *every day* since they saved the 5 cents rather than spending it on food. So, they minimized extreme suffering, but have a relatively high value of average suffering. This suffering, however, can be viewed (especially when sitting here at my computer) as a wise investment since it allowed the individual to accumulate wealth over their lifetime that could be useful in purchasing healthcare or other services, saving, or investment.

Next, consider what might be called a "spendthrift" strategy where the individual spends 5 cents more per day (when they have it) than they make on average, if they knew the average. In particular, choose $E = 1.05$ to get Figure 1.8. The average wealth level is low. The number of days that wealth is over $100 is zero (not one time in their whole life could they save $100), and the number of days the person went hungry because they spent less than $0.5 is 873 (quite a high number, and spread over their whole life). Each time this person had extra money, they spent it to satisfy their needs immediately at the expense of not being able to accumulate wealth (they did not think of the implications of not saving, understandably so). Should some unexpected event occur (e.g., health problem) they will not be able to pay for it, and perhaps they will not invest in education. Moreover, both their average expenses (average hunger) and number of times in extreme hunger are quite high. Overall, this is a bad strategy.

A disturbing fact is that the performance metrics are highly sensitive to the

A conservative spending strategy results in great suffering, but savings.

A spendthrift strategy results in suffering and no wealth accumulation.
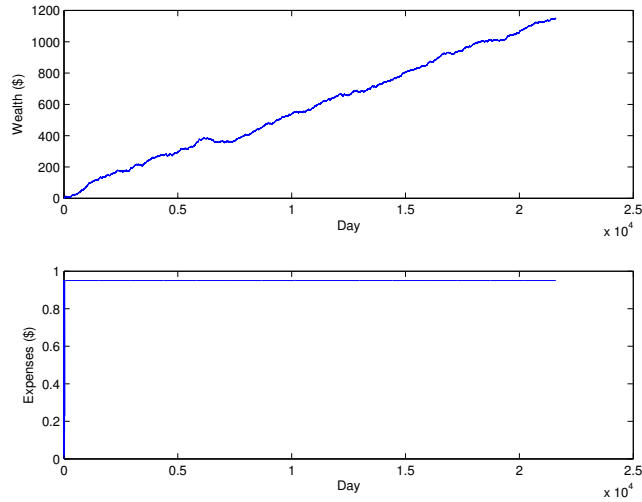
Figure 1.7: Wealth and expenses over lifetime for expenses upper limit of $E = 0.95$.
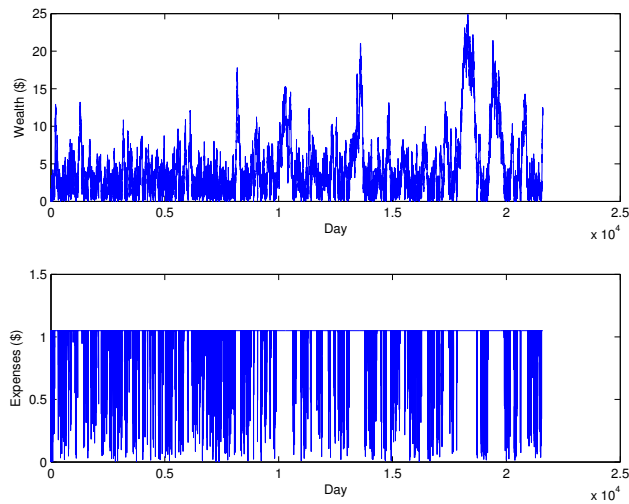


Figure 1.8: Wealth and expenses over lifetime for expenses upper limit of $E = 1.05$.

parameter $E$ (especially at $E = 1$) and hence the ability of the individual to estimate their average income. Being off in estimating average income by 5 cents has a significant impact. It is impossible to avoid suffering of some type using

this strategy, but with enough suffering, risk can be reduced by accumulating wealth.

**Effect of Spending Strategy on Metrics: Average lifetime**

Assume that an "average lifetime" represents one of two cases: (i) a community of $N$ individuals live under the same conditions but earn different random incomes each day of their lives; or (ii) imagining a person re-living their life many times. Here, we will assume case (i). The averages and standard deviations of the performance metrics will be computed over the $N$ people. Let $E$ take on 10 equally spaced values between 0.75 and 1.25 representing a range from conservative to spendthrift strategies. Suppose that we consider 100 lives, each having the same $E$ value, but then the $E$ value is changed to study average performance for different spending strategies (always assuming all $N$ people use the same strategy). This will give us the ability to study the average performance of each strategy (and the variability in performance metrics via standard deviations).

Figure 1.9 shows the results. Here, the mean wealth and mean expenses (and standard deviations of these) over any of the 100 lifetimes is random; hence, the "mean of the mean" values, and "mean of the standard deviations" is computed. The number of days where wealth is over \$100, and the number of days where expenses are under \$0.5, are random (different values are obtained for each lifetime) so their mean and standard deviation for 100 lifetimes is computed. Consider what happens as the spending strategy is changed by increasing the upper spending limit $E$ from 0.75 to $E = 1.25$. The top left plot shows that mean wealth, and variations of wealth as measured by the standard deviations, decrease up to $E = 1$ where they level out; as the spending upper limit increases, less wealth is accumulated. The top right plot shows that the mean number of times wealth is above \$100 decreases as the spending upper limit increases, and drops off sharply as $E$ gets close to one; this shows that if your upper spending limit is near to the amount that you earn on average, you accumulate little if any wealth. The bottom left plot shows that as the upper spending limit increases, the mean of the mean expenses increases, then levels off at one, representing simply the upper upper limit on spending. It is interesting, however, that as the upper spending limit increases beyond $E = 1$, the variance on spending increases; this shows that spending too much leads to significant uncertainty in being able to buy food each day (the person's suffering results in a negative side effect of making their spending highly unpredictable). The bottom right plot shows that as the spending upper limit increases the average number of times you spend less than \$0.5 increases, representing that over-spending costs you in extreme hunger more often.

The main conclusions about "spending strategy design" (choice) can be reached by considering all four plots in Figure 1.9. What is the best value of $E$? In terms of the two wealth metrics, you want a small $E$ value, that is, to cap your spending so you can save. In terms of expenses you probably want a value of $E = 1$ since this means that you typically spend the money to get
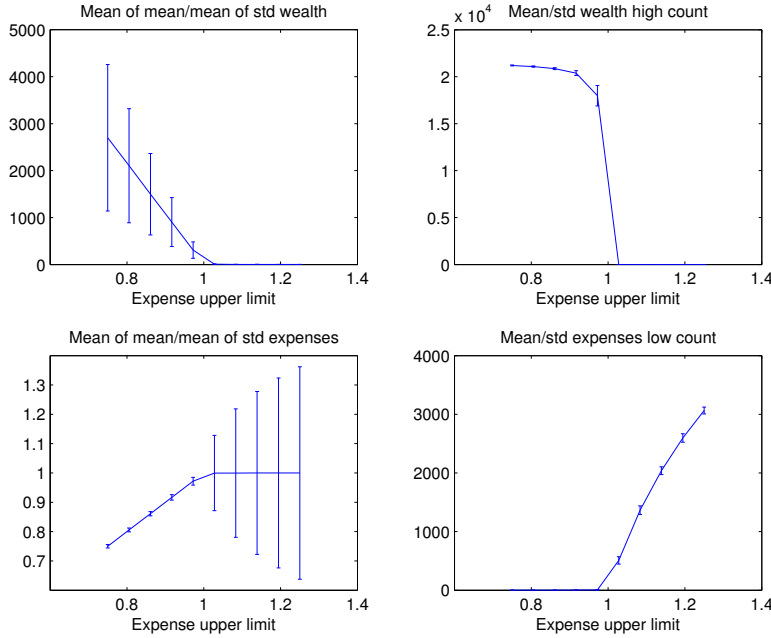
Figure 1.9: Performance metrics versus changing parameter $E$ over range $[0.75, 1.25]$. Top left plot shows the mean of the mean lifetime wealth and mean of the standard deviation of lifetime wealth (bars). Top right plot shows the mean and standard deviation of the number of days that wealth is above $100. The bottom left plot shows the mean of the mean lifetime expenses and mean of the standard deviation of lifetime expenses (bars). The bottom right plot shows the mean and standard deviation of the number of days that expenses are below $0.5.

enough food, are certain to get that food (low variance in bottom left plot), and there are few times when you spend less than $0.5 per day making you go hungry. But, as discussed above, a person cannot typically estimate their average income in the type of job market (day jobs) we have in mind. Hence, we reach the unfortunate conclusion that there is no spending strategy of this type that minimizes suffering *and* still allows for the accumulation of wealth in order to minimize risk with respect to the future. You have to suffer to reduce risk if you use this spending strategy.

**High-Risk/Low-Suffering Spending Strategy**

The last subsection showed that $E = 1$ corresponds to the high risk, low suffering case. This is a "sensitive" point in the sense that if you decrease $E$ slightly from

this value, wealth consistently increases, but if you increase $E$ slightly above this point, no significant wealth is accumulated and many days of extreme suffering occur. In this section, we will explore this particular strategy by considering a typical lifetime and discussing the dynamics. This should be considered a highly theoretical case in the sense that a person who lives in these general conditions could never know or estimate the actual mean of their income (at the end of their life, if they could remember their income every day of their life they would still only have an estimate of their mean income).

In one typical lifetime, Figure 1.10 shows wealth and expenses, the number of days that wealth is greater than \$100 is zero, and the number of days that spending is less than \$0.5 is 109. At first glance, it may appear from the wealth and expense plots that values are randomly going up and down with no pattern. This is not the case. Notice that when spending moves quickly to low values, it does so in randomly spaced "bursts." These are times of significant suffering. Notice, however, that after each period of suffering there is an accumulation of wealth. But, the causation is not in this direction. It is not that expenses are impacting wealth in that manner; it turns out that *wealth oscillations* are a result in the random nature of income coupled with the dynamics induced by the "feedback" process involved in wealth accumulation and expenses. When wealth is high, spending is high, and there is no suffering; however, when the wealth trends down to near zero, this induces low spending (the person cannot spend what they do not have). The expenses are "bursty" with relatively brief bursts since the dip in wealth is relatively short-lived. The timing of the bursts is random.
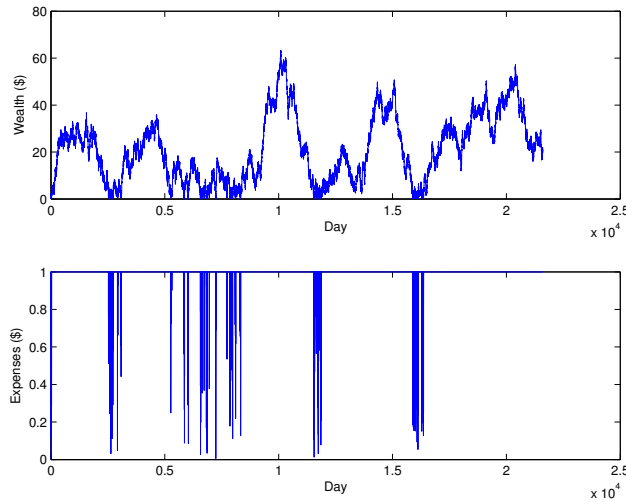


Figure 1.10: Wealth and expenses over lifetime for expenses upper limit of $E = 1$.

If you replace in the model the random income input with a deterministic offset sine wave oscillating at a low frequency between zero and two you can see what is happening. Basically, if the input is periodically above and below the mean of $1 per day, then in time periods when the income is higher than the average there is an accumulation of wealth and in time periods where income is below the average, wealth trends down since spending is outpacing income. The magnitude of the resulting wealth oscillation depends on both the amplitude and frequency of the sine input representing income: if the amplitude is higher and frequency lower, the wealth peaks will go higher. If the amplitude is lower and frequency is higher, then the wealth peaks will be lower (a method to analyze the size and frequency of the oscillations is the "describing function method"). Why are we seeing roughly this phenomenon when the input is random and not a sine wave? Over short time periods, simply due to randomness, short-term average (over a fixed number of days) income could be a bit higher or lower and this induces the oscillation (a true mean of zero only occurs for arbitrarily long lifetimes).

Overall, the $E = 1$ strategy may be viewed as reasonable for some people. But, when times are bad (low spending) the person will typically be optimistic that times will improve. Yet, when times improve, they can be assured that typically things will get worse. Randomness rules, creating either suffering or stress due to risk, or both. The model and analysis here are very simple (but, see Section 1.6.5 and Section 1.6.8); however, it is too tempting to ignore such interpretations of the data.

## 1.6.4   Proportional-Integral-Derivative Spending Strategy

Here, a proportional-integral-derivative (PID) spending (control) strategy is used to decide how to spend money each day (the PID controller is the most popular controller in use today and it is studied in the field of "feedback control systems"). The PID strategy uses the *same* input information (wealth) as the strategy of the last subsection and generates the same types of decisions (how much to spend) each day; the difference is that more knowledge about how to manage finances is built into the "intelligence" of the strategy and this will make a drastic difference in the life of a low-income person.

### PID Spending Strategy in Feedback Control

Figure 1.11 shows how to approach financial management as a feedback control problem. The block on the right holds the person and their savings (e.g., in their pocket). The vertical arrow represents an uncertain income stream. The input is "spending advice" to the person and the output is current (actual) wealth. The person also specifies desired wealth, and an error is formed between desired wealth and current wealth by a simple difference. This error represents how well the person is meeting their savings goals. The spending advisor (controller) in the block on the left either: (i) represents how the persons decides what to spend, or (ii) is designed by the engineer to get good performance of the

feedback control system (e.g., good tracking of the desired wealth by the actual wealth value), for instance via an electronic method that is discussed below.
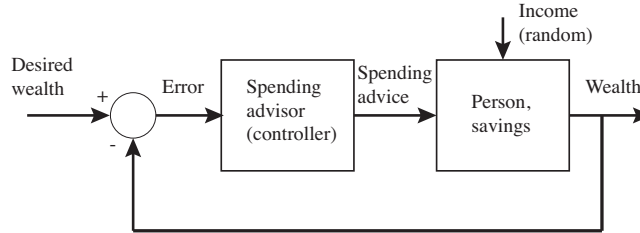


Figure 1.11: Spending strategy for closed-loop feedback control of wealth.

The Simulink model `DynamicalPovertyModelPID.slx` is shown in Figure 1.12 for the PID strategy. It is a specific approach to the implementation of Figure 1.11. Notice that there is much that is the same compared to Figure 1.6. First, notice that the random income, along with the possibility of adding a raise, is the same. Second, the savings model is the same, except now a "limiter" was added to make sure that a withdrawal of more than is in the person's pocket is not possible (in the case in Figure 1.6 this was not needed since by design spending was never above wealth).
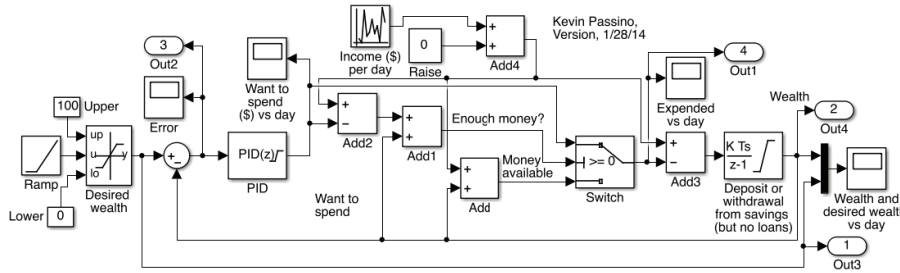


Figure 1.12: Simulink model of a PID spending strategy for closed-loop feedback control of wealth.

It is assumed that the person starts life with $1 though this value has hardly any impact. Notice that in this diagram the person is allowed to input the "desired amount of wealth" (savings) they want in order to avoid risk. The desired wealth increases like a ramp up to a maximum value of $100 where it holds constant for the remainder of the person's life. The slope of the ramp is set at 100/5000 to make the desired wealth reach $100 after 5000 days; higher slopes will demand more suffering due to the demand that the person build up their reserves as soon as possible in case some costly health event occurs. The current actual wealth (savings) is subtracted from the desired wealth each day to create an "error" signal. If this error signal is positive this means that wealth

is below desired wealth so it is necessary to spend less than is typically earned in order to save. If the error signal is negative this means that wealth is higher than desired so that more spending than usual can occur. The PID controller takes the error signal and generates a candidate amount to spend; this candidate amount will be spent so long as there is enough in savings to spend that amount (which will not be the case if wealth is $0.5 and the candidate spending amount is above, for instance, $2 that day). The remainder of the diagram, the part on the top right side, is simply for computing the amount that is spent by the individual each day; this is simply used for plotting purposes to illustrate the behavior of the system.

### Features of the PID Strategy

There are three "gains" that can be adjusted in the PID controller and these are the values of the variables $P$, $I$, and $D$. The PID strategy uses the following ideas to force wealth to "track" the desired wealth trajectory over time (i.e., it tries to force wealth to be as close to desired wealth each day of a person's life), that is, to make the error between the desired wealth and actual wealth go to zero.

**Proportional gain ($P$):**    (i) If the error is positive, wealth is less than desired wealth so spending should be *negative*; however, negative spending is not possible, and indeed spending will be limited to be above a positive value of $0.6, and on average this will result in savings since on average the person is earning $1 per day (of course other error values will result in spending more than $0.6, but less than the average of $1). This will drive the error signal to be lower, meaning that wealth will increase toward the desired wealth. (ii) If the error is negative, wealth is greater than desired wealth so spending should increase. If spending increases above the average $1 per day income, then wealth will decrease toward the desired wealth so that the error is reduced. If the gain $P$ inside the PID controller is increased, the effect is simply to make the saving/spending strategy more "aggressive" (i.e., it saves more or spends more) and thereby it tries harder to force the error to zero. If the integral and derivative gains are "turned off" (i.e., $I = D = 0$), a P-only strategy ("proportional controller"), fails in that wealth eventually becomes constant (plus some noise), possibly far from the constant desired wealth; that is, there is a "steady state error."

**Integral gain ($I$):**   The integral gain is used to solve the steady state error problem just discussed. An "integral" sums its inputs and holds the sum at its output. The PID feeds the error between the desired wealth and current wealth into an integral term multiplied by the integral gain $I$. If error is positive, and error stays positive for a sizable time period (as when the steady state error discussed above occurs), the integral's summing action results in an increasingly large output that is multiplied by the gain $I$. Essentially, this results in a large negative candidate expenditure, that forces expenditures to be at its positive minimum value, so that wealth can grow and move up toward the desired wealth.

On the other hand, if the error is consistently negative, then when it is summed by the integrator a large value will result, which indicates that an increasing amount can be spent so that wealth moves down to the desired wealth. A known problem with this strategy is that the integral term can result in oscillations or "overshoot" (i.e., the wealth going significantly above desired wealth before going back down to track the desired wealth).

**Derivative term ($D$):** This problem of overshoot (or oscillation) just discussed can often be solved by the derivative term. The derivative of a trajectory is the slope of the trajectory (e.g., for wealth, the difference between two day's wealth, divided by the time period, in this case one). The derivative term (in practice an approximation is used to compute the derivative to avoid very high values for the derivative when values change significantly) is composed of the slope of the error multiplied by the derivative gain $D$. If error is positive and quickly moving to zero, then spending is *increased* since the savings rate is high enough, and so that wealth will not suddenly rise over the desired wealth due to too much saving. If error is negative, and quickly moving toward a positive value, then the strategy is trying to save too much when it should be spending, and the derivative avoids overshooting the desired wealth here also. Other cases for error positive or negative, with it increasing or decreasing are similar. The derivative gives the strategy an ability to *predict* when overshoot/oscillations will occur and take early actions to avoid these.

There is a limiter (saturator) at the output of the PID strategy that limits the lower spending value at 0.6, above the extreme hunger point of $0.5 above. The performance of the strategy is not very sensitive to this lower threshold value, and it can be increased some if the person wants to avoid suffering, however, that will just result in less extreme suffering being "spread" over other days with some suffering since you must on average spend less than your average income in order to accumulate wealth. The maximum allowable candidate spending per day was set at $15, but you will see that this limit is not reached. Internally, there is "clamping" to make sure its internal variables stay bounded (and hence can be implemented in a computer).

> The PID spending strategy can be tuned to avoid both suffering and risk.

### Design for Avoidance of Suffering and Risk

We want to adjust the PID strategy so that the person's actual wealth "tracks" their desired wealth (i.e., so that wealth error goes to zero). Tuning the three PID gains results in different responses, with each response representing a different desired wealth tracking performance. After some manual adjustments (and use of the "auto-tune" function in Simulink), the following three gains were chosen $P = -0.316$, $I = -0.0007$, and $D = 0.547$ (and a "derivative filter gain" provided by Simulink of 0.321).

Figure 1.13 shows the results. Notice that the PID strategy is successful in the sense that it makes wealth track desired wealth relatively closely (there is about a $\pm$$2 variation around the desired wealth when it is constant and a similar variation around the ramp when it is increasing to $100). The middle

plot shows the error signal, the desired wealth minus the wealth, and illustrates that early in the person's life the wealth trajectory is on average above the desired trajectory (expenses could increase a little), but then reduce to around a mean of zero before the ramp reaches its maximum. The error plot "noise" illustrates what is more difficult to see in the top plot: the variation of wealth around the desired wealth is quite low. The bottom plot shows what the person spends each day of their life. While not evident by inspection, while the ramp is increasing the average spending is lower so that wealth can accumulate, but it is not too drastic since the ramp slowly increases and this corresponds to a reasonable savings rate, one not requiring an extreme daily suffering too often; but, the person is suffering some or the wealth could not accumulate. What is interesting is that it appears that the mean spending amount is close to $1, the same as the mean income rate. This is not, however, true. The mean spending amount is lower in the beginning to accumulate the wealth, then approaches $1 per day on the long flat part of the desired wealth trajectory.



Figure 1.13: The top plot shows wealth (solid line, red) and desired wealth (dashed line, blue) as functions of days. The middle plot shows the error, which is the desired wealth minus the current wealth. The bottom plot shows the amount of money spent each day. In this case, a constraint is added to the PID controller that never allows it to output less than 0.6 as a spending recommendation.

Next, Figure 1.14 shows the case where the PID strategy recommends spending no less than \$0.95 per day (of course, if wealth is lower than \$0.95, then only the available amount of money is spent). This represents that the person does not want to suffer as much in order to save. On average, the person will only be able to accumulate \$0.05 per day. Yet, even saving this small amount, if the person manages their wealth with the PID strategy, the person is able to accumulate \$100 as shown in the plot, although the variations around the desired wealth trajectory are larger in this case, which is due to the inability to quickly save to move wealth up toward the desired wealth when it is below the desired wealth. This accumulation comes at a cost. Notice that in the bottom plot of Figure 1.14, unlike the \$0.6 lower limit used in Figure 1.13, the bottom plot shows that there is spending that is below \$0.95 (recall the PID only *recommends* what to spend) since in those cases wealth is so low that only less than \$0.95 can be spent. Of course, this can result in significant suffering. The user has essentially demanded that they save at a low rate, and they pay for this mostly by suffering initially (and perhaps in the larger variations in the error trajectory that may create uncertainty and hence stress for them).

### The Intelligence of the PID Strategy

There are three important points about how "intelligent" the PID strategy is:

1. *Dynamical finance management:* Note that the spending trajectory rarely exceeds \$1.5 or goes below \$0.6. This range of variation is *less* than the range of incomes that are possible–between \$0 and \$2. The PID strategy is consistently taking income from good days and filling in for the bad days; it is redistributing wealth over time. It predicts (derivative) when this is necessary, and knows how much extra money is in savings over a time period that needs to be spent (to avoid suffering) or how much of a consistent deficit there is so saving needs to be done to increase wealth, and how fast (proportional). It is expertly micro-managing literally pennies to regulate the wealth around the desired wealth. It is avoiding the large oscillations we saw earlier, the instability (arbitrarily growing wealth that causes much suffering), and the unpredictability of how much wealth is accumulated. The PID provides the person with consistency and avoidance of effects of random incomes. It reduces risk.

2. *Suffering also leads to better long-term financial management:* Having the mean spending lower in the beginning is *very important* not just to accumulate wealth. It is crucial in order to increase wealth well above its lower threshold so that nonlinearity does not affect the PID strategy, and so that the spending does not hit its lower limit of \$0.6 so that the nonlinearity has no effect either. This puts the PID strategy in a "linear range," which is basically what the PID controller is tailored to take care of. The random income (disturbance) is additive and is a standard signal whose effects can be coped with via a linear strategy like the PID (of course this ignores the fact that the "clamping" is nonlinear, but such

Figure 1.14: The top plot shows wealth (solid line, red) and desired wealth (dashed line, blue) as functions of days. The middle plot shows the error, which is the desired wealth minus the current wealth. The bottom plot shows the amount of money spent each day. In this case, a constraint is added to the PID controller that never allows it to output less than 0.95 as a spending recommendation.

clamping will not occur if signals stay small). Essentially, initial suffering keeps you away from the nonlinearities that make it difficult to do good management of finances. It enables true "smarts" of the PID strategy outlined in 1. above.

3. *Coping with other income streams and risk-aversion demands:* The strategy was tested for a range of desired wealth trajectories by varying the slope and final values over a wide range. The same basic behavior as seen in Figure 1.13 was found. Next, the desired wealth trajectory was set at the one in Figure 1.13 and a wide range of "raises" were given to the person. Again, the same pattern of behavior found in Figure 1.13 was found, but so long a the mean income was above a certain amount, there were few if any days of spending beneath $1 per day in order to accumulate wealth. Having the benefit of extra income simply results in the expected reduction in suffering and eases the difficulty of generating savings. Other

deterministic income trajectories where input, with expected results.

While the PID has benefits, it is one of the simplest feedback control strategies known, yet one of the most effective in real applications (e.g., in industry). There are *many* other possible feedback control strategies (e.g., ones that learn how to improve their own performance), properties of dynamical systems, and analysis approaches that deserve attention. Some of these are outlined in the next section and in Section 1.6.8.

## 1.6.5 Modeling and Strategy Improvements

It is worth repeating that there is no perfect model. This model of a person's financial situation only focused on money. Of course, poverty is much more complicated than that. Other considerations like health and education, and how they impact financial issues, need to be considered. But, assuming the focus is only on money, what is wrong with this model? What makes it inaccurate with respect to real situations? There are a number of problems:

1. The possibility of theft of money from savings is not modeled; however, with a PID strategy, thefts could be dealt with as if life was starting over and wealth must be accumulated again, with suffering.

2. The possibility that as a person accumulates wealth, having that wealth helps her/him to accumulate more wealth was not considered as it often is in development economics. To model such an effect, a term is added to the income in the form of $\beta(x(k))^\alpha$ where $\beta > 0$ and $\alpha \in [0, 1]$ (Acemoglu, 2009). When $\alpha = 0$ we would get a simple constant added amount to the income stream (i.e., a raise). When $\alpha = 1$, the person's income would increase linearly with increasing wealth. Common values studied in the literature are $0.3 \leq \alpha \leq 0.7$, and such values provide a nonlinearly increasing amount of income as more wealth is accumulated ("the more you have, the more you can make").

3. It is assumed that the person can compute the difference between desired wealth and current wealth exactly. Moreover, it is assumed that the person can literally compute the PID strategy "in their head," something that would clearly be a great cognitive demand, especially when they have other things to worry about. The ability of a person to implement a PID strategy they are taught (which would take some educational effort) would have to be studied using large groups of people in experimental trials. But, see the discussion below on implementing the PID with a computer.

4. The quantization of wealth into the typical units used in a country would have an impact. Use of standard bills and coins means that amounts cannot be split so over-spending or over-saving can occur. Such quantization effects are easy to model and study.

5. It is assumed that the income arrives in a random manner but never goes over $2 per day; other income patterns, including deterministic ones, can be seen. There is a need to take data on typical income patterns for people making various amounts of money.

6. Studies need to be done on what is the minimum acceptable spending per day. Is the $0.6 lower limit on spending used in the PID strategy good? What would people say? Should that value be held constant over a lifetime, or should it be adjusted if the person says they are suffering too much?

7. There needs to be studies on the best desired wealth profile. What is the best way to increase wealth? How fast? What value of wealth needs to be maintained in order to avert risk? When does the desired wealth value need to increase or decrease (e.g., to save for a major purchase)?

Generally, as model improvements are made, it is possible to improve the design of the spending strategy by tuning it better via simulations. Except item 3., all of the above aspects of the model can easily be added to evaluate the performance of the existing PID strategy, and make any tuning adjustments needed to maintain a high level of performance. Item 3. is addressed below.

The PID strategy is not the only one possible, and it is not known to be the best one. There are a wide range of other possible dynamical strategies:

1. An estimate of the mean income could be useful in strategy design (e.g., by simply computing the mean of income values in a "sliding window," such as the past two weeks or month). For instance, the estimated mean income could be used to tune the $E$ value above to be just less than the estimated mean if wealth is below desired wealth, and just above the estimated mean if wealth is above desired wealth.

2. Signal processing methods could be used to predict the income values into the future and this could be quite useful in strategy design. Indeed, the fact that income for the day is known is *not* even used in the PID strategy (though it uses wealth from the previous day), nor is the possibility considered of asking the individual whether they will have a job tomorrow and hence be able to estimate their own income.

3. There is the potential that other more advanced "controllers" could improve performance over that of the PID strategy. The saturation in the storage of money that says that wealth cannot go negative, and the saturation at the output of the PID strategy, are nonlinearities and the income can be thought of as a random "disturbance;" these features present challenges to doing good financial strategy design. Yet, possibly using the above two points, there exist control approaches that may have potential: "model predictive control," "adaptive control," or other nonlinear control methods. See Section 1.6.8.

Finally, note that even if only money is considered, and not health or education as mentioned above, "wealth" could be broken into components such as cash-in-hand, savings, fixed assets, capital, and liabilities. Then, a feedback controller for this more complicated case could be developed.

### 1.6.6  Personal Spending Strategy Implementation

In this section, the modeling exercise above, where we represented both the person's income and wealth storage, along with their decision-making strategy for spending money, naturally leads us to "automate" that decision-making in a computer, which can be especially effective if the person reliably uses the computer as the computer algorithm can do things that a human generally cannot (e.g., remember lots of data for long periods of time, process it relatively fast, or use a very sophisticated decision-making strategy that is beyond the abilities of a typical person to use). The bottom plot of Figure 1.13 shows the amount of money spent each day by the individual. This is quite a sophisticated pattern of adjustment of spending, one that appears to naturally call for a computer to implement the PID spending strategy (or other suitable strategy). Before the actual technology implementation is discussed, consider some of the desired features such a technology:

> The potential exists to implement on a phone or computer the spending advisor for low-income people.

- *User inputs:* The daily user inputs to the device are the desired wealth (of course the device may allow for the input of all values of desired wealth in an easy way so that this value does not have to be input daily) and the wealth today. For the financial advisor, there is no need for the user to input what they obtained as income or spent daily as this information is sufficiently accounted for simply by them indicating their current wealth. Another parameter that should be input by the user is their lower-limit on spending per day (e.g., $0.6). For controllers other than the PID, it may be necessary for the user to input other information (e.g., their income each day).

- *Recommendations to the user:* The main recommendation from the device is how much should be spent today, which the device would have to display in some way to the person at the appropriate time of the day, or all day.

- *Graphical user interface (GUI):* Of course, a simple easy-to-use graphical user interface is needed if the technology has a screen. Plots of income, wealth, spending could be shown for all days up to today. Recommendations could be made to improve performance.

Additional analysis of the PID strategy is needed to study the impact of, and possible need for strategy redesign, the above three points: What if the user does not input their income on some days? Should an estimated income be used instead? The same value as yesterday? What if the recommendation on spending to the user is not followed? The person may simply refuse to follow the advice (e.g., if it says spend a low amount), or it may be that they do not

have the right "change" in their pocket to spend exactly that amount. Or, it may be that they do not easily control how much is spent (e.g., not knowing costs). Will advice suggested via the GUI be accepted? Can it be presented in a way that it is more likely to be accepted? All of these issues can be studied via field experiments and simulations. All these issues change per the culture or country you are in.

What computer? The following three options can be considered:

1. *Smart phone or cell phone:* Will a person making an average of $1 per day have a smart phone or cell phone? Perhaps. However, the UN estimates that as of 2015, when there was 7.3 billion people in the world, there were 7.3 billion mobile subscriptions. The line between smart and cell phones is blurry. Any of these devices certainly seem to have the computing power to implement the PID strategy as it is just some sums, multiplications, and divisions. It seems that a company that offered an "App" or feature on a cell phone that is a personal spending advisor, customers would be more likely to purchase their phone, especially if the feature was successful. Of course, other financial aspects of their lives could also be added to the PID strategy (e.g., loans or insurance).

2. *Personal electronic device:* Of course, a simple electronic device could be designed to implement the PID strategy, and it could be made to be much less expensive than a smart or cell phone. Microprocessors with all the needed computing power cost pennies. Achieving a very low cost is important and it seems that people may choose to live their lives without a cell phone, and instead choose a personal financial advisor that could greatly improve the quality of their lives. But, of course, at this point in time, cell phones have become very inexpensive so it may be the right delivery vehicle for financial advice, possibly allowing operation without a subscription that could be more costly.

3. *Centralized computer:* Suppose the "update rate" for inputting data and getting advice on what to spend changes from daily updates, to weekly (or monthly) updates. Suppose that at some central location (e.g., a micro-finance organization) there is a computer that manages the finances for low-income persons in the area. Each week the person goes to the bank and gives them their income data (either the total over the week or their income over each of the last 7 days) and spending data (total or daily), they input it into the computer, and the computer comes back and tells them how much they can spend for the week. Of course, such a computer could be in a kiosk and be self-operated in either an urban or rural area. In this case, there are PID spending strategies running for each person who can log into the computer as an "application" on the computer. Essentially, the Matlab-Simulink program used for the above simulations can be easily modified to provide a GUI interface to a user who needed their finances managed.

I am intentionally ignoring many aspects of the engineering of such a device as all these (e.g., user needs and context) will be covered in Chapter 4 and Problem 4.13.

### 1.6.7 The Impact of Development on Sustainability

In Section 1.3.6, the notion of the tragedy of the commons (Hardin, 1968) was introduced: Are humans, due to rational but short-sighted behavior, destroying the "commons" (natural resources under shared human use like air, water, land, and forests) that are needed for the survival of humanity? Will some users greatly exploit the resources of the commons solely for their own benefit, and at the expense of others who need the commons? In this section, a simple mathematical model of the commons from (Roopnarine, 2013) is used to study the following two questions:

- What is the effect of overutilization of the resources in the commons on its long-term health?

- What is the effect of increasing the size of the population of users of the commons?

**Dynamical Model of the Tragedy of the Commons**

Consider a renewable common resource, such as a forest that grows, a fishery where fish reproduce, etc. and denote the resource by $R(k)$, $R(k) \in [0, \infty)$, at time step $k$, where $k$ is dimensionless but it could be in decades, for instance. The time $k = 0$ corresponds to the starting time for the model. Let $N \geq 2$ be the number of users of the common resource; for the climate $N$ is greater than seven billion, the number of people on Earth. The resource dynamics model from (Roopnarine, 2013) is

$$R(k+1) = R(k) \left( e^{r\left(1 - \frac{R(k)}{K}\right)} - U(k) \right) \tag{1.6}$$

where $U(k)$ is the total utilization of the resource by all users at step $k$, $r$ is the intrinsic growth/renewal rate when $U(k) = 0$, $k \geq 0$, and $K$, $K > 0$, is a parameter (in ecology, called the "carrying capacity" of the environment with respect to the resource $R(k)$). The parameters of this model will not be tuned to represent any natural resource or population; the analysis here is purely *qualitative* and only has value in gaining an understanding of the *nonlinearities* and *dynamics* underlying the tragedy of the commons.

Suppose for a moment that $U(k) = 0$ for all $k \geq 0$; Figure 1.15 shows the resulting resource level over time for the case where $r \geq 0$, $r = 0.5$, and $K = 50$ for different initial resource levels $R(0)$. Notice that the ultimate value of the resource is the carrying capacity $K = 50$. The parameter $r$ changes how fast the ultimate resource value is attained. Also, if the initial resource value starts below the carrying capacity, then the resource will grow. However, if the initial

*The tragedy of the commons can be represented with nonlinear difference equations relating resource and utilization dynamics.*

Figure 1.15: Resource renewal/growth when there is no utilization.

resource value is above the carrying capacity, the resource value declines due to an low renewal rate.

While the total utilization is $U(k)$, individual users, $i$, $i = 1, ..., N$, have resource utilizations of $u_i(k)$ at step $k$ and

$$0 \leq U(k) = \sum_{i=1}^{N} u_i(k) \leq 1$$

Hence, $R(k)U(k)$ is the percentage of the total resources that are depleted by all users at step $k$ and $u_i(k)R(k)$ is the amount of user $i$'s resource consumption ("benefit") at that time (Roopnarine, 2013). For example, if for all $i$, $i = 1, ..., N$, and all $k \geq 0$,

$$u_i(k) = \frac{\alpha}{N}$$

$\alpha \in (0, 1]$, then all users are utilizing the commons at the same rate and $U(k) = \alpha$. Clearly, however, other utilization profiles over the set of users are possible as is discussed below.

What ever the individual utilization rates are, the key impact on the commons is the *total* utilization $U(k)$. Under a "low utilization" scenario, $R(k)$ can be maintained at an adequate level and the tragedy of the commons is avoided. However, there are underlying strong forces (i.e., each user wants to increase their benefit $u_i(k)R(k)$) to increase total utilization $U(k)$ and this can result in the commons being destroyed, assuming there is no management of the commons. Here, we will assume that the commons are destroyed if at some point in time $k$

$$R(k) < R_d$$

where the threshold value $R_d$, $R_d > 0$, is adjusted to represent a point at which the commons are destroyed.

To gain insight into the relation between utilization rates and resource increases and decreases do a simple rearrangement of Equation (1.6) to get

$$\frac{R(k+1)}{R(k)} = \left(e^{r\left(1-\frac{R(k)}{K}\right)} - U(k)\right) \tag{1.7}$$

and assume that for all $k \geq 0$, $R(k) > 0$. Notice that

- If for some $k \geq 0$, $\left(e^{r\left(1-\frac{R(k)}{K}\right)} - U(k)\right) > 1$, then $\frac{R(k+1)}{R(k)} > 1$ so the resource amount increases at this $k$. This is a desirable situation, one that results from low utilization.

- If for some $k \geq 0$, $\left(e^{r\left(1-\frac{R(k)}{K}\right)} - U(k)\right) < 1$, then $\frac{R(k+1)}{R(k)} < 1$ so the resource amount decreases at this $k$. This is (typically) an undesirable situation as the resource level is moving toward the case where it could hit the $R_d$ boundary.

- If for some $k \geq 0$, $\left(e^{r\left(1-\frac{R(k)}{K}\right)} - U(k)\right) = 1$, then $\frac{R(k+1)}{R(k)} = 1$ so the resource amount stays unchanged (i.e., it is sustained) at this $k$. This is a precarious situation as any increase in utilization will result in resource decline. Of course, also, any decrease in utilization will result in resource growth.

Per this last condition, let $R_u(k)$ (the index $k$ will be dropped below when it is not needed) be the value of $R(k)$ at which $\left(e^{r\left(1-\frac{R(k)}{K}\right)} - U(k)\right) = 1$. Then, at step $k$, $\left(e^{r\left(1-\frac{R_u(k)}{K}\right)} - U(k)\right) = 1$. Name the solution to this equation $U^*(k)$ and

$$U^*(k) = \left(e^{r\left(1-\frac{R_u(k)}{K}\right)} - 1\right)$$

which is the maximum utilization possible at $R_u(k)$ that still ensures there is not a resource decline by the next step.

Here, we are concerned with the question of how does the size of $U(k)$, $k \geq 0$, impact whether or not $R(k) > R_d$ for all $k \geq 0$ (commons not destroyed) or $R(k) < R_d$ (commons destroyed) for some $k \geq 0$? In particular, we are concerned about what happens when utilization increases due to development or population size increases.

### Analysis of Impact of Development and Population Size

Two key impacts on resource dynamics in the commons are individual utilization rates and the size of the population of users:

- *Individual utilization increases due to development:* If any individual $i$ increases their utilization $u_i(k)$, and all other $j \neq i$ keep their utilizations

the same, then $U(k)$ increases by exactly the amount the individual increased their utilization. All users are likely to be motivated to increase their utilizations as this will (at least in the short-term), increase their benefits from the resource. It is well-known that persons living in poverty generally use fewer resources than wealthy persons. This leads to the concern that ending poverty (e.g., for "the bottom billion") will increase the utilization levels of many of these people and this could destroy the planet, that is, cause a tragedy of the commons.

- *Increasing population size increases utilization:* Suppose the population size is $N$ and that each user has a utilization $u_i(k) > 0$, $i = 1, ..., N$. Next, suppose that the population size increases by just one, to $N + 1$ and logically the utilization of the new user is $u_{N+1}(k) > 0$. This implies that under a population increase, total utilization $U(k)$ will increase by the utilization amount of the new user. Hence, the overall likelihood of a tragedy of the commons increases with population size.

If one, or both, of these conditions occur, the net effect is the same: an increase in total utilization $U(k)$. Hence, to study the impact of both development and population increases, on resources of the commons, we will simply consider the effects of increasing or decreasing the total constant utilization $U(k)$, assuming that one or both of the two above issues are the driver(s) of the change in total utilization (for the population increase case, it is as if we restart the process when one more user is added).

Assume that the value of $R_d = 20$. Consider Figure 1.16, and in particular the two plots on the left side. The top-left plot shows $R(k)$ vs. $R(k+1)/R(k)$ as a blue line (see Equation (1.7)) for a "low utilization" case, here $U(k) = 0.05$ for all $k \geq 0$. The red vertical line is $(R(k+1)/R(k)) = 1$. Hence, per the analysis in the last section, for values of $R(k)$ such that the blue line is to the left (right) of the red line, and above (below) the black dashed line, the resource level is decreasing (increasing, respectively). This means that the point at which the blue and red lines cross (the black dashed line) is $R_u$, assuming a constant total utilization. In this low utilization case, $R_u > R_d$ and no tragedy occurs. The bottom left plot is for the "high utilization" case where the total utilization is increased to $U(k) = 0.6$ for all $k \geq 0$. Notice that in this case the point at which the blue and red lines cross (the black dashed line) is *lower* than the low utilization case, and in fact $R_u < R_d$ and a tragedy occurs. The particular resource dynamics for the low and high utilization cases, along with a line representing $R_d$, are plotted in the two plots on the right. In the top right plot, showing resource dynamics for different initial values of $R(0)$ for the low utilization case, the plots are qualitatively similar to the no utilization case in Figure 1.15. Also, the cross-point of the blue and red plots, $R_u$ indicated by the black dashed line, on the top left plot corresponds to the ultimate resource values shown on the top right plot (i.e., where, in all cases, the resource level converges). This value of $R_u$ is above $R_d = 20$, the straight line on the top right plot, so no tragedy occurs. The bottom right plot, is however the problematic

Increases in utilization cause decreases in resources; over-utilization results in the tragedy of the commons.

case. Here, for all cases, the resource levels go below $R_d = 20$ so that there is a tragedy of the commons due to the higher utilization, that is, $R_u < R_d$.
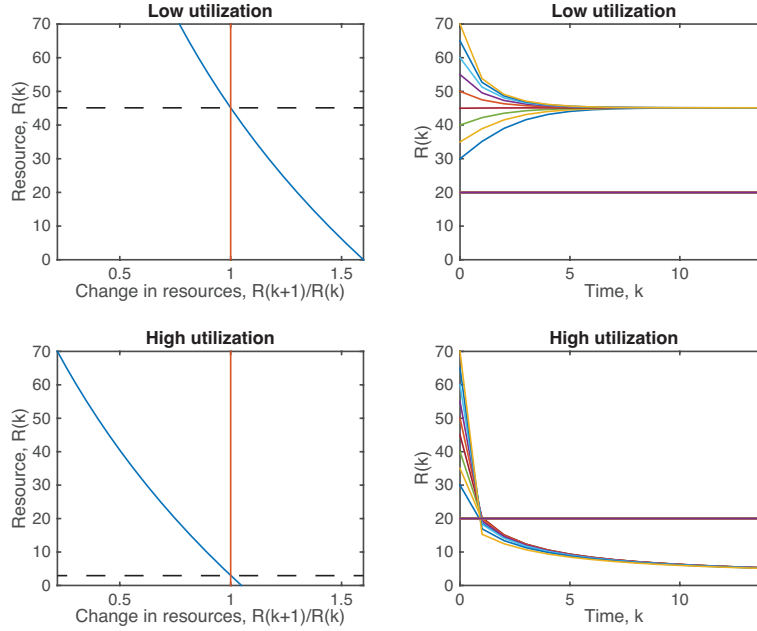


Figure 1.16: Dynamics of the tragedy of the commons and impact of total utilization level on the tragedy.

The only way that *management* of the commons is considered above is in the use of the model to predict, for a given total *constant* utilization level, whether the ultimate value of the resource level will result in a tragedy of the commons. If total utilization is too high, it can be reduced to avoid a problem. In the next two chapters we build on this section by considering the *dynamic* management of individual and total utilization levels to guarantee the avoidance of the tragedy of the commons. To do this, we first consider environmental justice issues in Section 2.4.5, and then resource utilization control in Section 3.6.6, that also shows the impact of development on the environment. In Section 4.12.2 a community is connected by common use of a resource, and *both* the impact of development on the common resource, and the availability of the common resource on development, are considered in the context of studying the impact of technology on community development.

## 1.6.8   Principles of Feedback Control

Control theory and engineering is a relatively well-studied field, with a large literature of books and papers. Here, a brief overview of key principles is provided

based on the treatment in (Passino, 2005), where all of the issues in this section are discussed in more detail. To start, consider Figure 1.17. Here, the "process" (often called the "plant" in the literature) is the entity that we desire to behave better, perhaps due to the "disturbances" that represent uncertain influences. To improve the process behavior, "inputs" are injected. The "reference input" specifies the desired behavior of the process, typically the process "outputs." The "controller" is synthesized so that by measuring the process outputs, it can inject inputs to the process so that the outputs behave according to how the reference input dictates they should behave. There are "performance objectives" that quantify how you want the closed-loop system to behave. As an example, you could map these ideas onto temperature control in a building, or cruise control on an automobile.
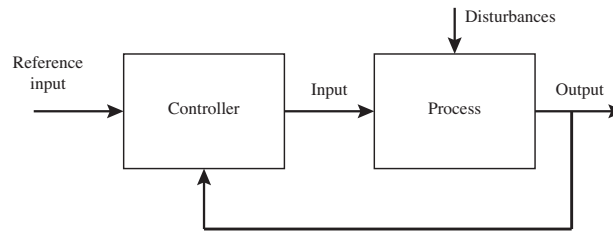


Figure 1.17: Feedback control system.

In terms of the financial advisor application in Section 1.6.3, the process is the person's holding of money (e.g., in their pocket), the disturbance is the uncertain daily income, the process output is current wealth, the process input is spending (assuming advice is followed), the reference input is desired wealth, and the controller is either the strategy in Section 1.6.3 or the PID strategy in Section 1.6.4. The undesirable behavior of the process is the difficulty to regulate personal wealth so that money is available in case of emergencies. The controllers inject spending amounts to make the behavior, quantified by the wealth output, "track" (become the same as) the desired wealth, in spite of unpredictable fluctuations in income: this is the performance objective. An alternative to the above feedback controllers is to use an "open-loop" controller, one that does not measure and use the process output. This, however, does not make sense for the application in Section 1.6.3 as it would correspond to trying to spend to achieve a desired amount of wealth, without knowing how much you have in savings. Such an approach is doomed to failure as the random nature of the income will result in it being impossible to achieve a specified desired wealth.

**Process Features and Properties**

Usually, the engineer starts by trying to understand the dynamical process. Science (e.g., physics and chemistry) can help with understanding, and the formation of mathematical and computation models for the process. Also, data

from the process in operation may help construct and validate a model (the area of "system identification"). A model is often useful for constructing a controller and/or evaluating the performance of the closed-loop system without implementing it. Some features of dynamical processes include:

- *Linear or nonlinear:* The process in Section 1.6.3 is nonlinear due to the lower-limit saturation on savings (money cannot be negative).

- *Single input single output, or multi-input multi-output:* The process in Section 1.6.3 is SISO.

- *Finite/infinite dimensional:* The process in Section 1.6.3 is finite dimensional.

- *Continuous/discrete time:* The process in Section 1.6.3 is discrete time, with time steps corresponding to days.

- *Stochastic/deterministic:* The process in Section 1.6.3 is stochastic due to the random income stream.

- *Large or small scale:* The process in Section 1.6.3 is small scale, focusing only on one person. Later chapters will consider larger scale cases involving groups of people (e.g., communities).

- *Multi-layer:* Later chapters will study multi-layer processes by considering higher levels with a wealth distribution policy, and a level above it with a democracy.

- *Distributed/centralized:* The controllers in Section 1.6.3 are centralized in that they have all process output information in order to make a decision. In Chapter 2 distributed control is considered where it is possible that individuals only make decisions based on their "neighbors," not the whole community.

- *Complexity:* The complexity for is very low, but the complexity for the cases considered in subsequent chapters can be very high (e.g., for a large community).

- *Hybrid:* The democracies considered later (e.g., in Section 2.4) result in a hybrid system with periodic discrete voting at the high level, and standard discrete-time dynamical processes at the low level.

Before the development of a controller for Figure 1.17, process properties are often studied. This facilitates understanding the process and choosing the type of controller that will be needed to meet performance objectives. Some common properties to study include:

- *Stability and boundedness:* If you put a bounded sequence of inputs into the process, will the outputs remain bounded ("BIBO stability")? Clearly, the process in Section 1.6.3 is not BIBO stable. Why? For stability, if you fix the control inputs, identify an "equilibrium," and perturb the system off that equilibrium, will the system return to that equilibrium?

- *Controllability:* Is it possible to steer the system to any condition via the proper choice of inputs?

- *Observability:* Using an informal way of thinking, is it possible to measure the process outputs and infer what the internal process conditions are?

Of course, these properties can also be studied for the closed-loop system, and often a key objective is the stabilization of a process via closed-loop feedback control. These days, I sometimes think of parenting teenagers as the challenge of working with complex lovable processes that are uncontrollable, unobservable, and unstable!

### Controller Functionalities

For the engineer, the challenge is how to design (synthesize) the controller so that good behavior is achieved. There have been *many* different approaches to controller design, ones that depend on process characteristics and performance objectives. Some approaches that have found utility in applications include:

- *Linear/nonlinear:* Linear controllers have a linear mapping between their inputs and outputs, and when the process is assumed to be linear also, there is a very well-developed theory. Everything else is a nonlinear controller and there are many approaches in the literature (e.g., feedback linearization). The controller in Section 1.6.3 is a nonlinear controller due to the saturation that it uses to limit the spending.

- *Static/dynamic controllers:* Static controllers include those that do not have dynamics. The controller in Section 1.6.3 is a static nonlinear controller. The PID strategy in Section 1.6.4 is a dynamic nonlinear controller, dynamic due to, for instance, the integrator it uses, and nonlinear due to the output saturation nonlinearity that was used.

- *Optimal control:* When optimization methods are used to construct a controller it is referred to as an optimal controller. For the linear case, the theory is well-developed.

- *Adaptive/learning;* When the controller can adapt (adjust itself based on experience), or more generally "learn," it is called an adaptive or learning controller. Adaptation/learning can be very useful in overcoming uncertainty effects, by creating a controller that learns how to control a process.

- *Planning:* If the controller predicts into the future, for instance, using a model of the process, in order to choose what input to inject, it is said to have the ability to plan. One example, is the "model predictive controller."

- *Stochastic:* When a controller takes into account uncertainty, such as noise, in the design process, or explicitly uses noise as part of its strategy, it is called a stochastic controller.

- *Discrete event/hybrid:* When the process is inherently discrete in time and space, and best-represented by an automaton, "discrete event system" controllers are used. If the equations representing the plant have both a discrete event and linear/nonlinear component that interact then we have a hybrid system that often demands the construction of a hybrid controller.

Many of the above functionalities have been profitably combined. For instance, there is optimal adaptive/learning control, adaptive model predictive control, etc.

**Properties and Analysis of Closed-Loop Feedback Systems**

There are a number of properties of interest in the study of feedback control systems, including:

- *Stability and boundedness:* First, and foremost, the objective is to stabilize the process if it is unstable, and not to destabilize it, if it started out as stable. For this, the most common approach is to use Lyapunov stability theory.

- *Response properties:* Quantification of performance of process output variables for a closed-loop system include rise-time, overshoot, settling time, and steady-state error between the output and desired output.

- *Disturbance rejection:* Can the random effects of disturbances discussed above be eliminated via feedback control? In many cases, they can and this is one key advantage of feedback control.

- *Robustness and sensitivity:* Robustness quantifies how process uncertainty (e.g., in inaccuracies in the model used for the process that was used to construct the controller, or in process parameter variations) affects stability and the performance metric. A closed-loop system is said to be robust if when such uncertainties are small, the system is not destabilized and the performance change is only small. Larger uncertainties may admit larger changes to performance. Robustness is an extremely valuable property as it then provides an assurance that even if you did not understand the process in its entirety, the closed-loop system will still behave with adequate performance. Many feedback control systems have excellent robustness properties.

There are three ways to evaluate the properties of a feedback control system:

- *Mathematical analysis:* Provided the process model is not too complex (e.g., with hard nonlinearities, high dimension, and stochastic behavior), mathematical analysis of most of the above properties is often tractable. Mathematical analysis has may advantages in studying feedback control systems, including an ability to cope with high dimensionality and an infinite number of process conditions. The most popular type of mathematical analysis for feedback control systems is stability analysis.

- *Computational analysis:* When the feedback control system complexity is too high, the model can be put in a digital computer (e.g., via Matlab/Simulink) and computer simulations can be used to study properties. Strictly speaking, however, it is not possible to study stability and boundedness in simulations as: (i) simulation time lengths must be bounded, and (ii) an infinite number of conditions (e.g., initial states) must be considered, which is impossible. Practically, however, you can stop your simulations after a long time. But, if the system is high-dimensional, the natural approach of considering many initial conditions (e.g., via a grid or random choices) will not work due to the "curse of dimensionality." While response properties are generally easy to study via a computational approach (e.g., as in Section 1.6.3), computational analysis of robustness shares the same problems with stability. Yet, in practical situations, Monte Carlo simulations (as in Section 1.6.3) can be quite useful. Moreover, while not reported here, if you consider periodic theft from a person's savings, or the possibility that the person does not exactly follow the spending advice, you can show via individual simulations, or a Monte Carlo simulation, that the PID strategy still performs well. In this sense we can, in a specific sense, say that it is robust.

- *Experiments for evaluation:* Another way to evaluate a feedback control system is to implement it and study its properties, such as response times. It is, however, typically difficult to fully evaluate stability and robustness in an implementation as it shares some of the features of the above computational analysis approach.

## 1.7   Conclusions

The broad conclusions for each section of this chapter are:

1. To understand poverty and underdevelopment you need a close-up view where you talk to people. World statistics use a number of ways to measure poverty and underdevelopment, and are used to show prevalence.

2. In the US, a significant poverty challenge is homelessness.

3. Air, water, and soil pollution, along with climate change, are significant and growing problems. The UN Sustainable Development Goals help set an agenda for socially-inclusive sustainable development.

4. The humanitarian engineer must have global competence, a key feature of which is an ability to work in cross-cultural settings where people have different values.

5. Each engineer decides for themselves what their role will be in humanitarian engineering, and this is typically connected to disciplinary considerations, and personal values and priorities.

6. In the analytical approaches, traditional feedback control design approaches can provide a financial advisor for low-income people and thereby help you understand what it is like to live in a very low income situation. A simple model of the tragedy of the commons illustrates basic principles of how development and population increases affect environmental sustainability.

## 1.8  Homework Problems

**How to Summarize and Critique:** For several problems in this and later chapters you will be asked to "summarize and critique" videos, papers, or parts of books (the "work"). To summarize a work:

1. State the basic overall message of the work,

2. State the key points of the work, typically in the order in which they appear, and

3. Summarize its main conclusions.

The summary shows that you understand the main points of the work, and this is the launching point to create a critique of the work in the following way:

1. State what you think is good and bad about the work in your opinion,

2. Overview the key claims and explain if you think they were properly substantiated (i.e., if the author was successful in arguing for the validity of the claims), and

3. For each claim, how important do you think it is (i.e., make a value judgement)?

4. Where possible, substantiate your judgments with references to the literature or other evidence.

**Problem 1.1 (Living on One Dollar):** View the (56:00) video, at Peña Blanca, Guatemala, Summer 2010, entitled

<div align="center">

Living on One Dollar

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(a) Summarize the main points of the video and critique it (see above for how to do that).

(b) What was your emotional reaction to the film?

(c) Name at least three issues you saw that technology may be able to help address.

**Problem 1.2 (Documentary on World Poverty):** For a country from the developing world, view one video you have *not* yet seen about: (i) living in poverty in Guatemala, Haiti, or other countries (e.g., Section 1.1.1); or (iii) videos from the UN or other sources (e.g., from Section 1.1.1). The video can be about any developing country in the world, multiple developing countries, or a contrast between countries in the developed and developing world; however, its primary focus must be on poverty and/or sustainability. If it is not one identified in the chapter, then you must get instructor approval.

(a) Summarize the main points of the video and critique it (see above for how to do that).

(b) What was your emotional reaction to the film?

(c) Define social mobility. Are there problems with people in the film with respect to lack of opportunities and restricted social mobility? Explain.

**Problem 1.3 (UN Public Data Explorer and World Bank Data Visualizer):** Using the

UN Public Data Explorer

and the

World Bank Data Visualizer

discussed in the chapter:

(a) Define the HDI formula. Provide data for HDI on two countries that you feel is important (e.g., if HDI is on the vertical axis, you choose what is on the horizontal axis). Your two countries should have quite different GDPs. Next, provide a plot of HDI on the vertical, your choice of variable on the horizontal, and many (if not all) countries. Provide a plot, or instead, consider providing a movie to illustrate key ideas.

(b) Define the Gini index, IHDI, and MPI. Compare what you find in (a) to the corresponding Gini, IHDI, and MPI data for the two countries you chose in (a). Next, provide a plot of IHDI on the vertical, your choice of variable on the horizontal, and many (if not all) countries. Provide a plot, or instead, consider providing a movie to illustrate key ideas.

(c) Define GDI and GII. Study the GDI and GII and choose your home country and a country from the developing world and compare (if your home country is a developing country, pick a country from the set of what are considered "developed" countries). Next, provide a plot of GII on the vertical, your choice of variable on the horizontal, and many (if not all) countries. Provide a plot, or instead, consider providing a movie to illustrate key ideas. What are the effects of living in a country with low GDI and GII?

**Problem 1.4 (The Gini Index for Measuring Inequality):** Consider the case where $N = 2$ in Equation (1.3), and where the $x_i \in [0, 10]$, $i = 1, 2$. Write down the simplified version of the formula for the Gini index in Equation (1.3) for this case. Use Matlab to plot a 3 dimensional plot of the Gini index versus the two variables $x_i \in [0, 10]$, $i = 1, 2$. Use the `surfc` command to create the surface. Explain the shape of the plot in terms of measuring inequality. Explain the contour lines in the contour plot in the $(x_1, x_2)$ plane. See Section 4.12.2 and Figure 4.19 for a plot like the one you are to produce, but for another inequality measure called the Atkinson index, the one used in the computations for the IHDI.

**Problem 1.5 (Social Progress Index (SPI)):** View the (14:56) TED talk by Michael Green

What the Social Progress Index Can Reveal About Your Country

that was filmed in Oct. 2014.

(a) Summarize the main points of the talk and critique it. See the note about how to summarize and critique at the start of Section 1.8.

(b) Do you think that the SPI is better than the HDI? IHDI? MPI? A measure that only uses GDP per capita? Explain your response in each case. To do the comparisons, use information from

Social Progress Imperative

Give specific reasons why you think one index is better than another to measure development.

**Problem 1.6 (The Social Progress Index (SPI) and the SDGs):** View the (14:39) TED talk by Michael Green

How we can make the world a better place by 2030

that was filmed in Sept. 2015.

(a) Summarize the main points of the talk and critique it. See the note about how to summarize and critique at the start of Section 1.8.

(b) Does he believe the SDGs can be achieved? He says we "Used up the easy wins." What does that mean? Can we get to global goals by just getting richer?

(c) Is GDP destiny? Why or why not? Can you get social progress without a high GDP?

(d) Do we already have solutions to problems that will lead us to meeting the SDGs?

(e) What will it take to get from the current SPI to a target SPI that will meet the SDGs? He mentions several approaches. What are they?

(f) What is the "People's Report Card" What is our current grade?

**Problem 1.7 (Comparing Poverty, Development, and Technology Data for Two Countries):**

(a) For two countries of your choice, one of which must be in the developing world (e.g., your native country and one you plan on traveling to) develop a relatively full set of data explaining the poverty and development for each (e.g., using UN data, for example, here, and World Bank data, here). Set a high goal of trying to list enough data to represent a wide range of indicators, monetary, inequality, and social (e.g., education and health). A key challenge of this problem is making the right choices. Do not choose too little information, so little that you do not get a good comparison. However, do not pick too much information as this may result in little additional understanding. If possible, identify important trends (positive or negative) in the data, and discuss implications. Compare and contrast the two countries in terms of the information you gathered.

(b) Using UN and World Bank information, repeat (a) for the two countries you chose, but for different aspects of science, technology, and engineering. For instance, at least consider electrification rate and mobile subscriptions.

**Problem 1.8 (World Bank Data, Additional Indicators):** For data *different* from what are different from what is requested to be studied in either Problem 1.3 or Problem 1.7, using World Bank data by topic, some of which is discussed in the chapter, consider the following:

(a) Explain some of the key conclusions you can make about the "key" aspects of their data for one indicator under three topics of your choice; say whether indicators are increasing, decreasing, or oscillating, and discuss the implications.

(b) Identify the trends in at least 3 indicators for any topic that give you the most reason for hope.

(c) Identify the trends in at least 3 indicators for any topic that are most troubling.

**Problem 1.9 (Documentary on Poverty in America):** View one video you have *not* seen (either The Line, invisiblePEOPLE, Poor America Panorama, A Year in Tent City, or Poor Kids, all with links given in Section 1.2.1) or one you find on the internet that the instructor approves of.

(a) Summarize the main points of the video and critique it. See the note about how to summarize and critique at the start of Section 1.8.

(b) What was your emotional reaction to the film?

(c) Define social mobility. Are there problems with people in the film with respect to lack of opportunities and restricted social mobility? Explain.

(d) Compare and contrast the film and your answers with a film on international poverty, such as one found in the chapter (e.g., Living on One Dollar), or what you perhaps studied in Problem 1.2. What do you see as the differences between the US case and the cases seen in the developing world?

**Problem 1.10 (Understanding Life in the US at the Poverty Line):** View the (4:05) video

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Living in Poverty USA

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Summarize the main points of the video and discuss the implications in terms of the discussion on US poverty rates in the chapter. Critique the video. See the note about how to summarize and critique at the start of Section 1.8.

**Problem 1.11 (Suburban Poverty in America):** View the (1:45) video

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Confronting Suburban Poverty in America

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that was published May 22, 2013. Summarize the main points of the video and discuss the implications. If you are interested in learning more on this subject, consider (Kneebone and Garr, 2010; Kneebone and Berube, 2013).

**Problem 1.12 (Hunger in America):** View the (50:36) video at PBS, Moyers and Company,

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Encore: The Faces of America's Hungry

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that was published Aug. 1, 2013. Summarize the main points. The video is an interview focused on the movie "A Place at the Table" (available on the internet).

**Problem 1.13 (Alternative Measures of Poverty Rates in America):**
Read the US Census Bureau report

The Research Supplemental Poverty Measure

and the article (Meyer and Sullivan, 2012).

(a) Summarize the main points in both and critique them. See the note about
how to summarize and critique at the start of Section 1.8.

(b) Do you think that there should be another measure used for poverty in
the US? What one? Why?

**Problem 1.14 (Comparing Global Income Inequality):** Read (Milanovic,
2012), summarize the main points of the paper, and critique the results. See
the note about how to summarize and critique at the start of Section 1.8.

**Problem 1.15 (Comparing the US to the OECD Countries):** Read
(Gould and Wething, 2012) and also read about the Economist data (Worstall,
2013). Compare and contrast the results.

**Problem 1.16 (Comparative Social Mobility):** Read (Causa and Johansson, 2010) and compare and contrast the social mobility of persons in the US
to other OECD countries in terms of earnings and education.

**Problem 1.17 (Pollution Facts):** Read the 51 pollution facts identified here.
List 5 of these facts that you feel identify the worst impacts on humans.

**Problem 1.18 (Impacts of Climate Change):** List the main impacts of
climate change on the 10 "sectors" at the EPA web site. Which impact worries
you the most?

**Problem 1.19 (Al Gore on the Climate Crisis):**

(a) View the (27:48) TED talk by Al Gore,

New Thinking on the Climate Crisis

which was filmed in March 2008. He discusses climate change, issues in
developed and developing countries, and the political dimension. Summarize his main points and critique the talks, separately. See the note about
how to summarize and critique at the start of Section 1.8.

(b) View the (25:20) TED talk by Al Gore,

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The Case for Optimism on Climate Change

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that was filmed in Feb. 2016. Summarize his main points and critique the talks, separately. See the note about how to summarize and critique at the start of Section 1.8. Identify five reasons for concern, and five reasons for optimism about climate change.

**Problem 1.20 (Personal Ecological Footprint):** Compute your personal ecological footprint using The Footprint Calculator by the Global Footprint Network. Give the results of your test: (i) the value of the number of planets needed if everyone had your lifestyle, and (ii) the number of global acres of the Earth's productive area needed to support your lifestyle. Ask a friend what values they get and compare. Is it sustainable to have everyone in the world have a lifestyle like you?

**Problem 1.21 (Carbon Footprint):** Using

<div align="center">

Global Footprint Network, Carbon Footprint

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(a) Define "carbon footprint."

(b) What percentage of humanity's overall ecological footprint is the carbon footprint?

**Problem 1.22 (Sachs: Introduction to Sustainable Development):** View the first part of the course "The Age of Sustainable Development" (Sachs, 2014) called "What is Sustainable Development." It has multiple subparts. It is at Coursera, is free to join and watch, and the link is at (Sachs, 2014).

(a) Define sustainable development and the key interconnected components of sustainable development.

(b) What is "BAU" and what are the paths to sustainable development?

**Problem 1.23 (Sachs: Sustainable Development Goals (SDGs)):** View the *last* part of the course "The Age of Sustainable Development" (Sachs, 2014) called "The SDGs." It has multiple subparts. It is at Coursera, is free to join and watch, and the link is at (Sachs, 2014).

(a) For the SDGs and "Rio+20," summarize his main points.

(b) What does he mean by "goal based development." Why should we have goal-based development? Which MDGs were best met, and which were not met? What is backcasting? What is road mapping?

(c) Per his discussion on "the feasibility of sustainable development," explain why Sachs says we should be optimistic about meeting sustainable development goals. Do you agree with him?

**Problem 1.24 (The Cross-Cultural Engineer and Global Competence):** Read Section 1.4.

(a) What features of culture do you think are most important for a humanitarian engineering who is planning on working with another culture to understand?

(b) Why is cross-cultural understanding important?

(c) What is "global competence"?

(d) What are good ideas for small-talk cross-cultural conversation? Religion? Money? Sex?

(e) A connection between the rate of technological advance and "cultural lag" is discussed on p. 273, (Volti, 2006), and in Section 3.1. Explain this idea. How will this affect your ability to work with people to introduce a new technology in a community?

**Problem 1.25 (Cultural Differences: Analysis of Two Countries Via World Values Survey Data):** For this problem you will study the World Values Survey and this problem is based on information from their

<p align="center">WVS survey data analysis tool</p>

and (Inglehart, 2008). Pick a country different from your native country and on other country, such as a country in which you plan on doing a project that is in the developing world. If your native country is where you plan on working and you are going to work with an immigrant group, then choose their country of origin (e.g., if you live in Columbus, Ohio, US, then you may want to pick your other country as Somalia, México, or El Salvador). Then, study your native country, and the other one you chose, on two levels:

(a) *Broad interpretation of data:* What conclusions can you reach about the relationships between your native country and the country you chose per the global cultural map? Via the "understanding democracy" map in the (Inglehart, 2008)?

(b) *Country-specific interpretations of data:* Use the on-line data analysis tool, pick two survey questions and two categories (e.g., country, age, or religion) that most interest you and generate four plots that you put in your solution and explain.

**Problem 1.26 (Documentary: The Humanitarian Engineer):** View the (1:07:40) documentary

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The Humanitarian Engineer

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that was written, produced, and directed by Sheena Ong. The overall goal of this video is to answer the question: "What does it mean to be a humanitarian engineer?" Summarize the main points and critique the film as you watch it.

(a) How does she define "humanitarian"?

(b) Explain the difference between humanitarian relief and long-term community development.

(c) Name what she considers the different forms of humanitarian engineering. She says that the commonality among these is "addressing disadvantage? in some way. Do you agree or disagree? Explain.

(d) Explain the differences between "engineering for humanity" and humanitarian engineering.

(e) What is "definition 2? of a humanitarian engineer?

(f) Does this film motivate you to be a humanitarian engineer? Why, or why not?

**Problem 1.27 (Humanitarian Engineering: Focus, Degree, Motivations, and Role?):**

(a) What development challenge interests you the most? What technologies are you most interested in to help meet that challenge? Where would you want to work? Base your answer on Section 1.5.2.

(b) Explain what a "degree" of humanitarian engineering means. What degree of humanitarian engineering does your envisioned work address? Base your answer on Section 1.5.4.

(c) Identify at least one reason why you are interested in being a humanitarian engineer based on the discussion in Section 1.5.5. Explain and justify your choice.

(d) Explain what role you envision for yourself (in the future) as a humanitarian engineer in terms of "level," working directly with people or at a high level such as in policy, in terms of the spectrum from charity to profit, and on the spectrum from theory to practice. Base your answer on Section 1.5.6, Section 1.5.7, and Section 1.5.8.

**Problem 1.28 (Is K-12 STEM Education Humanitarian Engineering?):**
Identify cases where you feel that K-12 "science, technology, engineering, and mathematics" (STEM) education is, and is not, humanitarian engineering. Consider both teaching and development of low-cost scientific/engineering equipment for projects for education. Use the concept of "degree of humanitarian engineering" in Section 1.5.4, and Section 4.8, to justify your explanation. Provide a case that you consider to be "in the middle of" the two extremes. Consider in your discussion both the types of students (e.g., socioeconomic background) and location (e.g., in the developed or developing world). Also, consider that HDI is based on indicators for health, education, and income; hence, education is considered by many to be a basic driver of human development.

**Problem 1.29 (Setting Priorities in Terms of Needs and Values for One Country):** Using UN or World Bank data (for poverty, development, and science and technology issues), the issues and technology solutions highlighted in Section 1.5.2, along with the data available at the World Values Survey (to determine what people value) and Section 1.5.3:

(a) Make a list of 1-5 of technologies most likely to meet the top 5 needs for the worst off in a country of your choice. If possible, prioritize the list *with a justification* for your ordering in terms of the data using the UN, World Bank, and WVS data. For this, to give you an idea of how to proceed, you should first use UN and World Bank information to try to identify what *appear* to be the greatest needs in the country. Next, use the WVS and Section 1.5.3 to try to determine what are the common values of the people in the country with respect to addressing the issues (needs) in the country. This may focus you on certain needs. Then, consider the science and technology data, and your own ideas for humanitarian technology (e.g., perhaps using Section 1.5.2), to make a guess at what technology solutions may be *useful and valued*.

(b) Contact a person from the country you chose (of course this could be a person from class), give them your list of their country's top 5 needs, but not in order, and ask them to order the list according to what they think is most important to help their country. Ask them if they want to add any items. Compare your list to theirs. Turn in their list and discuss similarities and differences between the lists.

**Problem 1.30 (Long-Term Technology Development Strategy):** Read Section 1.5.4. Traditionally, the overall strategy has been for engineers to focus on technology development for the *developed world*. If this strategy continues for a long time, what is the long-term impact in terms of "technology inequality" in the world? How would this contrast with a focus on low-IHDI countries?

**Problem 1.31 (Learning Matlab/Simulink):** For each of the four programs in Section 1.6.2, for one case in each program (i.e., one part where there are multiple examples in each program), adjust the input or processing and study the output (via the "scope"). Save the figure on the scope in each of the four cases to a file (.ps file or via a screenshot), embed it into an electronic document, and explain what changes you made, and why the output changed the way it did relative to the original unchanged program.

**Problem 1.32 (Life-Long Budget for You: Best and Worst Cases):** This problem is based on Section 1.6.2.

(a) Adjust the signals and parameters of `WealthCalculator.slx` so that it most accurately represents what you *optimistically* think will happen in your life (you do not have to change the fact that there is no spouse or more children, or no children, but can if you want). You can add inflation if you want. Run the simulation and provide a plot of the output "wealth plot," that is, wealth vs. year for 100 years (click on "scope" and save figure in file format that you can use in a word processor) and explain the results.

(b) Adjust the signals and parameters to represent a "worst case" for a life-long budget (e.g., assume your income is much lower than you think it should be, your living expenses are the same for you and your child, your healthcare expenses go up significantly, or are unpredictable). Determine how low your income expectations can go, or how high your healthcare costs can go, until you cannot pay for your child's college education without taking out too large of a loan–you define what "too large" is). You can determine if you need a loan simply by studying the wealth plot and seeing if it goes negative; if you want, you could add in to the model the processing of getting a loan and paying it back. Run the simulation and provide a plot of the output wealth plot. Explain.

For both (a) and (b), turn in as an attachment your Simulink diagram `.slx` file.

**Problem 1.33 (Computational Analysis of the Suffering/Risk Tradeoff for Low-Income People):** Based on Section 1.6.3, and

$$\text{DynamicalPovertyModel.slx}$$

study the following cases, and include plots from the simulations to explain and justify your answers:

(a) Simulate the system for $E = 0.9$. Explain the wealth and expense plots, along with the counts of the number of times wealth is over \$100 and expenses are below \$0.5. What are the implications for suffering and risk?

(b) Simulate the system for $E = 1.1$. Explain the wealth and expense plots, along with the counts of the number of times wealth is over \$100 and expenses are below \$0.5. What are the implications for suffering and risk?

(c) Give the individual a "raise" by adding 1 to the output of the random income generator (use the "raise" block for this). Choose a reasonable strategy by specifying a value for $E$ and use data from simulations in plots to explain the resulting behavior and performance metrics. What are the implications for suffering and risk?

**Problem 1.34 (PID Spending Strategy or Low-Income People):** Using Section 1.6.4 and

DynamicalPovertyModelPID.slx

(a) Give the person a raise of \$1 per day (constant) and study the effects on wealth, error, and spending. Repeat for \$2 and \$3. Explain the three resulting plots.

(b) Replace the desired wealth profile (signal) with a profile of your choice; however, represent that the person needs to have wealth increase to avoid risk, and be sympathetic and do not increase the desired wealth too fast as this causes reductions in spending that can correspond to suffering.

(c) Suppose that the PID spending strategy is implemented via a cell or smart phone and the person inputs income each day and gets a recommendation on what to spend each day at the output of the PID block. Suppose, however, that she or he often does not listen to the recommendation and spends a bit more (e.g., randomly between 0 and 20 cents more than suggested at he output of the PID block). Add this feature to the Simulink model and investigate via simulations its effect on wealth and spending by varying the size of the deviation off the recommended spending. Explain how the PID strategy overcomes the fact that recommendations are not be followed. Provide plots to support your answers.

**Problem 1.35 (Sustainability: Dynamics of the Tragedy of the Commons):** Using Section 1.6.7, and the Matlab program TOC.m:

(a) Provide a plot of $R(k)$ vs. $k$ for the parameter values provided in the program (i.e., without adjusting anything). Increase the value of the rate of renewal, $r$, in the program and explain the effect on the resources, i.e., give a plot of $R(k)$ vs. $k$ for this case. Compare to the two plots. Explain what happened.

(b) Return the value of $r$ to the value originally set in the program. Increase the value of the carrying capacity, $K$, in the program and explain the effect on the resources, i.e., give a plot of $R(k)$ vs. $k$ for this case. Compare the plot to the two found in (a). Explain what happened.

(c) Provide plots of $R(k)$ vs. $k$ for: (i) The cases of low and high utilization parameters used in the program ("`Ul`" and "`Uh`" parameters)–this will be one plot with both the low and high utilization cases shown as plots in the figure; and (ii) Adjust the low utilization parameter `Ul` down, and the high utilization parameter `Uh` up, and provide plots of $R(k)$ vs. $k$ for each case (this will be one figure, with two plots, one for the low utilization case and one for the high utilization case). Compare the four plots (two figures) from (i) and (ii). Explain what happened in the context of the dynamics of the tragedy of the commons. For your chosen `Ul` and `Uh` values in (ii), was there a tragedy?

## 1.9 Annotated Bibliography

**Poverty:** Help with poverty definitions and measures was obtained from (Lister, 2004). For studies on the end of world poverty see, for instance, (Economist, 2013; Chandy et al., 2013). For a moralistic view of the problem of world poverty see (Pogge, 2005). An alternative view on poverty in the US is given in (Meyer and Sullivan, 2012). Poverty in the US is discussed in (Abramsky, 2013; Cancian and Danziger, 2009; Edelman, 2013). Global income inequality is studied in (Milanovic, 2012). The sources used for modeling poverty for the personal spending advisor were (Collins et al., 2009; Banerjee and Duflo, 2012) (e.g., the ideas on the random nature of income streams and suffering to save and cope with risk). Information on people who are homeless in the US is in (NAEH, 2013). Extreme poverty in the US is discussed in (Edin and Shaefer, 2015). To learn about the rise of suburban poverty in the US, see (Kneebone and Garr, 2010; Kneebone and Berube, 2013). A comparison of low-income people in the US to other countries is given in (Worstall, 2013). Comparisons between the US and its peers on inequality are given in (Gould and Wething, 2012). A study of intergenerational social mobility in OECD countries is given in (Causa and Johansson, 2010).

**Environment and Sustainable Development:** The report (MEA, 2005) can be obtained at the

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UN Millennium Ecosystem Assessment program

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and other reports from this program (e.g., more on adverse impacts on health, biodiversity, and water) are here. Other sources used for the section on the environment include

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US Environmental Protection Agency (EPA)

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and

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Conserve-Energy-Future

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and (Sachs, 2014). The sustainable development ideas were partly based on (Sachs, 2014). The bibliographic reference (Sachs, 2014) includes the standard bibliographic information, a link to the on-line book, a link to how to download the book, and a link to Sachs' online course on sustainable development. Other books on sustainable development include (Blewitt, 2015; Elliott, 2013), and sustainable engineering is covered in (Allenby, 2012). The planetary boundaries section was based on (Rockstrom and et al., 2009; Sachs, 2014). The paper (Rockstrom and et al., 2009) was revised and updated in (Steffen et al., 2015). The section on ecological footprints is based on the

<div align="center">Global Footprint Network</div>

Earlier work on the development of the SDGs is in (OWG, 2014), and the Sustainable Development Solutions Network, in

<div align="center">Sustainable Development Solutions Network (goals and targets)</div>

and (Sachs, 2014). The UN Sustainable Development Goals are listed at

<div align="center">Sustainable Development Goals</div>

The case for more emphasis on sustainability and environment is given in (Friedman, 2008). Technology, energy, and the environment are discussed in Chapter 6 of (Volti, 2006).

**Culture:** Part of the section on culture was based on (Haviland et al., 2008). A treatment of cultural issues in international business is in (Morrison and Conaway, 2006), and for cross-culture management in (Dumetz and et al., 2012). See also (Moran et al., 2006). A synthesized view of culture and language is given in (Agar, 1994). Class and race issues for children are treated in (Lareau, 2011). Cross-class issues are discussed in (Lubrano, 2005). The section on the World Values Survey was based on information on their web site and (Inglehart, 2008). A connection between rate of technological advance and "cultural lag" is discussed on p. 273, (Volti, 2006), and in Section 3.1.

**Modeling and Analysis of Poverty and Sustainability:** There has been some extensions to the financial advisors studied in the chapter. In particular, using a stochastic nonlinear model with three states, cash-in-hand, capital, and debt, it has been shown that (i) PID and "model predictive control" (MPC) outperform the standard "dynamic programming" (DP) approach used in economics and finance, and (ii) enjoy the advantage of low complexity compared to DP (Gonzalez Villasanti and Passino, 2017). The model of the tragedy of the commons is based on (Roopnarine, 2013) and other related models and analysis are in (Hardin and Baden, 1977), along with experiments.

# Chapter 2

# Social Justice

## Chapter Contents

*Treat others as you would like them to treat you. / Do not treat others in ways you would not want to be treated.*

<div align="right">

*The Golden / Silver Rules*

</div>

*Human rights are not only violated by terrorism, repression, or assassination, but also by unfair economic structures that create huge inequalities.*

<div align="right">

*Pope Francis*

</div>

*Gender equality is more than a goal in itself. It is a precondition for meeting the challenge of reducing poverty, promoting sustainable development, and building*

*good governance.*

<div align="right">

*Kofi Annan*

</div>

*You must be the change you wish to see in the world.*

<div align="right">

*Mahatma Ghandi*

</div>

*I look to a day when people will not be judged by the color of their skin, but by the content of their character.*

<div align="right">

*Martin Luther King, Jr.*

</div>

*The theory of communism may be summed up in one sentence: Abolish all private property.*

<div align="right">

*Karl Marx*

</div>

*But if you're asking my opinion, I would argue that a social justice approach should be central to medicine and utilized to be central to public health. This could be very simple: the well should take care of the sick.*

<div align="right">

*Paul Farmer*

</div>

*The essence of sustainable development in practice is scientifically and morally based problem solving.*

<div align="right">

*Jeffrey Sachs in (Sachs, 2014)*

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What is social justice? Why can it be thought of as a goal? What are human rights? Who defines them? Whose duty is it to make sure they are satisfied? Why is discrimination wrong? What do social or economic inequalities demand of us? What is technological capacity? Is it a basic human right? Engineers are rich in technological capacity; does this mean that they have an obligation to share it?

What are some of the world's religions' views on social justice? Buddhist, Catholic, Confucian, Hindu, Islam, and Jewish? What are some prominent secular perspectives on social justice? John Rawls and Amartya Sen? What are the different goals set by these religious and secular perspectives on social justice? What is the relation between engineering ethics and social justice?

Almost all these perspectives have a common goal that special attention is deserved by the lowest-income and least developed; however, what are the

differences between the perspectives on this?

Using analytical approaches, can we learn about the dynamics of distributive justice in a community? If there is a democracy in the community with voting on the generosity of person-to-person donations, will it result in a significant level of community-wide generosity? What are the benefits of such generosity? Are there disadvantages of generosity? What is a fair environmental justice policy? What is the impact of population on the effectiveness of the policy in achieving its goals?

This chapter, which has the theme of "goals," will answer all these questions.

## 2.1 Social Justice and Engineering

"Social" can be defined as "of or relating to society or its organization" and "justice" can be defined as "just behavior or treatment: a concern for justice, peace, and genuine respect for people" or "the quality of being fair and reasonable" (New Oxford American Dictionary). "Social justice" can be defined as: "standards for, and a view on how to promote, human dignity, rights, fulfillment for all of humanity" (my own definition, provided for pedagogical reasons). Note, however, that defining social justice in a concise, inclusive, and general manner so that it is acceptable to all people is *impossible* (others would insist on including words like fairness, freedom, human capability, human development, human welfare, etc.) and some religions may feel that the term "social justice" is a distortion of what they are talking about in discussing what others consider to be the central issues in social justice (e.g., God(s), spirituality, and love). There is simply too great of a diversity of well-thought-out and opposing opinions on the subject to have a broadly-agreed-upon definition.

Social justice has been a ubiquitous and crucial issue throughout the history of humankind, and seems to be of ever-increasing importance due to globalization. Taking ideas from social justice into practice via business, institutions, economic systems, or political systems has, on the one hand, resulted in widespread malnourishment, many human rights abuses, wars, state-sponsored murder of tens of millions, and genocide, but on the other hand in some cases has promoted human rights, alleviated much suffering, and promoted peace. Social justice is typically an important part of a religion, and the fields of business, social work, economics, and political science (to name a few); also, it serves as the basis for parts of many political systems (e.g., via their "party platform") and governments, along with the United Nations via their "Universal Declaration of Human Rights" and efforts in peace-keeping, development, etc. Social justice matters, and this book is about how it matters to engineering, and in particular to the creation of technology for promoting social justice, and fighting injustices.

Having a single author present multiple social justice perspectives, especially those of religions, is fraught with peril since misrepresentations and biases can easily occur. This is why neither a comparative analysis, unification, or critique of the social justice perspectives is attempted, even though this could be useful

in making "definitive" statements on the impact of social justice on engineering (e.g., constraints on the engineering design process). Besides, there are fundamental problems with comparing, for instance religious social doctrine and secular perspectives on social justice: for instance, in doctrine the ultimate goal may not be social justice, but God. I leave comparative analysis, unification, or critique to the reader, in some cases via homework problems.

After a brief introduction to some key social justice ideas, the synergies between social justice and engineering are identified, and issues of bias and coverage are discussed in detail.

### 2.1.1  Human Rights: A Close Up View

This section introduces some of the ideas of social justice by trying to provide a close up view of actions to promote social justice.

**Human Rights: History and Overview**

View the YouTube (9:30) video

<div align="center">The Story of Human Rights</div>

which was uploaded May, 2011. What are the key human rights issues today? Is the world slowly making progress on achieving human rights for all? Can we expect a major set back in the future, like the world wars were in the past?

Human rights are often considered to be foundational to the area of social justice, though there can be disagreements on what should be on the list of human rights. One list of rights is the United Nations Universal Declaration of Human Rights (UDHR),

<div align="center">UN Universal Declaration of Human Rights (UDHR)</div>

Consider the following questions for the UDHR:

*Persons gain passion about the promotion of social justice when they personally experience or see the gross violation of human rights.*

1. *Priority of rights?:* Which are the most important of the human rights (e.g., what are the top five human rights)? Would everyone agree with you on your choice?

2. *Rights and duties?:* With every right, there is a duty (often not identified in a list of human rights such as the UN Universal Declaration on Human Rights). For at least three of the human rights mentioned in the UDHR, can you identify whose duty it is to make sure those person's rights are met?

3. *Levels of human rights?:* Human rights are often thought of as being met to a certain level, with higher levels corresponding to more fully meeting that right. Suppose that there are only five human rights. To have justice, must all five human rights be met to the same level for all persons on the planet? Is justice achieved if one right that you consider to be unimportant is not met, but all four others are fully met? Who judges what is a proper level of achievement of another's rights?

**Dr. Martin Luther King, Jr., I Have a Dream Speech**

Dr. King obtained his Ph.D. at Boston University, won the Nobel Peace Prize in 1964, and fought for civil rights using a non-violent civil disobedience approach based on his Christian beliefs. View the (17:28) YouTube video of his speech

<div align="center">I Have a Dream</div>

that was delivered on Aug. 28, 1963 in Washington DC; then: (i) Make a list his main points and the issues he identifies, and (ii) Think about whether anything he was concerned about in 1963 has changed in more than 50 years since his speech.

   For this video, which is primarily about discrimination in one form, racism, reconsider other issues:

1. Mistreatment and oppression of girls and women world-wide (Kristoff and WuDunn, 2010).

2. Discrimination against indigenous peoples of the world.

3. Extreme poverty, the many people in the world living on less than \$1 per day PPP.

At the heart of Dr. King's speech, and these three issues, is the issue of inequality, either people treating other people as if they are not equal to them, or inequality simply in terms of income or some other determinate of human development (e.g., healthcare or education). Much of the debate in social justice centers around inequality and what to do about it, if anything at all. What do inequalities mean for engineering?

*The world-wide high frequency of mistreatment and oppression of girls and women is a massive violation of human rights.*

## 2.1.2   The Synergy Between Social Justice and Engineering

Social justice can be viewed as a goal of humanitarian engineering, or by some as *the* goal. It is, however, more than that. It is also about human rights, and fair systems, structures, rules, and governance. You should be angry about the information about at least some of the poverty and inequality that you read about or saw in videos in Chapter 1. That anger, or at least deep concern or compassion, should instill in you a desire to speak out about it, e.g., via a protest, signing a petition, writing a letter to a politician, or to participate in some other "activism." Discrimination is wrong, and sometimes a deep evil injustice; you should want to do something about it, even if it does not directly and immediately affect you. Similarly, there is something deeply disturbing about extreme poverty and the immense suffering it leads to for so many people. Again, you should want to do something to fix it. Humanitarian engineering is about using engineering skills to do something about it.

**Inequality of Technological Capacity**

"Capacity" is "the ability or power to do, experience, or understand something" (The New Oxford American Dictionary). Hence, interpreting "do" as "make," "technological capacity" can be defined as

"the ability or power to create, modify, apply, experience (use), or understand technology."

The foundations for building technological capacity are (i) education about technology and its advancement (engineering), and (ii) ownership/use of technology (so you can experience it).

Educated engineers have technological capacity, and the more advanced your degree in engineering, or the more engineering experience you have via, for instance, a job, the more technological capacity you typically have. Owning or using technology also significantly enhances a person's technological capacity as they learn about the technology, use it to solve problems, understand its deficiencies, and may come up with ideas to improve the technology. There is a "positive feedback loop" since, if you have some technological capacity, you can make or get technologies, and owning and using these technologies can result in you improving these technologies (or others) that you can own, and so on. Of course, many other factors influence the ability to exploit your own technological capacity such as income level, availability of information, availability of local materials, other persons' expertise (for team-based technology building as is often done), business skills, etc. Developed technological countries are in a virtuous positive feedback loop of technological capacity and it often greatly contributes to the well-being of their citizenship.

Without a formal education, special individuals (e.g., "tinkerers") may have some level of inherent/native technological capacity, but typically experience without education does not provide an advanced level of technological capacity, especially if information for self-teaching is limited or not available (e.g., the internet or books). Lacking the underlying mathematics and science creates barriers to understanding and developing many technologies. Moreover, without an education, you may not earn enough to purchase a technology, and thereby gain its benefits or the insights on how to improve it (you do not experience it so you do not understand it). I call this the "technological capacity trap," in analogy to our discussions in Chapter 3 on "poverty traps." Below a certain level of education and technology ownership, it is difficult or impossible to improve your technological capacity to reach the point where the positive feedback loop starts, where having some technological capacity leads to you gaining more technological capacity.

> There are vast technological capacity inequalities in the world, and millions are in a "technological capacity trap."

**Social Justice's Mandate to Engineers: Reduce Inequality of Technological Capacity**

In terms of engineering, note that Dr. Paul Farmer, medical doctor, professor at Harvard University, humanitarian (e.g., working in Haiti) (Kidder, 2009), and

author of a  number of books, was quoted at the start of this chapter. I would propose a restatement of Farmer's quote for engineers:

> I would argue that a social justice approach should be central to engineering and utilized to be central to a country's technological development. This could be very simple: the engineers should help those without technological capacity to build it.

The analogy between medicine/medical care (technology/engineering) is apt. Why? Is technology a basic human right? I would argue that yes, it definitely is: technologies, in many cases, enable individuals to achieve rights themselves (e.g., the technologies of clothing and shoes help maintain health), or "capabilities" as Amartya Sen would put it (Section 2.3.2); alternatively, some people have a duty to help others achieve their rights that are often enabled by technology. In this sense, technology is clearly a basic human right that engineers are uniquely positioned to provide in order to reduce the technology capacity inequalities between people in the world. Engineers are typically "rich" in terms of technological capacity and in some people's view this creates an obligation to help others improve their technological capacity. Other people would not feel that it is an obligation, but that engineers should only be encouraged to help others build their technological capacity.

Engineering is however, sometimes called an "invisible profession:" many do not understand that engineers use mathematics and science to create, modify, or apply technologies or technological processes; simply put, most people do not understand what engineers do. It is difficult to imagine a million-person protest in Washington D.C. about individuals' technology capacity inequalities (i.e., the haves and have-nots), protesters with signs saying "Engineers, when are you going to help us?" or "Engineers, we are hungry for technology," or someone as eloquent as Dr. King speaking about inequality of technological capacity as the moral issue of our day. Or, is it?

### Why Social Justice in Engineering for Sustainable Development?

Social justice is a goal, constraint, and integral component of the process of sustainable development. Though unusual for an engineering book, there are a number of reasons to embed a treatment of religious and secular perspectives on social justice into humanitarian engineering.   These include:

1. *Social justice provides motivation and rationale for religious, secular, and professional engineers:* Engineers are motivated to work on humanitarian projects for a variety of reasons including compassion, sympathy, "wanting to do something to change the world for the better," opportunities to learn (e.g., about international engineering), and business opportunities to make profits (see Section 1.5.5). Another significant motivator for some is their religion that may call them to, for instance, help low-income people; this is one reason why religious perspectives on social justice are covered. Yet, there are many people in the world that do not need God or religion

to do good works. Similar rationale and motivation for non-religious (secular) engineers can be found in secular perspectives on social justice. For instance, the largely secular topic of engineering ethics will be covered. It will be explained how engineering ethics addresses some social justice issues, but ignores others. Engineers motivated to behave as professionals pay significant attention to competence, conduct, and service, and thereby attend to social justice issues.

2. *Social justice defines engineering challenges and goals in full complexity:* Social justice not only highlights what goals to focus on (e.g., human dignity, human rights, human welfare, and human well-being), but also the myriad influences on these. It helps specify the full "context" for an issue to be addressed. Humans are highly interconnected within a village, community, country, and world via, for instance, relationships, work, economics, (international) trade, politics, and war. Each of these deeply influences individual human welfare. Social justice explains these interconnections, discusses how they affect humans, and provides strategies to promote justice (e.g., via democracy) using the interconnections. Hence, social justice defines a very broad and ultimate goal for engineering, the goal of promoting global justice and human fulfillment.

3. *Social justice for scrutinizing the development and design processes:* Social justice provides a way for an engineer to scrutinize a specific approach to promoting justice. For instance, in this book there are a range of "development strategies" considered in Chapter 3. Does each of these adhere to principles of social justice? For example, is there anything wrong with direct aid (charity)? Is there anything wrong with the "profiting off the poor" approach? Next, social justice demands that we take an appropriately broad view of the traditional engineering design process and constraints to ensure that they are just. For instance, ensuring engineers are getting community inputs and involvement in the design process ("participatory development" and "participatory design" as in Chapter 4), environmental concerns, and cultural influences. All these are considered in traditional engineering, but often individual engineers are not involved in all these pieces of the process (e.g., consumer needs/desires and solution quality assessments may be done by non-engineers).

4. *Social justice is an important lesson in cultural differences:* In this book, several religious perspectives on social justice are covered. A number of differences will arise in these perspectives, indeed, the whole approach to formulating the perspectives is quite different. Religion (or the lack of it) is an important part of culture; hence, learning a diversity of perspectives on social justice (broadly, what people think of as a "fair system") provides an important lesson in cultural differences. For instance, if you are working in a predominately Muslim country, you must know at least something about Islam. If you work in Latin America you must know something about Christianity/Catholicism.

5. *Social justice for scrutinizing approaches in the engineering enterprise:* "Engineering enterprise" is basically anywhere an engineer works (entrepreneur, industry, government, etc.). Social justice teaches the practicing engineer how to set goals for, and go about, engineering in order to promote justice. Social justice can help answer the following questions: Which issues should be focused on when performing engineering for the low-income, weak, and developing communities? When is it acceptable to profit off humanitarian work in "social business" (see Section 3.5)? When is it acceptable to develop technologies and sell them to low-income people for profit? How should we do business with low-income people? How should we go about performing "technology transfer" to other countries, and establishing manufacturing sites in the developing world (to avoid the creation of "sweatshops")? What is the best approach to set up a fair technology supply chain? Is it *always* acceptable for an engineer to be involved in weapons development? See Problem 4.56. What if it is weaponry for humanitarian intervention? See Problem 4.57.

6. *Engineers, technology, and helping humanity:* Engineers often view themselves as "serving the public," and indeed all of humanity (Martin and Schinzinger, 2005). Engineers often feel that the technologies that they create can solve all the world's problems (unreasonably so, in my opinion, and occasionally to the point of technological arrogance). We view ourselves as people of action, problem-solvers, and "creators" (inventors) of technology, who can change the world as we find it. Social justice demands that we take our claims seriously, and make changes in the proper direction. In engineering ethics, a required subject in US engineering universities, it is taught that engineers should "hold paramount the safety, health, and welfare of the public" (National Society of Professional Engineers Code of Ethics) (Martin and Schinzinger, 2005). Social justice demands that we live up to this statement, and perhaps demands that we strengthen that statement per the discussion in Section 2.3.3.

### 2.1.3 Bias, Coverage, Controversy, Civility, and Tolerance

In an effort to be sensitive, a number of issues must be discussed in connection to the treatment of social justice here.

**Potential Sources of Bias**

It is hoped that the reader recognizes that it is very difficult to create a balanced, complete, and unbiased treatment of the topic of social justice. Every author has biases arising from a myriad of issues, even the order you learn about the perspectives. Here, there may be concern about at least the following potential sources for bias: only the English-language literature is considered; connected to this, and in spite of consideration of major global religions, and the fact that Amartya Sen is an Indian, I am sure there is a Western/US bias in the

It is impossible to present a view of social justice that is simultaneously comprehensive, uncontroversial, and unbiased.

treatment; there is likely racial bias embedded (e.g., I am white); and I am male, and it is/was probably more men than women who contributed to the development of the theory here considering the dominance of male roles in the religions considered and the fact that Rawls and Sen were/are men (this is not to say that the clear and major roles women have had in social justice are not recognized; my concern is only that the theory could possibly be male-biased). Some would argue that having a bias is indeed one of the mandates of social justice and this creates a problem for me in expressing my own views about some of the perspectives that are covered. While I personally have grave concerns about several aspects of several systems of social justice, I decided not to explicitly include my own opinions; however, I assign homework problems in Section 2.6 where the reader is invited to judge various cases.

Regardless, in spite of potential biases, I feel compelled to include social justice as it is foundational to (humanitarian) engineering. I leave it to a woman (engineer) or women to provide the feminist perspective, and members of other races or religions or others to provide their perspectives. I do, however, seek as global and inclusive a treatment as possible; hence, I would invite your inputs via the email address provided in the Preface to help me improve the coverage.

**Coverage and Scope**

For pedagogical reasons, the religious and secular perspectives are presented as unified and distinct, ignoring how controversial they are between members of the religions or apparent adherents to secular views, and how the various views have been influenced by each other over history (e.g., the impact of social conditions and the success or failure of political systems on the religious perspectives, or the possible influence of the individuals' religious backgrounds that developed the secular perspectives).

The six religious perspectives chosen for coverage were the Buddhist, Catholic, Confucian, Hindu, Islamic, and Jewish views, even though in some ways some of these are related. The Confucian perspective is included among these perspectives though most would not consider it a religion (even though some in the past have wanted to make it a religion); I used the word "religion" as I have seen this done in the literature a number of times. This broad coverage of six cases resulted from a desire to have a diversity of viewpoints, and perspectives from religions with a large number of followers (e.g., there are about 350 million Buddhists, more than 2.1 billion Christians, around 6.3 million Confucians, more than 1.6 billion Muslims, around 900 million Hindus, and 14 million Jews in the world). Catholicism was chosen to represent the Christian perspective since it is both large (more than 1.2 billion people), and the largest of the faith traditions in Christianity. These choices, however, do not mean that other perspectives (e.g., other Christian perspectives, such as Methodist or Mormon, or indigenous faith traditions) are not important, good, or will not introduce other ideas or issues. Social justice is typically only one part of any religion or faith. The lack of any treatment of the spiritual dimensions here could justifiably be viewed as a serious deficiency; however, I am not capable of providing these.

The lengths of the treatments of the religious perspectives here are different. This does not mean that one is more important or better (e.g., in the Catholic case the treatment is longer since it was easy to find a single unified and comprehensive source). The ordering of the treatment of the religious perspectives is simply alphabetical.

With respect to the secular perspectives, though related, the views of John Rawls and Amartya Sen are both treated. Since these partly consider (sometimes via critique) the utilitarian, communist, socialist, and libertarian perspectives those are not considered separately here; there are, however, homework problems on these other perspectives in in Section 2.6. Rawls's/Sen's perspectives are covered after the religious perspectives since Rawls considers, and in one sense incorporates (via "reasonable pluralism" and an "overlapping consensus"), these perspectives. Sen's builds on, and critiques Rawls's perspective, and hence is treated second. The third secular perspective that is considered is that of engineering ethics, even though it is somewhat unusual to include engineering ethics under social justice. Engineering ethics is covered since (i) the typical reader of this book, an engineer, may have some familiarity with it since it is a required subject in many engineering universities, and (ii) it provides a number of perspectives on social justice issues, more from an engineering standpoint, even though it would not normally be thought of as a "theory of justice." Engineering ethics is covered after all the other perspectives so that a critique of the current practice of engineering ethics education can be provided from a social justice perspective. The balance of length of treatment for the secular, and secular vs. religious perspectives, is not meant to be indicative of their relative quality or importance. There are less than 2% of the people in the world that are atheists, but around 16% who are non-religious (World Fact Book).

Connected to these issues, it is, unfortunately, significantly beyond the scope of this book to provide treatments of social justice for all world religions and faiths; admittedly, this may leave some readers disappointed (but homework problems are provided at the end of the chapter in Section 2.6 on some of these). The interested reader could, however, see (Palmer and Burgess, 2012) for an overview of social justice for other religions, sources the reader may know for their own religion or find via a leader in their religion, or many available web sites. Next, it was analogously not possible to cover all the secular perspectives on social justice since there is clearly a need to limit the scope. Absent here are, at least, complete treatments of the communist or socialist perspectives, the libertarian view, and the secular humanism viewpoint (and the many movements within each of these that lead to inter-perspective controversy). This may disappoint some readers, while it may please others in some respects; however, the reader can find many sources on these topics in the open literature. Again, there are homework assignments connected to these other secular perspectives at the end of the chapter in Section 2.6. The existence of other perspectives from still other fields, like psychology, social work, sociology, and medicine, is acknowledged but were not included simply due to the need to limit scope. Due to its importance in humanitarian engineering, however, Problem 2.29 is

provided to study the social work case from a US perspective.

**Controversy**

Social justice is often a very controversial topic since the perspectives disagree with each other on a variety of issues, and hence readers may find that they disagree in whole or part with, or even may be offended by, some aspects of the religious or secular perspectives. Some people, for example extreme individualists or anti-socials, may dislike the whole of social justice since it encourages or demands social concern for others and efforts to try to achieve social justice. It is sometimes said that "polite conversation should never include religion or politics" and social justice sometimes integrally involves both. On the other hand, it is likely that some people will be impressed with at least some aspects of the different viewpoints, and hence change their feelings about, or acceptance of, other religions or secular viewpoints. Studying multiple social justice perspectives certainly promotes cultural understanding.

Extremely controversial topics (including ones that not everyone would agree are even social justice topics) that are completely or mostly irrelevant to humanitarian engineering are not covered here (e.g., artificial contraception, abortion, technology-assisted fertilization, family size restrictions, polygamy, and euthanasia). It is recognized that some of these issues are connected to the basic issue of what rights women (and men) should have, and to the fact that for some people grave moral issues are connected to an engineer's development of any associated enabling/disabling technologies, but the overall impact on humanitarian engineering seems minimal relative to other issues and hence is considered beyond the scope of this book, especially since there are many good sources on all these issues in the literature.

Social justice issues are quite controversial even amongst members of a single religion or adherents to secular viewpoint, by both typical members and leaders and scholars of the religion or viewpoint; such "intra/inter-perspective" controversies are largely not covered here even though this then limits the diversity of viewpoints considered (but homework problems are provided in Section 2.6 that connect to some of the controversies). It must also be acknowledged that even a single individual may have conflicting views on a single issue in social justice. The many conflicting interpretations of statements from deities have influenced perspectives on social justice but these are not covered here. Also not covered here are the comments made by (even expert) writers from one perspective about another; when encountered, these were most often judged to be either quite inaccurate, not consistent with modern thinking, or at least partial misrepresentations (my own experience in finding these created in me a deep sense of concern that I would also create errors).

It is hoped that you will be flexible and open in your assessments of the viewpoints, and willing to accept parts of a whole perspective on social justice, and not condemn the whole viewpoint if you strongly (or partially) disagree with one aspect. Connected to your respect and acceptance of the religious social justice perspectives, keep in mind that just because a religion consistently

professes a stance on social justice, does not mean that the members of that religion know about it, understand it, feel it is relatively important, agree with it at all, may follow an older related precept, or reflect it in their actions. One must be very careful in blaming a whole religion, or secular perspective, including all its members, for the views or actions of a relatively small number of individual members. Recognizing that practicing the ideals of any system of thought on social justice is very difficult, it is important to be compassionate towards others' (and our own) failings to practice what we supposedly believe. Passion for, and strong commitment to, social justice is often good, but should be tempered by compassion for others, civility, and tolerance.

### A Call for Civility and Tolerance

There is plenty in this chapter to upset people who are religious or secular, liberal or conservative, men or women. Biases may upset people. Disputes can justifiably lead to reasoned and passionate discussions over ideas in social justice; however, civility must rule the day. This subject should be approached with open-mindedness, an analytical stance, reason and reasonableness, and sometimes a type of "scientific detachment." It is hoped that readers will take their own stance on social justice, perhaps blending different perspectives, go to the primary literature to study it themselves, reflect carefully on how it applies to engineering and technology, and at the same time, and perhaps most importantly, learn tolerance for all religious and secular perspectives. Why? Well, these may be the perspectives of the people helped by humanitarian engineering, the ones you will work with, or other engineers you will cooperate with in developing technology for helping. Civility and tolerance are essential for the success of the humanitarian engineer.

## 2.2 Religious Perspectives

The six perspectives considered here are, in alphabetical order: Buddhist, Catholic, Confucian, Hindu, Islamic, and Jewish. The explanation for the inclusion of these cases is given above in Section 2.1.3. In each case, only a relatively brief treatment is provided.

### 2.2.1 Buddhist

Buddhism is a nontheistic religion largely based on the teachings of Siddhartha Guatama, who is called the "Buddha" (the awakened one or enlightened teacher). Here, ideas related to social justice in Buddhism are discussed by using the treatments in (Fen, 2012; Emmanuel, 2012).

### Social Order and Concern for Others

Buddhism views the social order as hierarchical, and in the following top-to-bottom order: priestly class, warrior/noble class, peasant class, and servant

class. This order is viewed as "eternal, unchangeable, and sacred" (Fen, 2012). This social order developed into the caste system and the belief that people are born into their class. Buddhism does not believe there is a moral component to class; any class can have good or bad people. A central idea in Buddhism is *karma* which means "act" and it is believed that we should engage in positive acts that will then produce good results in this life and the next. Karma is thought to condition how we start in life, our physical and mental characteristics, social position, and luck. If you are born with a congenital condition or bad social circumstances, it is felt that this is the result of actions in a past lifetime. But, the future can be changed by positive actions, which result in being reborn as physically attractive, being in a fiscally secure family, and with features that result in a good future.

Concern for others in Buddhism is along the following lines (Fen, 2012):

> The *Metta Sutta* notes that all beings wish to be happy and free of suffering, and there is a series of meditative exercises in which one meditates on generating and radiating loving-kindness in progressively wider circles, finally reaching "all living beings."

Folk narratives in Buddhism say that great benefits can be obtained from doing even small well-intentioned acts such as giving to low-income people, or giving food to an ascetic or Buddha. Buddhists call for a redistribution of wealth through giving, that develops the virtue of generosity.

They say that poverty does not arise due to karma, but political failure. Poverty is, however, thought to cause acts that are karmically bad, but that the consequences of bad deeds "are shared by the entire populace, a general decline in attractiveness, lifespan, health, and moral behavior" (Fen, 2012) and human immorality can have adverse effects on parts of the environment.

**Government, Social Engagement, and Mindfulness**

With respect to the king, (Fen, 2012):

> ...lays out all the traditional elements required for this sacrifice, but does so in terms of the qualities of the king who wishes to perform it and his adviser who directs its performance. Eight instruments of the sacrifice are described as qualities of the king: rich, pure in lineage, handsome, militarily strong, faithful, generous to the poor, one who does good deeds, and intelligent in the senses of being learned and able to think matters out.

and

> The king should end disorder in the kingdom, not through rigid policies of law and order, but through measures we would refer to as job-creation programs, equitable taxation, and good wages and benefits for government workers. These are elements that, taken together, we would claim today as essential ingredients for social justice.

Good karma produces good results in this life and the next.

Meditative exercises of loving-kindness wish all to be happy and free from suffering.

Actions of the populace are to emulate the king to produce a society that is "generous, nonviolent, mutually supportive, and of benet to the natural world (no animals are slain) as well as to its human inhabitants" (Fen, 2012). We see then a concern in their system of social justice not just for humans but for all of nature.

Buddhism does not envision equality of resources, just that everyone has sufficient resources to care for themselves and can contribute to the collective: both of these are required of everyone. Also, (Fen, 2012):

> Nagarjuna's position is that the goal is a society in which there are favorable conditions for each person to move toward enlightenment or, in other words, to work out their karma. Nonviolence, including compassion for animals and abolishing the death penalty, education, and care for the poor, are advocated as good social policy.

Buddhism is socially engaged in that it seeks to promote peace and well-being in the world today. The activist-leaning organic movement of "engaged Buddhism" seeks to address social, political, and economical roots of suffering in the modern world; however, it it has strong historical roots in these directions also. Suffering forms the basis for spiritual and moral engagement in society. Also, (Emmanuel, 2012):

*Engaged Buddhism, the practice of mindfulness in daily life, seeks to address roots of suffering.*

> To bring the transformative power of mindfulness into places of suffering–to be peace in the midst of suffering–is the practice of engaged Buddhism.

and

> Simply stated, the practice of engaged Buddhism is the practice of mindfulness in daily life. For when we nurture peace and well-being in ourselves, we are already addressing the root causes of the conicts that arise within families, within communities, and among nations

### Suffering and Interconnectedness

Buddha said "I teach only *dukkha* and the cessation of *dukkha*" and *dukkha* is normally translated as "suffering," but it includes more than just physiological and psychological aspects, such as craving worldly pleasures or attachment to changing things. Buddha's teaching on suffering is summarized in his "Four Noble Truths" (Emmanuel, 2012):

*The existence, origin, and cessation of suffering are central to Buddhism.*

1. The truth of the existence of suffering.

2. The truth of the origin of suffering.

3. The truth of the cessation of suffering.

4. The truth of the path leading to the cessation of suffering.

The fourth is known as the "Noble Eightfold Path" and has the following guidelines to ending suffering: "promote the virtues of Right View, Right Thought, Right Speech, Right Action, Right Livelihood, Right Effort, Right Mindfulness, and Right Concentration" (Emmanuel, 2012).

In Buddhism, it is thought that there is a type of interdependence of suffering by individuals; hence, ending individual suffering for even one person helps others. Buddhists say that we must be mindfully aware of how we are connected to the suffering of others, that this suffering cannot be separated from how we live, or the institutions in operation in a society. Indeed, (Emmanuel, 2012):

> Once we grasp the truth of emptiness (*sunyata*), we see that our personal suffering exists interdependently with the suffering of others. Thus, when we work to transform the conditions that give rise to suffering, either in ourselves or in society, our work contributes to the liberation of all beings. In Buddhist thought, this realization is the basis for true compassion.

Indeed, "Buddhism simply is the compassionate response to suffering in the world" (Emmanuel, 2012). Also, Buddhists teach that wisdom only has value in so far as it benefits others.

## 2.2.2 Catholic

The Catholic Church's stance on social justice is given via "Catholic social teaching," also called its "social doctrine," which has its origins in the teachings of Jesus and the bible. Catholic social teaching has been updated throughout the more than 2000 year history of the Catholic Church to reflect changing circumstances (e.g., worker conditions resulting from the industrial revolution, the rise of information technology, the knowledge economy, the impact of biotechnology, globalization, and growing concern over environmental degradation). The teaching is based on the dignity of the human person and human rights, is centered around a set of core principles (e.g., the common good and solidarity), and the application of these to family, work, economic life, political community, international community, safeguarding the environment, and promotion of peace. Here, in the interest of brevity, the whole of Catholic social teaching is not covered, only parts relevant to engineering, science, technology, and development (e.g., biblical foundations, some issues related to families, some aspects of love, and spiritual dimensions, are largely ignored even though this runs the risk of distorting the teaching since it is best understood in its unity). The treatment below of the Catholic social teaching follows the development in (Compendium, 2005) where the interested reader can obtain the full details of the teaching; all quotes in this section were taken from this source.

### Dignity of the Human Person and Human Rights

In every man and woman there is the living image of God; hence, every person has an incomparable and inalienable dignity, and all humans have equal dignity

and value. This is regardless of race, nation, sex, origin, disabilities, culture, or class. Societies must respect the dignity of all human persons. For instance, no human is to be manipulated contrary to the development of that individual. Indeed, only recognition of human dignity can make possible the common and personal growth of everyone. It is only possible to safeguard and promote human dignity if this is done as a community, by the whole of humanity. All of Catholic social teaching is based on the dignity of all human persons.

Recognition of the dignity of all human beings leads to human rights. Human rights are to be defended both by individuals and society as a whole; lack of protection for human rights is a type of failure to recognize them. The identification and proclamation of human rights is an important attempt to meet the demands of human dignity. For instance, Pope John Paul II said that the United Nations Universal Declaration of Human Rights (December, 1948) is "a true milestone on the path of humanity's moral progress." Some "basic" rights include (other rights are listed in the sections below):

*Equal human dignity is the basis for Catholic Social Doctrine.*

*Human dignity implies basic human rights.*

- Right to life,

- Right to live in a united family,

- Right to develop one's intelligence and freedom in seeking and knowing the truth,

- Right to share in the work which makes wise use of the Earth's material resources,

- Right to derive from that work the means to support oneself and one's dependents,

- Right to freely establish a family and have and to rear children, and

- Right to religious freedom.

Duties are inextricably linked to rights, duties by the individuals who have the rights, and duties of others to recognize the rights of others. Catholic social teaching, however, has consistently demanded that the fortunate renounce some of their rights so as to place their goods more generously at the service to others. In spite of rights, we are all answerable to the "common good" (more on the definition of the common good is given below).

Human rights have expanded to include the rights of peoples and nations. What is true for individuals is also true for peoples. The rights of nations are "human rights" at the level of community life. Hence, a nation has a right to existence, a right to its own language and culture, a right to its sovereignty, a right to shape its life according to its own traditions (excluding every abuse of human rights and oppression of minorities), and a right to provide appropriate education for its young. Unfortunately, the proclamation of human rights is contradicted by many existing violations of human rights: wars and violence of every kind; genocides and mass deportations; forms of slavery including trafficking in human beings, child soldiers, and exploitation of workers; illegal drug trafficking; and prostitution.

**Principles of Catholic Social Doctrine**

The principles to be outlined here form the heart of Catholic social teaching. These principles include the dignity of the human person, covered in the last section, which is the foundation of all the other principles. A proper interpretation of these principles requires viewing them in their unity and interrelatedness (i.e., each principle cannot be properly understood or applied in isolation, but only in unity with all the other principles).

**The Common Good:** The principle of the common good stems from the dignity, unity, and equality of all people. The common good is the "sum total of social conditions which allow people, either as groups or as individuals, to reach their fulfillment more fully and more easily." The common good is not the simple sum of goods of each person of a social entity. The common good involves all members of society and no one is exempt from cooperating (according to their possibilities) to help develop and achieve the common good. It requires efforts to seek good for others as if it were the same as seeking good for oneself.

A person cannot find fulfillment in himself or herself that is separate from the fact that he or she exists with and for others. Demands of the common good depend on the historical period and are closely connected with respect for and promotion of all people and their human rights. The demands of the common good include a commitment to peace, organization of the nation's powers, an effective juridical system, protection of the environment, and provision of essential services to all people, often based on their human rights: food, housing, work, education, access to culture, transportation, basic health care, freedom of communication and expression, and protection of religious freedom.

The common good is to be viewed as the social and community dimension of the moral good. The actions of a society are best when they bring about the common good. If a society wants to serve its individuals, it must have as a goal the good of all people and good of the whole person. Every nation has the duty to cooperate world-wide for the common good of all humanity ("universal common good"), and for future generations. Political authority exists to develop and promote the common good. It is the duty of each government to "harmonize" different interests with the requirements of justice. Democratic governments interpret the common good not only in terms of the majority but also according to all of society, including the minority. The common good of a particular society is not the ultimate goal; the goal is the universal common good for all humanity.

**The Universal Destination of Goods:** All goods are to be shared fairly by all, and justice and charity must guide this sharing. God gave the earth to all of humanity without "excluding or favoring anyone." This is the universal destination of goods. The universal destination of goods leads to a universal right by all to use all goods. Other rights, such as property rights and the right of free trade are subordinate to the principle of the universal destination of goods. Such rights should expedite rather than hinder the universal destination

> The common good is the set of social conditions that facilitate people reaching self-fulfillment, and everyone must contribute to it.

of goods. The universal destination of goods principle does not mean that all goods are at the disposal of each person or all persons, or that the same object may be useful or belong to each person or all people. All people have a right to use the goods of the Earth; however, to ensure that this right is exercised in an equitable and orderly fashion, regulated interventions are necessary (according to national and international agreements). The universal destination of goods requires a common effort to obtain for each person and all peoples the conditions needed for integral human development.

Via work and intelligence humans develop part of the Earth's resources themselves, and this is the basis of the idea of individual property. Private property allows individuals to have personal and family autonomy and is a basic human freedom. Right of ownership of goods should be equally accessible to all persons. However, the right to private property is not absolute and untouchable. The right to private property must be considered in the context of rights common to all to use resources. That is, the right to private property is subordinate to the right of common use since goods are meant for all humans. Basically, the universal destination of goods is not opposed to the right of private property, but regulates it.

There is a social function to any type of private ownership in that it has a necessary relationship to the common good. Private property also has a purpose to benefit others and this creates obligations for owners. Owners have an obligation not to let their resources go idle and to direct them to productive activity. New "goods" such as knowledge, technology, and know-how must also be placed in the service of humankind. Community property must also be respected, appreciated, and directed toward the common good. Equitable distribution of land remains critical (i.e., "land reform" via redistribution of land).

The principle of the universal destination of goods requires that the poor, marginalized, and those whose fulfillment is hindered be of particular concern (i.e., have "primacy"). This is called the "preferential option for the poor." The "poor remain entrusted to us." The bible says "you have received without paying, give without pay." Helping the poor is not limited to charity, but also includes efforts to address social and political dimensions. Love of the poor is not compatible with love of riches and their selfish use.

**Subsidiarity:** To promote human dignity, aspects of civil society are important. These aspects include economic, social, cultural, sports-oriented, recreational, professional, and political. It is wrong to take from individuals what they can achieve by their own initiative and industry and give it to the community. Correspondingly, it is also an injustice to assign to higher associations what lesser and subordinate organizations can achieve on their own. Social activities should help members and never destroy or absorb them. Hence, all societies of a superior order must adopt attitudes of help (support, promotion, development) towards less developed societies. Subsidiarity is the economic, institutional, or juridical assistance offered to lesser social entities. It requires, however, that

*The preferential option for the poor results from the tension between universal destination of goods to all vs. private property.*

*Subsidiarity is a balance between the activities of higher associations and subordinate associations, that respects individual and subgroup initiative.*

the State not restrict the existential space of smaller essential cells of society, and not hinder their initiative, freedom, and responsibility.

"The principle of subsidiarity protects people from abuses by higher-level social authority and calls on these authorities to help individuals and intermediate groups to fulfill their duties." The intent of the principle is to recognize that every person, family, and intermediate group has something different to offer to the community. Subsidiarity is opposed to certain forms of centralization, bureaucratization, and welfare assistance, and to the "unjustified and excessive presence of the State in public mechanisms." A balance must be found between public and private spheres. Of course, circumstances can arise when the State should step in to provide certain functions (e.g., to stimulate the economy, to address some social imbalances and injustices, to try to achieve greater equality, justice, and peace). But, institutional involvement should only last as long as needed. Overall, the achievement of the common good guides the application of the principle of subsidiarity.

**Participation:** A key result of subsidiarity is participation. Participation is when individuals or groups (perhaps via representation) contribute to the cultural, economic, political, and social life of their community. Participation is a duty for all, with a responsibility to contribute to the common good. Participation must be especially encouraged for the most disadvantaged. Participation is a pillar of all democratic orders and a guarantor of the constancy of democracy. Every democracy must be participative. Sources of grave concern include countries ruled by totalitarian or dictatorial regimes since the right to participate in public life is denied.

*Participation arises from subsidiarity and the need to contribute to the common good, and is the basis of democracy.*

**Solidarity:** Solidarity highlights human beings' instinctual social character, the equality of dignity and rights of all humans, and the "common path of individuals and peoples towards an ever more committed unity." The interdependence between individuals and peoples is found at all levels and today's real-time communications enabled by information technology, and the increased volume of world-wide commerce, and shows that relationships can be established between people in distant parts of the globe. The accelerating human interdependencies require efforts to avoid consequences of perpetrating injustices on a global scale.

New relationships of interdependence between individuals and peoples (forms of solidarity) should be relationships supporting ethical-social solidarity. Solidarity is both a social principle and a moral virtue. Solidarity determines the order of institutions (we need "structures of solidarity" via laws, market regulations, and juridical systems). Solidarity is a true moral virtue, "not just a feeling of vague compassion or shallow distress at the misfortunes of so many people, both near and far." Solidarity is a firm determination to commit to contributing to the common good. Solidarity is a social virtue since it promotes justice. Solidarity is "a commitment to the good of one's neighbor." Solidarity is intimately connected to the common good, the universal destination of

*Solidarity is based on interdependence and is a commitment to the good of one's neighbor.*

goods, equality among humans and peoples, and peace. Solidarity summarizes the need to recognize the many ties that unite humans and social groups, and the goal of human freedom for common human growth that all people share and participate in. Solidarity requires that men and women have an awareness of the debt they owe to society (e.g., culture, scientific and technical knowledge, material and immaterial goods). We share solidarity with future generations also.

**Fundamental Values of Social Life:** The relationship between the principles covered above, and values, is one of reciprocity in that social values are an appreciation of the moral good that the principles foster. Social values are inherent in the dignity of the human person and support human development. The social values are truth, freedom, justice, and love:

1. *Truth:* All men and women have a duty to strive for the truth, respect it, and responsibly witness it. We need extensive educational efforts to support the search for truth.

2. *Freedom:* Freedom is a sign that all humans were created in the image of God, and all have equal dignity. "Freedom only truly exists where reciprocal bonds, governed by truth and justice, link people to one another." Freedom is properly respected when every human is permitted to fulfill themselves; "to seek the truth and profess his religious, cultural and political ideas;" to express his or her opinions; to choose his or her state of life; and to the greatest extent possible, his or her line of work; to pursue initiatives of an economic, social, or political nature. There are limits to freedom imposed by the common good.

3. *Justice:* Justice is "the constant and firm will to give their due to God and neighbor." Justice in many forms must be respected: commutative (a virtue that regulates the rights of one individual and another's), distributive (socially just allocation of goods), and legal. Social justice is worldwide in scope, and concerns the social, political, and economic aspects, and especially structural problems and their solutions. Global social justice promotes peace. Justice in all forms is particularly important today as human dignity and rights are threatened "by the widespread tendency to make exclusive use of criteria of utility and ownership."

4. *Love:* Love is the "highest and universal criterion of the whole of social ethics." Love promotes truth, freedom, and justice. "Human relationships cannot be governed solely by the measure of justice", they also require love. "No legislation, no system of rules or negotiation will ever succeed in persuading men and peoples to live in unity, brotherhood and peace; no line of reasoning will ever be able to surpass the appeal of love." Helping one's neighbor (which includes a society) is an act of love and mercy.

**Application Areas**

In this section, the application of the above principles to family, work, economic life, political community, international community, environment, and peace are considered.

**Family:** The family makes a unique and irreplaceable contribution to the good of society. Family does not exist for society or the State, but vice versa. Children are often educated about social relationships first in a family. Families should help protect children's dignity and rights. Unfortunately, a large number of the children live under unfavorable conditions for their integral development (e.g., lack of health care, inadequate food and water supply, inadequate shelter, and lack of educational opportunities). It is everyone's responsibility to help remedy such problems. For instance, it is important that a "family wage" be provided in compensation for work, one sufficient to maintain a family and allow the family to live decently. Such a wage should allow for savings to permit the acquisition of property to guarantee freedom.

**Human Work:** Work is to be honored and appreciated. Jesus was a man of work. Work helps meet the conditions for a decent life and in principle should be an effective instrument against poverty. Work should not, however, be idolized; it is not the ultimate goal. Work is for men and women, not men and women for work. Humans should not be enslaved by work. Work often involves acts of creation. No one should feel they have a right not to work (i.e., all have a duty to work) and to live at the expense of others (but recall that we are all called to contribute to the common good only according to our "possibilities"). The call to work is due to the need to provide for ourselves, but also to be able to help our neighbors (i.e., help achieve the common good). Yet, "rest from work is a right."

"The course of history is marked by the profound transformation and the exhilarating conquests of work, but also by the exploitation of so many workers and an offense to their dignity." Workers have dignity and a right to property. Cooperation is important among the social classes, the rights of the weak and poor must be protected, and the obligations of workers and employers be recognized. The right of workers to form associations must be upheld (e.g., unions, cooperatives, rural banks, insurance groups, and assistance organizations).

Human work is superior to all other factors related to productivity, in particular, "capital" (material means of production and financial resources for production). "Labor has an intrinsic priority over capital." But: "Capital cannot stand without labor, nor labor without capital." The origin of the conflict between capital and labor was found in that workers put their powers at the disposal of entrepreneurs who, trying to maximize profits, tried to give the lowest possible wages to workers. New aspects of this problem arise today in the presence of scientific and technological progress, and globalization of markets (which can be a source of development), leading to the exploitation of workers via mechanisms in the economy and an unconstrained quest for productivity.

Excessive demands of work can lead to destabilization of family life (traveling great distances to work, working two jobs, physical and psychological fatigue all reduce time dedicated to family). "The relationship between labor can capital also finds expression when workers participate in ownership, management, and profits."

"Private and public property, as well as the various mechanisms of the economic system, must be oriented to an economy of service to mankind so that they contribute to putting into effect the principle of the universal destination of goods (including modern "goods" such as technologies and knowledge). New technologies can make significant contributions to social progress; however, if they remain concentrated in wealthier countries, or a small number of powerful groups, there is the risk that they can become sources of unemployment and a cause for an increasing gap between developed and underdeveloped areas (e.g., countries).

"Work is a fundamental right." Work is necessary. It is needed to form and maintain a family, to have a right to property, and to contribute to the common good. Unemployment is a social disaster, especially with regard to younger generations. Work must be made available to all capable people. "Full employment" is a mandatory objective for every economic system that is oriented toward justice and the common good. "The high level of unemployment, the presence of obsolete educational systems and of persistent difficulties in gaining access to professional formation and the job market represent, especially for many young people, a huge obstacle on the road to human and professional development." "In general, this is the drama that strikes not only young people, but also women, less specialized workers, the persons with disabilities, immigrants, ex-convicts, the illiterate, all those who face greater difficulties in the attempt to find their place in the world of employment." In particular: "The feminine genius is needed in all expressions in the life of society, therefore the presence of women in the workplace must also be guaranteed." "The persistence of many forms of discrimination offensive to the dignity and vocation of women in the area of work is due to a long series of conditioning that penalizes women, who have seen 'their prerogatives misrepresented' and themselves 'relegated to the margins of society' and even reduced to servitude." There is an urgent need to recognize the rights of working women to aspects of pay, insurance, and social security.

Staying employed increasingly depends on one's professional capabilities. Educational systems should not ignore human or technological formation, which are needed to fulfill job responsibilities. The State and civil society have a role in promoting the right to work (e.g., via policies) in a country. International cooperation is needed to foster job creation around the world.

Child labor in some forms is a type of violence. However, in certain countries, the contribution made by child labor to family income and the national economy is indispensible, and some types of part-time work prove beneficial for the child. Yet, the Church condemns the increase in "the exploitation of children in the workplace in conditions of veritable slavery."

"Immigration can be a resource for development rather than an obstacle

to it." There are grave inequalities between rich and poor countries and hence an increasing number of immigrants seeking a better life. Most often, such immigrants are not a threat to well-being of the host country, but fill sectors of the job market that others are unwilling to fill. Foreign workers should not be exploited; they are entitled to the same rights as nationals. Immigrants are to be received as humans with dignity and helped to become a part of society.

Workers have dignity and their rights must be respected; these include:

- Right to a just wage;

- Right to rest;

- Right to a working environment and to manufacturing processes which are not harmful to the worker's physical health or to their moral integrity;

- Right that one's personality in the workplace should be safeguarded without suffering any affront to one's conscience or personal dignity;

- Right to appropriate subsidies that are necessary for the subsistence of unemployed workers and their families;

- Right to a pension and to insurance for old age, sickness, and in case of work-related accidents;

- Right to social security connected with maternity;

- Right to assemble and form associations; and

- Right to strike (when it cannot be avoided, or when it is necessary to obtain a proportional benefit, but it should always be peaceful–it is morally unacceptable when it involves violence, is not directly linked to working conditions, or when it is contrary to the common good).

Such rights are often violated. "It often happens that work conditions for men, women, and children, especially in developing countries, are so inhumane that they are an offense to their dignity and compromise their health." A just wage is the most important means for achieving justice in workplace relations. However, the "agreement between the employee and employer with regard to the amount of pay to be received is not sufficient for the agreed-upon salary to qualify as a "just wage," because a just wage 'must not be below the level of subsistence' of the worker: natural justice precedes and is above the freedom of the contract."

The fundamental role of labor unions to defend vital interests of workers is recognized. Unions should pursue the common good and are a positive force for solidarity. Unions should promote the struggle for social justice. Relations in the workplace must, however, be governed by cooperation. Unions have the responsibility to try to influence the political arena, making it aware of labor problems and helping it to work so that worker rights are respected. Unions are today presented with new challenges to widen their promotion of solidarity to include: workers with non-standard or limited-time contracts; employees

> There is a range of worker rights that arise due to worker dignity.

whose jobs are threatened by business mergers that occur with ever-increasing frequency, even at the international level; those who do not have a job; immigrants; seasonal workers; and those who have been dismissed from their job due to a need for re-training.

Globalization is changing the organization of work. Industrial plants can be located far from locations where strategies are decided (so there is a great distance to implications of decisions) and from markets where goods are consumed. Speed of communications and ease of world-wide transport of materials are supporting this. "Globalization of safeguards, minimum essential rights, and equity is necessary." One important feature of the new organization of work is the fragmentation of the production cycle brought about by efforts to obtain greater efficiency and profits (partial manufacture of products at distant locations). This requires a new system for the defense of work. New social protections are needed in an economy based on such fragmented work, services, and technological innovations. The decentralization of production often assigns to smaller companies tasks previously centralized in larger production sites and this gives new vitality and energy to small and medium-sized businesses; such businesses, along with artisans and independent work, may help make the work experience more human. However, these sectors have had a number of cases of unjust treatment, poor pay, and uncertain work. In developing countries there has been an expansion of "informal" and "hidden" economic activities. This can represent a promising sign of economic growth and development, but ethical and legal problems arise (e.g., terrible work conditions, lack of rules to safeguard worker dignity, and low incomes). Overall, the globalization of work calls for global development of solidarity. "Economic and social imbalances in the world of work must be addressed by restoring a just hierarchy of values and placing human dignity of workers before all else."

**Economic Life:** "Economic activity and material progress must be placed at the service of men and society." The production of goods should be made efficient; however, it is not acceptable to achieve economic growth at the expense of humans, populations, or social groups, condemning them to indigence. "Everyone has the right to participate in economic life and the duty to contribute, each according to his own capacity, to the progress of his country and to that of the entire human family." Business owners and managers should structure work so as to promote family. A duty in solidarity and justice is that each person contribute to the economic development of every other person. The objective of an economy to develop wealth is morally correct if it is directed to all humans' development in solidarity in a society. Never before has the role of business been so decisive for human development in solidarity.

"Everyone has a right to economic initiative." "The State has the moral obligation to enforce strict limitations only in cases of incompatibility between the pursuit of common good and the type of economic activity proposed or the way it is undertaken." An important dimension of businesses is their capacity to serve the common good through the production of useful goods and services.

Economic activity should serve humanity.

While it is justified that businesses earn profit, it is unacceptable that business not serve society or protect the dignity of its workers. It should be recognized that a business can be a community of solidarity. Usury (loaning money at unreasonable rates) as a business is to be condemned.

The free market can guarantee effective results in the production of goods and services. It has proven to provide sustained economic development for long time periods. The market enables better use of resources and facilitates exchange of products. "A truly competitive market is an effective instrument for attaining important objectives of justice: moderating the excessive profits of individual businesses, responding to consumers' demands, bringing about a more efficient use and conservation of resources, rewarding entrepreneurship and innovation, making information available so that it is really possible to compare and purchase products in an atmosphere of healthy competition." The free market must be judged based on what it seeks to accomplish and on the values it transmits to a society. Individual profit is not the sole objective; social usefulness is of fundamental importance. "When the free market carries out the important functions listed mentioned above it becomes a service to the common good and to integral human development." While the importance of markets is clear, they must be rooted in ethical objectives. The market has limits in its proven inability to satisfy important human needs, which "require goods that 'by their nature are not and cannot be mere commodities,' goods that cannot be bought and sold according to the rule of the 'exchange of equivalents' and the logic of contracts." "Freedom in the economic sector, however, must be regulated by appropriate legal norms so that it will be placed at the service of integral human freedom."

*The market must have both economic and social usefulness.*

Actions of the State and public authorities must respect subsidiarity and create conditions that promote the free exercise of economic activity; also, they must be inspired by solidarity and put into place limits on autonomy of the parties to defend those who are weaker. The State's involvement must be neither invasive nor absent, but appropriate to society's needs. The basic responsibility of the State is to set up an appropriate juridical framework to regulate economic affairs (e.g., to safeguard the weak from the powerful, to promote the observation of fair and transparent rules, or to put the principle of redistribution into effect, to encourage business to promote the common good by trying to involve all citizens in the activities of production). Tax revenue and public spending should be directed towards development and solidarity (e.g., to protect the weakest). "Public spending is directed to the common good when certain fundamental principles are observed: the payment of taxes as part of the duty of solidarity; a reasonable and fair application of taxes; and precision and integrity in administering and distributing public resources." For redistribution of resources, public spending must "observe the principles of solidarity, equality, and making use of talents."

*The proper basis should be in place for public spending to be directed at the common good.*

"Purchasing power must be used in the context of the moral demands of justice and solidarity, and in that of precise social responsibilities." The duty of charity demands that we give from our abundance, and sometimes from our needs, to provide essentials for the poor. Consumers can essentially direct the

*Charity demands that we give from our abundance, and sometimes from our needs, to the poor.*

behavior of producers through their individual and collective preferences for products taking into account not only price and quality, but also "the presence of correct working conditions in the company as well as the level of protection of the natural environment."

Globalization of economic and financial sectors is an on-going reality. "Globalization gives rise to new hopes while at the same time it poses troubling questions." It has the potential to provide benefits to all of humanity. However, there are growing trends of increasing inequality both between developed and developing countries and within industrialized countries. Growing economic wealth is accompanied by an increase in relative poverty. We must look for new opportunities for the redistribution of wealth to benefit the underprivileged that have been excluded or marginalized in social and economic progress. We need a globalization in solidarity, without marginalization. "Technological progress itself risks being unfairly distributed among countries." To exploit technical knowledge a society needs enough knowledgeable citizens and sufficient financial resources, something a developing country may not have.

International trade can promote development, create new employment opportunities, and provide useful resources. There are problems, however, with international trade, often stemming from protectionist policies, that discriminate against products coming from poor countries and hence hinder growth of industrial activity in, and the transfer of technology, to those countries. "Freedom of trade is fair only when it is in accord with the demands of justice." The widening gap between rich and poor countries demands that ethical criteria form the basis for international economic relations: "the pursuit of the common good and the universal destination of goods; equity in trade relationships; and attention to the rights and needs of the poor in policies concerning trade and international cooperation." Otherwise the rich nations get richer and the poor nations stay forever poor.

Solidarity in the age of globalization demands that human rights be defended. There is currently hesitation by the international community about the obligation to respect and implement human rights. There is a growing gap between achievable human rights in developed counties (e.g., right to self-determination and independence) and developing nations (e.g., the right to food and drinkable water, to housing, and security). Globalization demands an awareness of responsibilities for tasks called for on a world-wide level. This will make it possible to guarantee human rights, and equitable distribution of resources within every country and between different countries. Globalization should not be a new version of the colonialism of the past. It must respect the diversity of cultures, must not deprive the poor of what is most important to them, including their religious beliefs and practices. In the presence of globalization, we must emphasize solidarity between generations (as often happens in families and communities). Global planning is needed according to the universal destination of goods in order not to burden future generations with the costs, especially for the earth's resources and for safeguarding creation (i.e., the single ecosystem of the Earth).

Those involved in international economic matters should seek to achieve an

Solidarity needs to be globalized.

Protectionist trade policies discriminate against products from poor countries, and thereby hurt them.

integral development in solidarity (i.e., to promote the good of every person and the whole person). This requires equitable distribution of resources, an awareness of the interdependence (economic, political, and cultural) that unites people and makes them feel linked to a sole destiny. We need models of development that seek not only to raise all peoples to the level of the richest countries, but rather "of building up a more decent life through united labor, of concretely enhancing every individual's dignity and creativity, as well as his capacity to respond to his personal vocation."

**Political Community:** "The human person is the foundation and purpose of political life." Political community must recognize and respect human dignity by defending and promoting human rights. It must promote the common good by seeking to create a human environment "that offers citizens the possibility of truly exercising their human rights and of fulfilling completely their corresponding duties." "The political community is responsible for regulating its relations with civil society according to the principle of subsidiarity." Volunteer organizations and cooperative endeavors in the private-social sector represent the most appropriate ways to develop the social dimension of the human person.

The existence of a public authority is needed to promote the common good, yet political authorities must not usurp free activity of individuals, but discipline and orient individuals freedoms (while respecting their independence) towards the common good. Political authorities are only legitimate if they seek the common good. Political authorities must be guided by moral law, and respect and promote essential human and moral values. To this end, political authorities must enact just laws. Citizens have a right of conscientious objection if precepts are "contrary to the demands of the moral order, to the fundamental rights of persons or to the teachings of the Gospel." Refusal to follow an unjust law is a moral duty and human right. Civil law must recognize this right and not penalize its use.

*Public authority is needed to promote the common good.*

"Armed resistance to oppression by political authority is not legitimate, unless all the following conditions are met:"

1. There is certain, grave, and prolonged violation of fundamental human rights;

2. All other means of redress have been exhausted;

3. Such resistance will not provoke worse disorders;

4. There is well-founded hope of success; and

5. It is impossible to reasonably foresee any better solution.

The dangers of recourse to violence make it preferable in any case that passive resistance be practiced, since it is more conformable to moral principles and has no less prospects for success.

To protect the common good, public authority has the right and duty "to inflict punishments according to the seriousness of the crimes committed." Punishment serves to defend public order and safety of persons and is an instrument of correction for the offender. "The regulation against the use of torture, even in the case of serious crimes, must be strictly observed." Nothing can justify the use of torture. The "growing public opposition to the death penalty" is a sign of hope. Yet, "presuming the full ascertainment of the identity and responsibility of the guilty party," the traditional Catholic social teaching does not exclude the use of the death penalty "when this is the only practicable way to defend the lives of human beings effectively against the aggressor." "Bloodless methods of deterrence and punishment are preferred as 'they better correspond to the concrete conditions of the common good and are more in conformity to the dignity of the human person." The increasing number of countries who are abolishing the death penalty shows that cases where the death penalty must be used "are very rare, if not practically non-existent."

"The Church values the democratic system inasmuch as it ensures the participation of citizens in making political choices, guarantees to the governed the possibility both of electing and holding accountable those who govern them, and of replacing them through peaceful means when appropriate." A true democracy respects the dignity of the human person, respects human rights, has a commitment to the common good as "the purpose and guiding criterion for political life." Corruption in politics betrays moral principles and norms of social justice. Political parties should foster participation (e.g., via the free flow of information, including via the media) and orient aspirations toward the common good.

**International Community:** There is a need to for all people in the world to promote the "universal" common good, that is, the common good for all of humanity. "The coexistence among nations is based on the same values that should guide relations among human beings: truth, justice, active solidarity and freedom." There is a need for an international agreement on "the rights of nations," one that deals with questions of justice and freedom. Moral law that governs humans should also govern nations' relations with each other. For instance, justice should not be sought through war (e.g., the Charter of the United Nations bans recourse to force and threats of the use of force). "The United Nations 'has made a notable contribution to the promotion of respect for human dignity, the freedom of peoples and the requirements of development, thus preparing the cultural and institutional soil for building peace.'" There is a need to establish "some universal public authority acknowledged as such by all and endowed with effective power to safeguard, on the behalf of all, security, regard for justice, and respect for rights." International political authority must seek the universal common good, and respect the principle of subsidiarity. Globalization demands international political action with the goals of peace and development, and seeking the universal common good.

Challenges to development require international cooperation and resolute

*Public authority has the right and duty to punish serious crimes in order to protect the common good.*

*A properly run democracy can promote the common good.*

*The world needs to promote a universal common good for all humanity.*

determination since every nation has right to development based on: "unity of origin and a shared destiny of the human family; equality between every person and between every community based on human dignity; the universal destination of goods of the earth; the notion of development in its entirety; and the centrality of the human person and solidarity." "The right to development must be taken into account when considering questions related to the debt crisis of many poor countries." Development is often aided by fair access to international markets. "Among the causes that greatly contribute to underdevelopment and poverty, in addition to the impossibility of acceding to the international market, mention must be made of illiteracy, lack of food security, the absence of structures and services, inadequate measures for guaranteeing basic health care, the lack of safe drinking water and sanitation, corruption, instability of institutions and of political life itself." "The spirit of international cooperation requires that, beyond the strict market mentality, there should be an awareness of the duty to solidarity, justice and universal charity."

Poverty of billions of people in the world significantly challenges our consciences, and "poses a dramatic problem of justice." The universal destination of goods, and preferential option for and love of the poor, demand that all humans work to end poverty in the world. In this work, the principle of solidarity must be accompanied by subsidiarity to create a spirit of initiative in developing countries (the poor should not be viewed as a problem, but as "people who can become the principle builders of a new and more human future for everyone").

*Pervasive world-wide poverty is a dramatic injustice.*

**Safeguarding the Environment:** With the help of science and technology, humans have extended their mastery over almost all of nature. Through science and technology, humans are co-creators with God. But, as humans' capability has extended they gain more responsibility. Biotechnology and genetics offer great promise for producing more advanced and vigorous strains of plants (e.g., to help efficiency of food production) and advanced medicines. But, science and technology should serve humanity, respect men and women, and have an attitude of respect for other creatures. This creates concerns with, for instance, indiscriminate genetic manipulation, and unscrupulous development of new forms of plant and animal life. There is grave concern about interference in ecosystems and long-term impact on future generations.

Problems with the environment have arisen from humans' attempt at unconditional dominion over creation and "ill-considered" exploitation of resources. Basically, "the environment as a 'resource' risks threatening the environment as 'home.'" Other living creatures are not above the dignity of the human person. Yet, creatures are gifts to be nurtured, safeguarded, and respected. Humans have a responsibility for "the preservation of a sound and healthy environment for all." "Care for the environment represents a challenge for all of humanity. It is a matter of a common and universal duty, that of respecting a common good, destined for all, by preventing anyone from using 'with impunity the different categories of beings, whether living or inanimate–animals, plants, the natural elements–simply as one wishes, according to one's own economic needs." The

*Care of animals and preservation of a healthy environment promote the common good.*

environmental value of biodiversity must be responsibly and adequately protected since "it constitutes an extraordinary richness for all of humanity." Responsibility for the environment includes current needs and the needs of future generations. International laws need development, and mentalities and lifestyles need to change (e.g., "to break the logic of mere consumption"). When scientific data on health and environmental impact are scarce or not available, it may be appropriate to use the "precautionary principle" to develop guidelines to manage the situation that has uncertainty.

"Programs of economic development must carefully consider 'the need to respect the integrity and cycles of nature' because natural resources are limited and some are not renewable." Today's exploitation is seriously affecting resource availability for now and the future. Relations between human activity and climate change must be monitored at all levels. The climate must be protected and all consumers and industrial activities "must develop a greater sense of responsibility for their behavior." To protect the environment, maximization of profits cannot be the only objective; the environment is not one of those "goods" that is safeguarded by market forces. Particular attention needs to be paid to energy sources. Non-renewable energy sources should be at the service of all humanity, but there is a need to identify new sources of energy.

Biotechnology's impact on agriculture, animal farming, medicine, and environmental protection is both a source of hope and concern that is actively debated today. Biotechnology development must be done for the common good. While human intervention in nature is acceptable ("nature is not a sacred or divine reality"), but must be done responsibly. Nature is a gift "to the human community, entrusted to the intelligence and moral responsibility of men and women." Damaging the environment and living beings deserves condemnation, but actions to improve these are praiseworthy. Modifications with wide-spread and long-term impact deserve serious consideration. It is not the benefits of biotechnology that will alone solve the problems of poverty and underdevelopment. It is important that necessary scientific and technological autonomy be established in developing countries to promote "exchange of scientific and technical knowledge and transfer of technologies to developing countries." Solidarity means that developing countries should promote trade policies that are favorable to their countries and the "exchange of technology that can improve the conditions of their food supply and health." Developing countries need an increase in research investment, especially as it focuses on their needs.

The environmental crisis and poverty are interconnected but can be addressed by the principle of the universal destination of goods (which would, for example, imply that there is a human right to clean water). The environmental crisis especially affects the poor via, for example, erosion or desertification, living in polluted suburbs of large cities, or "living in make-shift residences or in huge complexes of crumbling and unsafe houses (slums, bidonvilles, barrios, favelas)." Often, in developing countries, "hunger and poverty make it virtually impossible to avoid an intense and excessive exploitation of the environment." "The close link that exists between the development of the poorest countries, demographic changes and a sustainable use of the environment must not become

a pretext for political and economic choices that are at variance with the dignity of the human person." "There is wide-spread agreement that a population policy is only one part of an overall development strategy."

**Promotion of Peace:**   Peace is a value and a universal duty; it is not just the absence of war. Peace requires an order based on justice and charity. Peace is threatened when men and women are not given what they are due as humans, when human dignity is not respected, when defense and promotion of human rights is not achieved, and when society is not seeking the common good. "Another name for peace is development." Pope Paul VI said "if you want peace work for justice." Peace is the fruit of love; justice does away with the obstacles to peace, but true and lasting peace results only from love. Everyone is responsible for promoting peace.

"Violence is never a proper response." War is the failure of peace. The Catholic social teaching condemns the "savagery of war," cannot imagine how in an atomic era that war could be an instrument of justice, considers war to be a "scourge" that is never "an appropriate way to resolve problems that arise between nations," "is an "unnecessary massacre," and views war as "the failure of all  true humanism" and a "defeat for humanity."

"A war of aggression is intrinsically immoral." But, a State that has been attacked as a right and duty to defend itself even with arms. "To be licit, the use of force must correspond to certain strict conditions:

1. The damage inflicted by the aggressor on the nation or community of nations must be lasting, grave, and certain;

2. All other means of putting an end to it must have been shown to be impractical or ineffective;

3. There must be serious prospects of success;

4. The use of arms must not produce evils and disorders graver than the evil to be eliminated."

*Just war doctrine gives conditions for a moral defensive war.*

These are the traditional elements of what has been called the "just war" doctrine. The evaluation of these conditions is the responsibility of those responsible for the common good. The possession of war potential does not justify the use of force, and if war breaks out all is not fair between warring parties.

The United Nations generally prohibits the use of force between States, except in the cases of legitimate defense and measures taken by the Security Council in its responsibility for maintaining peace. The right to self-defense must respect "the traditional limits of necessity and proportionality." Hence, "engaging in a preventive war without clear proof that an attack is imminent cannot fail to raise serious moral and juridical questions."

Making contributions to defense of a country is an authentic contribution to peace. People serving in armed forces are called to defend good, truth, and justice in the world. In this regard, there is an increasing number of military personnel serving multinational forces "on humanitarian or peace-keeping missions

promoted by the United Nations." Members of the armed forces are obliged to resist orders to "perpetrate crimes against the law of nations and the universal principles of this law." "Military personnel remain fully responsible for the acts they commit in violation of the rights of individuals and peoples, or of the norms of international humanitarian law." Conscientious objectors to military service should be open to instead accepting other forms of community service.

The right of legitimate defense is associated with the duty to protect innocent victims unable to defend themselves. In modern conflicts, often within a State, "the precepts of international humanitarian law must be fully respected." The civilian population should be protected from the effects of war. There is a need for a new "consensus on humanitarian principles and to reinforce their foundation to prevent the recurrence of atrocities and abuse." Refugees are war victims whose dignity and human rights must be protected. "Attempts to eliminate entire national, ethnic, religious or linguistic groups are crimes against God and humanity itself, and those responsible for such crimes must answer for them before justice." Even considering national sovereignty, the international community "has a moral obligation to intervene on behalf of those groups whose survival is threatened or whose basic human rights are seriously violated." The Church supports the International Criminal Court that is responsible for punishing those responsible for particularly serious acts such as genocide, crimes against humanity, war crimes, and crimes of aggression. Sanctions must be adopted with clear objectives and periodically reviewed by the international community for their effectiveness and impact on the civilian population. "Sanctions must never be used for the direct punishment of an entire population." It is not acceptable that an entire population, especially its most vulnerable members, suffer due to sanctions. "Economic sanctions in particular are an instrument to be used with great discernment and must be subjected to strict legal and ethical criteria. An economic embargo must be of limited duration and cannot be justified when the resulting effects are indiscriminate."

Catholic social doctrine proposes a goal of "general, balanced and controlled disarmament." The principle of sufficiency indicates that each State should only possess the means for legitimate defense. Excessive stockpiling or indiscriminate trading in arms "cannot be morally justified." The accumulation of arms for deterrence presents strong moral reservations, and an arms race does not ensure peace, and indeed it increases the risk of war. Nuclear deterrence should be replaced by multilateral negotiations for disarmament. Weapons of mass destruction (biological, chemical, or nuclear) create an enormous responsibility on the part of their owners since any act of war aimed at indiscriminate destruction cities, areas, and populations, is a terrible crime. "It merits unequivocal and unhesitating condemnation." "Disarmament must include the banning of weapons that inflict excessively traumatic injury or that strike indiscriminately. This includes anti-personnel land mines (since they continue to inflict injury long after hostilities have ended). We need to control the production, sale, importation and exportation of small arms and light weapons, "armaments that facilitate many outbreaks of violence to occur." "The use of children and adolescents as soldiers in armed conflicts must be condemned." It is an "intolerable crime."

The Catholic social doctrine supports disarmament, if it is done properly.

"Terrorism is one of the most brutal forms of violence traumatizing the international community today; it sows hatred, death, and an urge for revenge and reprisal." Completely innocent people have been the victims of terrorism. Terrorism does not respect traditional rules of conflict, for instance through international humanitarian law. "Terrorism is to be condemned in the most absolute terms. It shows complete contempt for human life and can never be justified, since the human person is always an end and never a means." Terrorism strikes at human dignity and is an offense to humanity; hence, there is a right to defend oneself from terrorism. However, the struggle against terrorism must respect human rights and law. The fight against terrorism must not just be via repressive and punitive operations, but the causes of terrorism must be clearly understood (e.g., abuse of human rights and injustices over a long time period). "It is a profanation and a blasphemy to declare oneself a terrorist in God's name." Terrorists who die while committing their acts are not "martyrs" ("which is the witness of a person who gives themselves up to death rather than deny God and his love"). "No religion may tolerate terrorism and much less preach it." Indeed, religions should cooperate to remove the causes of terrorism and promote friendships between all peoples.

Finally, true peace "is made possible only through forgiveness and reconciliation." Forgiveness for violence and suffering due to hostilities is very difficult, but possible. "Justice and truth represent the concrete requisites for reconciliation." Respect for the right to peace must be promoted to encourage replacement of structures of power with structures of cooperation aimed at achieving the common good.

*The Catholic social doctrine condemns terrorism.*

### A Call to Action

The Catholic social teaching is a call to action by all people: "As far as the Church is concerned, the social message of the Gospel must not be considered a theory, but above all else a basis and motivation for action" (Centesimus Annus, 57). "Action," which must be taken with careful reflection, love, and prudence, includes many activities outlined in the above Catholic social teaching (e.g., defending human rights, strikes by workers, and fighting against oppression), including (some of these are from practice, not the above doctrine):

- Fighting for human rights and human development and fulfillment, including taking a stance against discrimination you encounter;

- Actively helping the poor, weak, and disadvantaged using your "time, talent, and treasure;"

- Fighting against social injustices (e.g., structural problems within business organizations, military, society, economic, and political systems);

- Voting, letter-writing to politicians, lobbying, or other involvement in politics;

*Catholic social doctrine is not just to be believed, but to be followed and acted upon for the sake of others.*

- Protecting the environment via your own lifestyle (e.g., recycling, purchasing environmentally sound products, and minimizing energy use at home);

- Peaceful protest against injustices and demonstrations supporting social justice (including marches in the streets) along with passive resistance when necessary; and

- Expressing consumer preferences via your buying patterns and boycotting products (e.g., based on a company's poor treatment of workers or lack of respect for the environment).

It is not that the Catholic social teaching is just to be "believed"; it must be followed in every respect, especially via concrete actions for all areas it applies to.

### 2.2.3 Confucian

Confucianism is a nontheistic system of ethics and philosophy that has evolved from Confucius (551-479 BC), and others, and that is occasionally called a religion, though it has never been an established religion. It does have a religious dimension in emphasizing "harmony and the unity of humanity and Heaven" (Chan, 2012). According to (Chan, 2012):

> Confucianism holds that people should cultivate their minds and virtues through lifelong learning and participation in rituals, that they should treat their family members according to the norms of filial piety and fatherly love, and that they should show a graded concern and care for all outside of the family. Political leaders should do their best to care for the ruled and serve as moral exemplars for them. Learned intellectuals, above all others, should devote themselves in politics and education to promote the Way and help build a good society.

Hence, it holds that everyone should have some level of concern for others ("graded love" for those not in the family and more "distant"), and government should in a sense work for the people. Confucians value family, respect education and learning, and order and harmony, the latter of which is intimately tied to their notion of social justice (Angle, 2012).

**Distributive Justice, Sufficiency, and Inequality**

There is not much emphasis on justice in Confucianism as politics are seen as an extension of personal ethics and society is viewed as a large family. The emphasis is on personal virtues, and benevolent leadership, rather than law. Yet, there are Confucian political principles and policies, one of which is that benevolent rule should include the "proper distribution of economic resources" and that "justice or fairness consists in rendering to each person his due according to

his personal characteristics, circumstances, or conduct" (Chan, 2012). For Mencius and Xunzi, great Confucian thinkers, "justice is a moral constraint on people's pursuits of goals and benefits" (Chan, 2012). Mencius said that proper distribution of land is an important function of a benevolent government, and that an equal distribution is one that gives each person enough to live; perfect equality is not the objective, only sufficiency in the sense that it will provide for material well-being. He also said that the allocation should be roughly equal for each person, and that it is the government's responsibility to ensure sufficiency and rough equality. Mencius also said that if a person dies due to poverty under a ruler, then the moral judgement of that ruler is viewed as if the ruler had killed the person directly. Such a failure of sufficiency by the government is viewed as a serious violation of justice.

> Confucians support a proper distribution of resources.

Mencius thought that there is a moral imperative that each person is able to have well-being, which is only possible with sufficient material resources. He said that nature provides enough resources to support everyone; however the social structure (government) must manage land distribution and use of common resources like forests and fish. That is, the government must be just, and give everyone a fair share as everyone has the capacity for well-being. Yet, everyone must contribute to government revenues and thereby help everyone else get sufficient resources. Mencius says there should be communal relationships, beneath the government, where people help each other out, as there should be familial relationships with mutual aid. The government should step in when these familial and communal relationships fail to provide proper assistance.

Mencius and Xunxi say that the salary from one's work is due to one's merit or contribution, and that the salaries do not have to be equal. People may get more rewards or have more wealth due to their merit, contributions, or productivity. Xunxi says that it is not family background but ability that matters, and supports class mobility based on this. Past the level of sufficiency, inequality is allowed if it is based on merit and contribution. Mencius and Xunxi said (controversially) that all persons are born with the same natural talents. Differences arise due to "different individual's willingness to think, learn, and cultivate himself" (Chan, 2012) and their social environment and customs, but for the latter reasons they do not feel that people should be compensated. Also, Tan says (Angle, 2012):

> A person with the Confucian virtue of *ren* would certainly share what she has earned with her abilities and merits with those who are worse off than herself, even when they do not fall below "sufficiency" level, and spend it on various projects aimed at improving people's lives (and not just in material terms). This will lead to a more egalitarian social outcome than a straightforward meritocracy, or even one tempered only by the sufficiency principle and priority for the badly off.

Confucians generally oppose wide disparities between haves and have-nots (Angle, 2012), and Tan has concerns about a pure meritocracy (e.g., in education).

**Contemporary Political and Economic Views**

Kang Youwei argues for abolishment of distinctions between "nations, classes, races, genders, families, and occupations" (Angle, 2012) as well between the ruler and ruled, and wants the world to be shared by all. Building on his ideas, Sun Yatsen mixed Confucian and socialist ideas. Mou said that "private property is the defense line of the human individual and protects the dignity of the human being" (Angle, 2012).

Jiang felt that Confucianism should be institutionalized as a religion, but felt that any discussion of global values and justice is utopian, and did not advocate egalitarianism. Also, (Angle, 2012):

Modern Confucian thought has considered relations to communism.

> Jiang argues that Confucian values like harmony, concern for others (*youhuan yishi*), and opposition to economic inequity (*bujun*) can enable us to avoid market failures and alienation, if these values are primary and the pursuit of profit–which is perfectly legitimate, in moderation–is secondary.

Jiang feels that economic inequalities should not have an impact on humans' flourishing.

Kang Xiaoguang felt that China should replace its Communist ideology with a "soft authoritarianism based on Confucianism" (Angle, 2012). He felt that the system was failing on social justice and in a number of other respects (e.g., legitimacy). He did not feel that democracy was the solution (but others had an integrated view of democracy in some forms and Confucianism), but a type of authoritarianism what properly addressed social justice. He recommended "humane government."

Confucianism is not opposed to commercial activity and profit (Angle, 2012). For instance, Fan endorses private property and capitalism. Yet, some have sought to combine a socialist and Confucian tradition by combining leftist and Confucian ideas.

## 2.2.4 Hindu

The caste system holds a central role in Hindu social justice. While it has had some positive aspects, for instance in preserving Hindu culture and intellectualism, it has also been controversial and problematic. It was originally set up to help individual and societal well-being to divide labor per people's skills and aptitudes. Though there have been efforts to reform it (e.g., by Lord Krishna, the saints of the Bhakti, Mahavir Jain, and Guatama Buddha, the latter two of which rejected the caste system and favored spiritual liberation, and Buddha who which argued for equality, even based on gender), for centuries the caste system has promoted discrimination and oppression (Dwivedi, 2012). There are a number of modern movements against the caste system, and gender inequality, and these will be discussed below, after a brief overview of the caste system is provided.

**The Caste System**

Caste is a stratification of social classes with hierarchical closed layers (social rankings) where social contact and mobility are limited to each layer (e.g., marriage is only allowed within a layer). Even though there was significant egalitarianism in ancient India, to help Hindus succeed based on their natural tendencies and capabilities, there were four social classes created that are considered natural and God-ordained, and where they are interdependent but ordered top to bottom in social ranking as follows(Dwivedi, 2012) (quoted exactly, except parts in brackets):

Caste is a hierarchy of social classes.

1. *Brahmans* (Brahmins, in the anglicized version): educators, trainers, priests, theologians, philosophers. [Priests advised rulers, Brahmans provided military training, and often were military commanders, and governed the land.]

2. *Kshatriyas:* rulers, defenders from enemy attacks, military, administrators. [Also, governed the land.]

3. *Vaishyas:* producers of wealth and prosperity, businessmen, traders, professionals. [Merchants and traders provided financial and resource support for governance. Except from military service, but provided resources to Kshatriyas who protected society.]

4. *Shudras:* artisans, service providers, and laborers. [Except from military service, but provided resources to Kshatriyas who protected society. In villages, they "provided support services to all as barbers, blacksmiths, water drawers, potters, skinners, and midwives" and "laborers received money or a portion of the harvested crop" (Dwivedi, 2012).]

Clearly, each group depends on the others; however, the top three castes were dominant. Over time, these divisions were institutionalized so people were not free to choose their line of work, and "Hindu society's degradation, fragmentation, and disintegration began" (Dwivedi, 2012).

The *Shudras* have been discriminated against, exploited, humiliated, and receive harsher punishments for the same actions as those at other levels, and as a result became socially and financially handicapped. When you are born into one of the levels, you spent your life at that level. A *Jati* is a social category or "subcaste" that is used to define an occupational subgroup at each of the above four levels. You were born into a *Jati* and could not change to another. There was a separate category for conquered people, servants, and invaders.

Also, there were the *Ati-shudras* that were lower than the *Shudras*, viewed as less civilized as they were tribes of forest and hill people, and were called the "untouchables" (*Achhoot*). They live at the periphery of a village or in seclusion, are not allowed to drink from the same water sources (including a river), live in the worst socioeconomic conditions, and are treated with apathy by the other castes. Today, untouchables are called *dalits* (or depressed classes) and even after independence (Singh, 2012):

> The National Commission for Scheduled Castes and Scheduled Tribes reveals horrifying data of more than 115 million *dalit* children in slavery and at least two *dalit* women and children raped every hour.

**Hindu Social Justice Concepts**

Historically, there does not exist an Indian term for "social justice." However, (Dwivedi, 2012):

> ...the current term *Sarvodaya* (Sanskrit for "awakening of all") refers to the goal of effecting changes in the social-political and economic structure to create social responsibility and equity.

Also, there is the important idea of *Dharma*. "*Dharma* has been interpreted variously as a religious code of behavior, a divine system of morality and righteousness, and conformation to one's cosmically allotted duty and nature" and related to social justice, "*Dharma* also denotes the sustaining of the principles of social harmony through the preservation, progress, and welfare of humanity" (Dwivedi, 2012). Also, (Dwivedi, 2012):

> *Dharma* ought to be interpreted in terms of *niti* and *nyaya*. *Niti* indicates "justice" in Sanskrit in terms of organizational propriety and correct behavior. *Nyaya* refers more to a comprehensive concept of "realized justice." Thus, *niti* requires one to perform one's duty unconditionally, while *nyaya* considers the consequences of one's actions before and after decision making.

These ideas are discussed further in Section 2.3.2 when Amartya Sen's viewpoints are covered.

Doctrines of rebirth and *Karma* provide the Hindu explanation of suffering, early death, poverty, and caste inequality (e.g., birth of persons into the lowest class). It is believed that persons in a low class "committed a negative karmic act in a previous life, resulting in their present low status in society" (Dwivedi, 2012) (i.e., this results in a low-caste birth in the next life) and this is used to justify the terrible conditions many people live under in India. These doctrines legitimatize class structure. Yet, there is an opposing view within Hinduism, where in some respects "the religion accorded proper recognition to individual merits and virtues, irrespective of a person's birth caste" (Dwivedi, 2012).

**Modern Reform Movements for Caste and Gender Equality**

Swami Dayananda said that the hereditary caste system was evil, that women were equal to men, and that the categorization of people as untouchables was sinful. Arya Samaj opened his temples to all, declared untouchables equal to all other castes, argued that widows should be allowed to remarry, and pursued a policy of education for all, especially women. Brahmo Samaj opposed *sati*, the burning of widows at their husband's funeral pyre (still practiced today in some places though it is against the law), polygamy, and discrimination against

widows. Mahatma Gandhi "declared the treatment of untouchables to be a great blot on Hinduism" (Dwivedi, 2012). Today untouchables are called *dalits*, or depressed classes, which per India's 2001 census was 25% of the population (Singh, 2012).

Upon receiving independence from the UK, the newly established constitution guaranteed equality and special privileges for the depressed and oppressed classes (to social, economic, and political status); however, the caste system persists in rural villages. Yet, since India has a democracy, and since the disempowered castes have numerical majority in most geographical areas of India, they have been able to use the electorate to improve their social and economic position. Due to this effect, some say that the caste system will die way.

The constitution declared that classifying someone as an untouchable was a punishable offense under law, yet there are few convictions. The constitution also declared that women should get equal pay for equal work, and 33% of positions in politics in rural and urban local governments are reserved for women. Many, however, discriminate against single women, unmarried or divorced women, or widows (they become outcasts, unwanted in her family home and sent away, often to suffer physical and sexual abuse and to be forced into prostitution). But, some Hindu writings say that women are superior to men since men are born from women, they are more faithful, and have better conduct. Yet, in other philosophy (Singh, 2012):

> ...the Hindu scripture *Ramcharitmanas*, which even today is the single most important influence over the Hindu psyche, sums up the status of woman in a couplet: "*Dhol, Ganwar, shudra, pashu nari, yeh sab taran ke adhikari*" (an idiot, illiterate, untouchable, animal, and the woman are worthy to be reprimanded).

Generally, in a Hindu home the birth of a son is celebrated, but the birth of a girl is considered unimportant. Rituals for birth, death, and property purchase have to be conducted by a male.

"*Raja Ram Mohun Roy* may be remembered as the widows' messiah, since he raised the bogey of legislative reforms to eradicate *sati* and promote widow remarriage" (Singh, 2012). Today, Hindu girls are rejecting the dowry because it treats a girl as someone else's property, something boys are not treated like. Also, "Social reforms and constitutional changes have raised the age of marriage and given women the right to own their matrimonial share of property, or even their husband's property in case of abandonment" (Singh, 2012).

### 2.2.5 Islam

The Prophet Muhammad said

> "No, he does not believe in Allah, nor in the Day of Judgment, he who eats his full at night while his neighbor is raked with hunger."

Social justice is one of Islam's basic principles. Muslims are called collectively and individually to seek to eliminate injustices. Duties that the Qur'an pre-

There are caste and gender inequality reform movements in India.

scribes lead to justice in the community. The Qur'an speaks against social and economic injustices and calls for their elimination. The Qur'an allows for the ownership of property and accumulation of wealth provided the wealth is shared with the rest of society and especially the poor. God owns all wealth. "The Qur'an prescribes that Muslims make their "zakat" (almsgiving) to fulfill one of mandated five pillars of Islam" (Timani, 2012). Committing an act to humiliate another human being (e.g., highlighting to a poor person that you gave them something) is an act of injustice. The zakat should not be made public. Muslims are called to be a moderate community (e.g., between pride and suffering, greedy and spendthrift, excess in worship and no faith). Muslims believe that they will not become poor by sharing with others. Muslims must share because what they share is not their own, but God's. If a Muslim does not have the financial means to make a zakat, the pillar can be achieved by kind words and forgiveness, contributing their time in community service, by giving advice, or by teaching.

*Zakat (almsgiving) is needed to fulfill one of the five pillars of Islam.*

### Social Justice in the Qur'an and Later Reform Trends

The Qur'an was a response to social injustices of the time. The Qur'an promoted social justice, equality, and human rights in Islam. The Qur'an emphatically denounces the abuses of the weak (e.g., orphans) and warns those who abuse their wealth. The Qur'an values wealth and considers economic prosperity a blessing from God, but it says that wealth is an illusory pleasure and brief enjoyment. Muslims are required to be just in the distribution of wealth and honest in business (e.g., they are warned against corruption). The Qur'an insists that the poor and destitute should share in the wealth of the rich. It bans usury (loans with high interest) and supports the "zakat" tax for redistribution of wealth. If you do not share, you are considered greedy and will suffer the consequences.

*The Qur'an says that the poor should share in the wealth of the rich.*

"Islam established justice and equality for all regardless of ethnic, racial, and religious backgrounds and some qur'anic injunctions extended social justice to slaves" (Timani, 2012). For example, there are calls for Muslims to free their slaves, and this is considered a highly praiseworthy act. Freeing a human from bondage can also mean freeing a person of debt or poverty.

"The message of the Qur'an teaches that both wife and husband have equal rights and should exercise these rights to serve each other and maintain justice and peace" (Timani, 2012). A wife has freedom to education and expression, to enter into contracts, to engage in trade and business, and to earn and possess wealth and property. Muhammad realized that no society is "viable where women do not enjoy rights as well as duties". The Qur'an brought rights and justice to orphans (e.g., their right to property not to be infringed upon). The Qur'an says that punishment should be equal to (or appropriate for) the crime. The Qur'an prohibits taking a life except in the pursuit of justice. The Qur'an does not, however, generally say how social justice should be achieved.

Reform and revival movements occurred in many parts of the Muslim world in the nineteenth and twentieth centuries, and often included the topic of social

justice. Some reformers were concerned with the extensive focus on tradition and medieval thought of some Muslims and wanted to promote a more contemporary view (e.g., to address pressing issues of the day at home and coming from abroad). They argued about, for instance, issues of the role of Islam in society, world-wide Muslim unity, women's rights, and polygamy.

### Hasan al-Banna, Sayyid Qutb, and Muslim Brotherhood

Hasan al-Banna founded the Muslim Brotherhood and was concerned with institutional approaches to addressing the needs of the poor and oppressed. He felt that Islam was a comprehensive way of life that addressed social problems. Al-Banna felt that Islamic society should be just and take measures to achieve social justice. He advocated "zakat" to redistribute wealth. He felt that morality was important in economic activity to achieve social justice. The Muslim Brotherhood, as an Islamic social and political movement, adopted these views. They criticized the capitalist economy of Egypt since they felt it hurt the people and exploited the poor. They criticized other Muslims (the "ulama") for not responding to the needs of the modern age and the resulting problems it created.

One prominent member of the Muslim Brotherhood was Sayyid Qutb who wrote the book "Social Justice in Islam" that was influential in the Brotherhood. He emphasizes the need for Islamic concern about worldly problems, and the welfare of humanity. Qutb felt that the concern for justice included all of humanity, all sides of life and activity. He argued for mutual responsibility and stated that the foundations of justice were: "Freedom of conscience, Freedom of all men, Mutual responsibility of society" (Stiles, 2012). He did not demand equality of wealth to achieve social justice (modern thinkers emphasize equity and fairness rather than equality). The Muslim Brotherhood has taken what some view as radical, and sometimes violent, approaches, and has been persecuted (e.g., al-Banna and Qutb were executed by the Egyptian state). The Brotherhood has advocated for labor, assisted in forming labor unions, participated in strikes, tried to protect the people from greedy companies, helped with the poor, and promoted educational reform (along an Islamic view).

Some Muslims question whether the State can or should preserve social justice (Stiles, 2012). Many, including Sayyid Qutb and another member of the Brotherhood, Muhammad al-Ghazali, say the State can and should promote social welfare in society. Abu-l-'Ala Mawdudi uses statements from the Qur'an to argue that the Islamic state should guarantee social justice. M. Umer Chapra has argued that it is the duty of an Islamic state to provide a reasonable standard of living, and feels that individual freedoms must be curtailed to provide for the needs of society.

### Muslims and Social Justice Today

In recent years, gender justice has been a significant social justice issue for many Muslims. Many Muslims (especially progressive ones) are seeking via scholar-

ship and organizations to advance women's rights (e.g., equality between men and women and the right to participate in politics) in an Islamic context (Stiles, 2012). While controversial, many Muslims are calling for a reinterpretation of the "sacred sources" in light of modern ideals. For instance, creating controversy, some have called for Islamic law ("shari'a") to correspond to modern notions of social justice. Areas of reform in some places include "women's rights in marriage and divorce, women's financial rights in marriage, and limiting or restricting polygamous marriages" (Stiles, 2012). Many organizations today work on social justice issues beyond gender and legal reform, including poverty, education, and economic development. Some Muslims now feel that environmental degradation is a type of injustice since the poor are disproportionately affected by it. Indeed, the Qur'an has "injunctions proclaiming humanity's stewardship of the earth" (Stiles, 2012). There are Muslim advocates for the protection of land and biodiversity.

Gender justice is a concern for some Muslims today.

### 2.2.6 Jewish

Social justice "is inseparable from the Jewish creed " (Hellinger, 2012). The value of the individual is acknowledged, but Judaism puts a great emphasis on the strong bond between the individual and the community. Community plays a crucial role in an individual's life. "Collective Jewish identity is both religious and national" (Hellinger, 2012). Individuals are required to help the weak and there are clear public obligations to do so. "The community was required to provide educational, health, and welfare services, raising the necessary funds partly through institutionalized public taxation" (Hellinger, 2012). Jewish perspectives on morality "accord great importance to social justice" (Hellinger, 2012). Jewish religious traditions hold that "justice functions both as a moral virtue and as a personal and collective religious duty" (Hellinger, 2012). "Prophecy injected into Judaism a moral passion and deep concern for the plights of humanity and society, including a consciousness of how urgent it is to correct social inequities and strengthen justice on the practical plane" and "God's principal concern is with the needs of widows and orphans" (Segal, 2012).

#### The Jewish Notion of Social Justice

The basis in the bible for the egalitarian view of justice is that humans were created in the image of God. The relationship between God and humans is the basis for all moral, social, and political issues, and hence foundational to social justice. Human dignity comes from the creativity and majesty of God. Humility is important in some streams of Judaism. Respectful humility must be used in confronting environmental issues and interpersonal relations. Humans are called to be holy, gracious, and compassionate. In the Talmud it says: "As He clothes the naked, so do thou also cloth the naked." There are close connections between tsedek (justice), tsedakah (charity), and righteousness. The call to be just is based on the belief that God is just and this to be emulated.

The Jewish faith supports tsedek (justice) and tsedakah (charity).

The Jewish view of social justice is strongly influenced by the orientations in Judaism of universalistic individualism (the common ground of all humanity) and Jewish-particularistic collectivism (placing Jews at the center of creation so they have immanent spiritual uniqueness and intrinsic superiority). Jewish tradition has elements of both these, with relative weight given to each depending on different formulations of Jewish philosophy. Even the famous phrase "love thy neighbor as thyself" in interpreted in both contexts depending on the interpretation of the  meaning of "neighbor" as being all of humanity or only Jews. The universalistic and particularistic views have survived till today.

Social justice based on the universalistic perspective would strongly oppose restricting social justice only to Jews, with no concern for universal injustice and distress. A relevant Jewish prayer identifies the need "to perfect the world and to restore it to its pristine condition; to make the world a better place" (Hellinger, 2012). Along with this view, subgroups of Jews feel that every Jew must make a contribution to universal social justice. Based on this, many rabbis joined the civil rights movement and the fight against apartheid in South Africa. Also, following this view the lesson of the Holocaust teaches the duty to fight against oppression, racial discrimination, and genocide.

Social justice from the particularistic perspective places an emphasis on the Jewish community. Such Jewish communality is based on the biblical notion of the covenant (e.g., between God and the people of Israel). The love between God and the Jewish people is the basis for love between Jews, and for compassion between Jews. The strictly particularistic perspective is opposed to an egalitarian view toward Israeli Arabs.

*The universalistic and particularistic views result in different conceptions of Jewish social justice, either toward only Jews, or toward all humanity.*

### Charity in Judaism

There is not an unequivocal stand on liberalism (e.g., political structures to support the "welfare state" and income redistribution) vs. libertarianism (which would be morally opposed to taxing the rich at higher rates) in Judaism. There is a dominant trend, however, to approve or not be opposed to private property, to be socially aware and assist the weak via charity, and a mandate to support social justice. Judaism does not support socialist tendencies or extreme liberal capitalist ideas. Limitation on private property, however, arise from the view of the individual as a part of the Jewish collective and its solidarity and the belief that humans were created in God's image.

"The Hebrew Bible and the Talmud do not disapprove of accumulating possessions as long as it is done honestly and moderately" (Hellinger, 2012). Wealth is viewed as a gift from God to be used for "mitzvoth" (a good deed done from religious duty) and charity.  Talmudic sages denounced those who pursued wealth and possessions for their own sake, but Judaism finds no problem with gaining wealth and material success. "According to the Talmud, the Divine Presence is more likely to rest on a wealthy man than a poor one, provided he also excels in other things" (Hellinger, 2012).

The duty to work is considered a religious value in Judaism. Work is not a degrading burden, but a virtue leading to happiness. Maimonides says that

*The Jewish faith supports "mitzvoth" (a good deed done from religious duty) and charity.*

there is a "duty to take from public coffers when life is at risk, but forbidding it when driven by the wish to avoid hard work" (Hellinger, 2012). Great importance is given in the Jewish tradition to charity and justice, and having compassion for the weak. The Torah insists on helping the poor, fatherless, widows, and strangers. Practicing charity and justice binds the individual, society, and its institutions. Jewish tradition in no way shares the view with libertarian capitalistic view that helping the weak is mainly a voluntary compassion, with little state involvement. "Judaism accords great weight to the individual face of the recipient of charity and makes sure that he or she is treated with warmth and dignity by the community" (Hellinger, 2012).

Human dignity cannot be achieved in the presence of uncontrolled capitalism. Laws of charity dictate that the community give the poor clothing, house furnishings, and marriage expenses due to the dignity of the poor. While people have a right to private property, this right is limited since everything belongs to God. Moreover, there is the view that God commands that farmers not harvest the corners of their field to leave it to the poor. According the Rabbinic interpretations, a community can take from the rich without committing a moral injustice. There is a tithing obligation to benefit the poor, and restrictions on the ability to collect debts from the poor.

The Jewish social justice perspective says that "voluntary personal assistance should go hand in hand with communal, institutional, and state assistance, which is to be funded by mandated charitable contributions" (Hellinger, 2012). There are three levels of charity. First, there is the personal level where individuals should be charitable. A number of Jewish views feel that charity is prioritized, first to family members, then relatives, then persons in your city, in other cities, and so on. Also, it is felt that concern for the poor should include the individuals' emotional state. The second level of charity is that of the group towards the poor (i.e., the communal aspect). At the third level, it is felt that Jews can be forced (e.g., by the community or state) to give charitably.

The goal of charity to the poor is to make them independent. "Those who are unwilling to make an effort and prefer to live at the expense of others or the state must be denied support" (Hellinger, 2012). The approach toward developing countries should not just include charity, but also enhancement of occupational opportunities. Central to the Jewish view of social justice is the support of education of all, including the poor.

## 2.3 Secular Perspectives

Three secular perspectives are considered: Rawlsian justice, Sen's idea of justice and development as freedom, and engineering ethics (where a critique of current approaches to teaching engineering ethics is given per a social justice perspective).

### 2.3.1 John Rawls's Justice as Fairness

John Rawls was an influential philosopher who worked in a number of areas, including political and moral philosophy, and of particular importance here, he developed the notion of "justice as fairness" (presented in (Rawls, 1971) and later updated in (Rawls, 2001); this section is based on (Rawls, 2001) and all quotes in this section are from (Rawls, 2001) and I even frequently use his section headings). In this section, a brief overview of his theory is presented. A number of parts of his work are ignored, most notably his arguments to support his views and claims. His work is still controversial. I do not cover others' views on his work, except in Section 2.3.2 where I will cover some of Amartya Sen's objections.

Rawls mentions the term "social justice" in his book, but seems to contract it to the use of "justice" since he covers many types of justice (local, domestic, global, background, etc.) including what he calls social justice. Rawls's justice as fairness is a "political conception of justice" rather than comprehensive religious, philosophical, or moral doctrine, yet is general enough to allow such doctrines to influence key aspects of political justice. Also, it is not the application of some comprehensive doctrine of justice to the basic structure of society. He views his political philosophy as "probing the limits of practical political possibility." He assumes at the outset the existence of a democracy and makes extensive use of that assumption. He essentially asks what a perfectly just (or nearly just) constitutional regime would look like, whether it could occur, and be stable. Rawls calls this "realistically utopian." You could think of Rawls's theory as providing a definition of an ideal goal for a society.

**Fundamental Ideas**

Rawls's views society as a "fair system of social cooperation over time from one generation to the next." Citizens in such a society are free and equal. Society is "well-ordered" in the sense that it is regulated by a "public conception" of justice. The features of social cooperation include the following:

1. Social cooperation is guided by publicly recognized (and accepted) rules and procedures.

2. Terms of cooperation are "fair" in the sense that each participant reasonably accepts (or should accept) them if everyone else accepts them. Such terms involve reciprocity or mutuality: if you do your part, you are to benefit in a way that is publicly agreed upon.

3. The notion of cooperation includes the idea that each participant has "rational advantage" or good (i.e., what it is that those cooperating seek to achieve for their own good).

"Principles of justice" (more on this below) specify fair terms of social cooperation. Such principles indicate the rights and duties for key political and social

institutions, regulate the division of benefits from social cooperation, and assign the necessary "burdens" to sustain it.

A "well-ordered society" (a "considerable idealization") is one in which "society is effectively regulated by a public conception of justice," and has the following three features:

1. Everyone accepts, and knows everyone else accepts, the same political conception of justice.

2. The basic structure of society is known and understood to meet the principles of justice.

3. Citizens "understand and apply the publicly recognized principles of justice" and largely "act accordingly as their position in society, with its duties and obligations, requires."

Given that there will be "reasonable pluralism" (a variety of people with different views), it is impossible for a well-ordered society to have all its members agree on a comprehensive doctrine (a religious one). Yet, it is possible in a democracy for citizens to hold different comprehensive doctrines and there to exist agreement on political conceptions of justice.

The "basic structure" of society is how key political and social organizations fit together into a system of social cooperation, and how they assign basic rights and duties, and regulate the division of advantages that arises from cooperation. The notion of justice as fairness regulates the basic structure, but does not apply to (or internally regulate) institutions or associations in society (e.g., firms, labor unions, churches, universities, and families). "Justice as fairness is a political, not general, conception of justice." Its primary target is domestic justice. Questions of local justice (principles applying directly to institutions and associations) or global justice (e.g., involving international law) need to be separately considered; however, to some extent Rawls starts from domestic justice and works toward local and global justice (but this is in his other works and is not covered here).

How shall the "fair terms" of social cooperation in a society to be arrived at? He considers religious or moral orders, but rejects these due to the presence of reasonable pluralism and his view that people cannot agree on a moral authority (e.g., sacred texts, traditions, or religions). Rawls says fair terms should be based on an agreement by the members engaged in social cooperation. Such an agreement must occur under certain conditions to be a valid argument from a political justice perspective. Citizens must be situated in this agreement in fair, free, and equal conditions (e.g., so that none has an unfair bargaining advantage over another and threats of force, coercion, deception, and fraud are not allowed). Justice as fairness extends the notion of a fair agreement to the basic structure. A key difficulty is to "specify a point of view from which a fair agreement between free and equal persons can be reached; but this point of view must be removed from and not distorted by the particular features and circumstances of the existing basic structure." The "original position," with a feature of the "veil of ignorance" gives this point of view.

The original position is a viewpoint from which fairness between free and equal persons is judged.

In the original position the following hold:

1. Parties (citizen's representatives) "are not allowed to know the social positions or the particular comprehensive doctrines of the persons they represent."

2. Parties do not know persons' race, ethnicity, sex, or their "native endowments" (degrees of intelligence, physical strength, etc., all within the normal range).

These two stipulations are the parties' veil of ignorance. "To persons according to their threat advantage" (due to their political power, wealth, or native endowments) is not the basis for political justice. Historical advantages and accidents "should not affect an agreement on principles that are to regulate the basic structure."

The original position idea is used to extend the notion of a fair agreement to "an agreement on principles of political justice for the basic structure." The position assumes free and equal people that are informed and rational; hence, agreements made by the parties are fair. The agreement in the original position specifies fair terms of social cooperation between citizens (this is why Rawls calls it "justice as fairness"). The agreement is hypothetical "since we ask what the parties (as described) could, or would, agree to, not what they have agreed to," and nonhistorical: "since we do not suppose the agreement has ever, or indeed ever could actually be entered into. And, even if it could, that would make no difference." The agreement represents "fair conditions under which the representatives of citizens, are to agree to the fair terms of cooperation," and it represents acceptable restrictions on the reasons on the basis of which parties, situated in fair conditions, may properly put forward certain principles of political justice and reject others."

Persons engaged in social cooperation have "the two moral powers:"

1. *The capacity for a sense of justice:* The capacity to understand, apply, and act from (not just in accordance with) "the principles of political justice that specify the fair terms of social cooperation."

2. *The capacity for a conception of good:* The capacity to have, revise, and rationally pursue a conception of good (ends and aims that specify a person's idea of what is of value in human life, or, said another way, "what is regarded as a fully worthwhile life"). Elements of this conception are often set by comprehensive religious, philosophical, or moral doctrines which order and explain ends and aims.

Justice as fairness views citizens as "free" in two ways:

1. Citizens view themselves and others as having a conception of good (even if they change it over time).

2. Citizens "regard themselves as self-authenticating sources of valid claims." They view themselves as entitled to make claims on institutions to advance

their idea of good (if their idea falls within "the range permitted by the public conception of justice").

A political conception of justice has three features:

1. It is a moral conception for the basic structure of a democratic society (it does not directly apply to associations and groups in society).

2. It is not assumed that the moral conception is based on a single comprehensive doctrine. It is a "reasonable conception for the basic structure alone and its principles express a family of political values that characteristically apply to that structure."

3. It is formulated to the greatest extent possible "solely in terms of fundamental ideas familiar from, or implicit in, the public political culture of a democratic society."

The political conception of justice "establishes a shared basis for citizens to justify to one another their political judgments: each cooperates, politically and socially, with the rest on terms all can endorse as just." This is the meaning of "political justification."

It is not expected that all will agree on all political questions, but it is expected that disagreements can be narrowed, particularly to get agreement on constitutional essentials:

1. Principles that specify the general structure of the government and political processes (legislature, executive, and judiciary, along with limits of majority rule).

2. Equal basic rights and liberties that must be respected (e.g., by legislative majorities) such as voting rights, right to participate in the political process, freedom of thought, freedom of association, liberty of conscience, and protections of the rule of law.

"Justice as fairness hopes to put aside long-standing religious and philosophical controversies and to avoid relying on any particular comprehensive view." It seeks "a public basis of justification that all citizens as reasonable and rational can endorse from within their own comprehensive doctrines." Rawls calls this an "overlapping consensus" of reasonable doctrines (see below also).

Citizens have a capacity for reason and a sense of justice. Our judgments may differ from others, or even conflict with each other. How can we get consistency of judgments without an imposed political authority? Justice as fairness views all rational judgments as intrinsically reasonable. For a single individual, when they consider a political conception of justice and bring their judgments in line with it (with the fewest possible changes), then that individual is said to be in "narrow reflective equilibrium" ("narrow" in the sense that we "looked for a conception of justice that called for the fewest revisions to achieve consistency, and neither alternative conceptions of justice nor the force of the various

*It is assumed that in the presence of reasonable pluralism an overlapping consensus can be reached on constitutional essentials.*

arguments for those conceptions have been taken into account" by the individual). For an individual, a "wide reflective equilibrium" is achieved via a careful consideration of "alternative conceptions of justice and the force of various arguments for them." Suppose each member in a society has achieved wide reflective equilibrium; this results in society-wide (full) "reflective equilibrium" since all agree on the same political conception of justice.

Consider a democracy with a permanent feature of reasonable pluralism. Given pluralism, and the fact that there will be a variety of different doctrines, there is no doctrine that everyone can agree to and hence settle the questions of political justice. The political conception of justice can, however, be established via a "reasonable overlapping consensus." Rawls feels that this is the "most reasonable basis of political and social unity available to citizens of a democratic society." Citizens agree with two distinct views: (i) a political conception of justice; and (ii) that there are opposing doctrines (religious, philosophical, and moral) in society. A persistent adherence to only one comprehensive doctrine can only be maintained by oppressive state power (via crimes, brutality, and cruelty). A political conception of justice must be endorsed by "widely different and even irreconcilable comprehensive doctrines" or the regime cannot endure or be secure.

It must be acknowledged that reasonable disagreement can occur and arise from:

1. "The evidence–empirical and scientific–bearing on a case may be conflicting and complex, and thus hard to assess and evaluate."

2. Even if there is agreement on what needs to be considered, there may be different views on how these should be weighted.

3. The vagueness of concepts leads to indeterminacy so we must rely on judgments and interpretations within some range.

4. Different persons have different experiences and this causes a divergence of judgments.

5. Often, there are different normative considerations on each side of an argument that make an overall assessment difficult.

Rawls recognizes that a number of doctrines are "incompatible with the values of democracy." The political conception of justice does not outweigh religious, philosophical, or moral values though it may possibly conflict with these.

### Principles of Justice

"Once we view a democratic society as a fair system of social cooperation between citizens regarded as free and equal, what principles are most appropriate to it?" Suppose that the "fundamental social and economic inequalities are the differences in citizens' life-prospects (their prospects over a complete life)." These inequalities are affected by social class of origin, native endowments, educational opportunities, health care opportunities, and luck or bad luck over a

life time, among others. When are such differences in life prospects "legitimate and consistent" with the notion of free and equal citizens in a fair system of social cooperation?

Rawls assumes political society is "closed" in the sense that you are born into it and die in it and cannot enter or leave it voluntarily. He also claims that political power is always coercive power; however, in a constitutional regime political power is the citizens' power they impose on themselves and others as free and equal persons. The fact of reasonable pluralism and collective political power give raise the issue of "political legitimacy." For what reasons, and due to what values, can citizens legitimately use coercive power over each other? Rawls claims it is only legitimate when consistent with the constitution that all reasonable and rational citizens endorse.

What principles of justice should be used to specify basic rights and liberties and regulate social and economic inequalities? Rawls proposes two principles of justice to address this question (quoted exactly):

1. Each person has the same indefensible claim to a fully adequate scheme of equal basic liberties, which scheme is compatible with the same scheme of liberties for all; and

2. Social and economic inequalities are to satisfy two conditions:

    - (a) First, they are to be attached to offices and positions open to all under conditions of fair equality of opportunity; and

    - (b) Second, they are to be to the greatest benefit of the least-advantaged members of society (the difference principle).

*Rawls's two principles of justice are about equal rights and liberties, and social and economic inequalities.*

The principles are ordered as follows: 1, 2a, and then 2b. This ordering means that it is assumed that prior principles are fully satisfied. Fair equality of opportunity requires demands that all have a fair chance to attain all offices and positions. What does "fair chance" mean? Rawls says "supposing that there is a distribution of native endowments, those who have the same level of talent and abilities and the same level of willingness to use these gifts should have the same prospects of success regardless of their social class of origin." He goes on to say that "certain requirements must be imposed on the basic structure" and in particular the "free market system must be set within a framework of political and legal institutions that adjust the long-run trend of economic forces so as to prevent excessive concentrations of property and wealth, especially those likely to lead to political domination."

Distributive justice pertains to how the basic structure should be regulated "so that a fair, efficient, and productive system of social cooperation can be maintained." It is not just about how to allocate commodities. Assuming 1 and 2a are satisfied by the basic structure, the distribution of wealth and income is considered to be "pure background procedural justice." Rawls says that: "background institutions must work to keep property and wealth evenly enough shared over time to preserve the fair value of the political liberties and fair

equality of opportunity over generations. They do this by laws regulating bequest and inheritance of property, and other devices such as taxes, to prevent excessive concentrations of private power." Not only does the basic structure need to be regulated, but also "free transactions between individuals and associations." Rawls emphasizes that our prospects in life are affected by "the means and opportunities we can realistically expect" that affect our hopefulness and optimism about the future; he sees justice as promoting further desires and aspirations.

In 2b Rawls refers to the "least-advantaged." Who are they, and how are they identified? To answer this question, he defines "primary goods" to be "various social conditions and all-purpose means that are generally necessary to enable citizens adequately to develop and fully exercise their two moral powers, and to pursue their determinate conceptions of the good." Primary goods are those needed and required to fully cooperate in society, they are not simply wants, desires, preferences, or cravings, even if these are rational. Rawls uses a political conception, not a comprehensive moral doctrine, to specify needs and requirements. Rawls identifies five kinds of primary goods as follows (quoted exactly):

1. The basic rights and liberties: freedom of thought and liberty of conscience, and the rest. These rights and liberties are essential institutional conditions required for the adequate development and full and informed exercise of the two moral powers (in the two fundamental cases).

2. Freedom of movement and free choice of occupation against a background of diverse opportunities, which opportunities allow the pursuit of a variety of ends and give effect to decisions to revise and alter them.

3. Powers and prerogatives of offices and positions of authority and responsibility.

4. Income and wealth, understood as all-purpose means (having an exchange value) generally needed to achieve a wide range of ends whatever they may be.

5. The social bases of self-respect, understood as those aspects of basic institutions normally essential if citizens are to have a lively sense of their worth as persons and to be able to advance their ends with self-confidence.

The inequalities that the difference principle applies to are "differences in citizens' (reasonable) expectations of primary goods over a complete life." Expectations are life prospects. If all citizens have equal basic rights and liberties (principle 1) and fair opportunities (principle 2a), then the "least-advantaged are those belonging to the income class with the lowest expectations." The social cooperation scheme of society is to be chosen so that the least-advantaged "are better off than they are under any other scheme." Rawls's view of primary goods is within a political conception of justice, not some comprehensive religious, philosophical, or moral doctrine.

The difference principle in 2b is subordinate to 1 and 2a. A social scheme of cooperation results in a distribution of wages and salaries between the advantaged and disadvantaged groups. All things equal, the difference principle directs society to maximize the income of the group of advantaged, but only to the extent that it will not reduce income to the disadvantaged group. If the expectations of the advantaged are less, so are the expectations of the least-advantaged. The difference principle demands that no matter how great the differences in income and wealth are, the inequalities must effectively contribute to the least advantaged. "Otherwise, inequalities are not permissible." Inequalities are to benefit both ourselves as well as others. Hence, Rawls views the difference principle as a principle of "reciprocity" (exchanging things for mutual benefit).

Principles of justice must be assessed from the point of view of equal citizens and ones with different levels of income and wealth; however, other positions must sometimes be taken into account such as those based on gender and race. So, if men have greater rights and opportunities these can only be justified if they are to the advantage of women and are acceptable to them. The same idea holds for minorities. It seems though that the inequalities are of no advantage to women and minorities. This has implications for the difference principle.

Justice as fairness accepts "the moral worth of a person's character as a whole (and of a person's several virtues) as given by a comprehensive moral doctrine; as well as the moral worth of particular actions." It also recognizes legitimate expectations and entitlements, and the idea of "deservingness" given by "a scheme of public rules designed to achieve certain purposes." Rawls feels that "moral worth or character and actions cannot be incorporated into a political conception of justice in view of the fact of reasonable pluralism."

Rawls says we do not "deserve" our native endowments. He views the difference principle as an agreement to view the distribution of natural endowments across people (in particular, the differences in native endowments among persons) as a common asset, and to share the benefits of the distribution. It is not that the distribution is a common asset; by agreeing to the difference principle "it is as if they agree to regard the distribution of endowments as a common asset." The "distribution" of native endowments is viewed as a common asset, not specific person's native endowments (society does not owns specific individual native endowments). Rawls feels that people own their own native endowments due to recognition of basic rights and liberties. Rawls asks if it is "possible for persons free and equal not to view it a misfortune (though not an injustice) that some are by nature better endowed that others." Rawls says "the better endowed (who have a more fortunate place in the distribution of native endowments they do not morally deserve) are encouraged to acquire still further benefits–they are already benefited by their fortunate place in that distribution–on condition that they train their native endowments and use them in ways that contribute to the good of the less endowed (whose less fortunate place in the distribution they also do not morally deserve)."

**The Argument From the Original Position**

The original position is a representation of two things (quoted exactly):

1. It models what we regard–here and now–as fair conditions under which the representatives of citizens, viewed solely as free and equal persons, are to agree to the fair terms of social cooperation (as expressed by principles of justice) whereby the basic structure is to be regulated.

2. It models what we regard–here and now–as acceptable restrictions on the reasons on the basis of which the parties (as citizens' representatives), situated in those fair conditions, may properly put forward certain principles of justice and reject others.

Rawls goes on to say:

It is essential that the parties as rational representatives be led to the same judgment as to which principles to adopt. This allows that a unanimous agreement can be reached. The veil of ignorance achieves this result by limiting the parties to the same body of general facts (the presently accepted facts of social theory) and to the same information about the general circumstances of society: that it exists under the circumstances of justice, both objective and subjective, and that reasonably favorable conditions making a constitutional democracy possible to obtain.

The veil of ignorance does not allow the parties to know the comprehensive doctrines and conceptions of good of the citizens they represent. Clearly, justice as fairness will not work without parties' agreement on the principles of justice.

To ensure that an agreement on the principles of justice is "effective" and supports a public basis of justification for those principles there must also be an associated agreement on guidelines for public inquiry and criteria on the type of information and knowledge relevant to discussing political questions, especially when these involve constitutional and justice basics. Hence, the original agreement as two parts (quoted exactly):

1. First, an agreement on the principles of political justice for the basic structure (for example, those of justice as fairness); and

2. Second, an agreement on the principles of reasoning and the rules of evidence in the light of which citizens are to decide whether the principles of justice apply, when and how far they are satisfied, and which laws and policies best fulfill them in existing social conditions.

Comprehensive religious, philosophical, and moral doctrines can be used by individuals in public reason. Such doctrines inform others of their point of view and basis to support a public political conception of justice. The political values stated via justice as fairness include values of political justice including equal political and civil liberty, fair equality of opportunity, social equality,

and reciprocity via the difference principle. Justice as fairness also represents values of public reason, including guidelines of public inquiry, steps to ensure that inquiry is free and public, and informed and reasonable. Public civility is needed. In summary, "public reason is the form of reasoning appropriate to equal citizens who as a corporate body impose rules on one another backed by sanctions of state power." Of course, private discussions, including those in private associations, are freely allowed.

"No basic liberty is absolute, since these liberties may conflict in particular cases and their claims must be adjusted to fit into one coherent scheme of liberties." It is the whole scheme of liberties that has priority in the statements of the principles of justice. Each of the basic liberties has fundamental importance and "could not be compromised unless doing so were unavoidable." The priority of liberty (item 1) over inequality (item 2) implies that a basic liberty can "be limited or denied only for the sake of one or more other basic liberties, and never for a greater public good understood as a greater net sum of social and economic advantages for society as a whole." One basic right is to possess and have sole use of personal property. However, persons do not have the right to private property in natural resources (for production, acquisition, and bequest) which are socially owned.

Justice as fairness is egalitarian (views all people as being equal) in the sense that it regulates economic and social inequalities:

1. It views gross inequalities in economic and social conditions as wrong and that all citizens should have enough to meet basic needs.

2. It seeks to prevent one part of society from dominating the rest. Large inequalities tend to support political inequality.

3. Large political and economic inequalities are often associated with inequalities of social status that "encourage those of lower status to be viewed by both themselves and by others as inferior." Among the least-advantaged this leads to deference and servility, while among the most advantaged it promotes a will to dominate and arrogance.

4. Even when a society uses just procedures, inequalities can be wrong or unjust. For example, open and workable competitive markets and fair political elections. These require equality or regulated inequality to get economic or political justice (e.g., to avoid monopolies or dominance of political processes by a few wealthy individuals).

*Justice as fairness is egalitarian and regulates economic and social inequalities.*

### Institutions of a Just Basic Structure

Rawls acknowledges that his stands on the "just basic structure" are controversial. He considers five types of regimes with their political, economic, and social institutions: laissez-faire capitalism (i.e., unrestricted capitalism), welfare-state capitalism, state socialism with a command economy, property-owning democracy, and liberal (democratic) socialism. With respect to any such regime, there are four questions Rawls considers:

1. *Right and just:* Are the institutions right and just?

2. *Design:* Can its institutions be designed to meet its declared aims and objectives?

3. *Compliance:* Can citizens with their own interests and goals reliably comply with just institutions and applicable rules (this raises the issue of corruption)?

4. *Competence:* Are the tasks assigned to offices and positions simply too difficult?

Whether the above regimes satisfy Rawls's two principles of justice is considered via these questions:

1. *Laissez-faire capitalism:* Ensures equality and "rejects fair value of equal political liberties and fair equality of opportunity." It seeks economic efficiency and growth "constrained only by a rather low social minimum."

2. *Welfare-state capitalism:* Rejects fair value of political liberty, but does have some concern for equality of opportunity (but polices for that are not followed). It permits "very large inequalities in the ownership of real property (productive assets and natural resources, including the possibility of monopolies) so that control of the economy and much of political life rests in few hands." It may result in generous welfare provisions to meet basic needs of everyone, but "the principle of reciprocity to regulate economic and social inequalities is not recognized." Problems of creation of an underclass chronically dependent on welfare, and with little involvement in political culture, exist.

3. *State socialism with a command economy:* Supervised by a one-party regime, it will violate equal basic rights and liberties (and fair value of these liberties). The command economy follows a general plan from the party and makes little use of democratic procedures or markets (except to ration).

4. *Property-owning democracy or liberal socialism:* Both these, in their ideal form, can satisfy the two principles of justice. They set up a constitutional framework for democracy, guarantee liberties and their fair value, fair equality of opportunity, and regulate economic and social inequalities via "mutuality," if not the difference principle. In liberal socialism the means of production are owned by society (but private property is allowed), it could be assumed that economic power is dispersed across firms (e.g., if a firm's management is elected by workers). Compared to a state socialist command economy, firms under liberal socialism use "free and workably competitive markets." Free choice of occupation is assured. Property-owning democracies seek to: (i) disperse wealth and capital to enable citizens to fully cooperate and to prevent relatively few people from controlling the economy and politics; (ii) "put all citizens in a position to

manage their own affairs on a footing of a suitable degree of social and economic equality" (i.e., enable citizens to cooperate); (iii) it seeks to ensure that the least-advantaged are not simply objects of charity, compassion, and pity, but ones that are owed reciprocity as a matter of political justice as free and equal citizens; and (iv) while the least-advantaged may control fewer resources "they are doing their full share on terms recognized by all as mutually advantageous and consistent with everyone's self-respect."

"Just institutions and the political virtues would serve no purpose–would have no point–unless those institutions and virtues not only permitted but also sustained conceptions of the good (associated with comprehensive doctrines) that citizens can affirm as worthy of their full allegiance." Given reasonable pluralism it is assumed ideas are shared by citizens and the group does not presuppose any particular comprehensive doctrine. Six ideas of good are in justice as fairness (to be thought of as achieved in sequence):

1. *Goodness as rationality:* It supposes that citizens have a plan of life that involves scheduling endeavors and allocating resources to pursue their idea of good throughout their life. This assumes that human existence and fulfillment of basic needs and purposes are good, and that "rationality is a basic principle of political and social organization."

2. *Primary goods:* These specify needs of citizens as free and equal persons.

3. *Permissible conceptions of the good:* Only those concepts of good are allowed, if when pursued are compatible with the two principles of justice.

4. *Political virtues:* These specify the ideal of "a good citizen in a democratic regime."

### The Question of Stability

The question of whether justice as fairness is "stable" is whether it "is able to generate sufficient support for itself." Can the political conception of justice gain the support of a diversity of comprehensive doctrines via an overlapping consensus (leading to the political conception of justice) that lasts over many generations (i.e., is stable)? Unreasonable comprehensive doctrines cannot come to dominate to compromise justice of institutions. So, Rawls tries to come up with a political conception of justice that is sound and reasonable, and then he says we need ways (i.e., state power) to bring others who reject it or do not follow it, to do so. He feels that justice as fairness is not even reasonable unless it is stable. If some means of persuasion or enforcement can be found, the political conception is considered stable. Rawls views stability for justice as fairness in a different way than this. He assumes a reasonable human psychology and normal conditions in life for those who grow up with just institutions and then feels that citizens acquire "reasoned and informed allegiance" to institutions sufficient to render them stable. He feels that citizens' sense of justice when they live under a just basic structure is strong enough to resist typical tendencies to injustice.

The type of stability needed by justice as fairness aims to be acceptable to citizens as reasonable and rational (and free and equal).

Given the ideas of reasonable pluralism and an overlapping consensus, it is not expected that a political conception of justice arises via a "balancing of forces between" comprehensive religious, philosophical, or moral doctrines. For instance, to specify a list of primary goods, a "center of gravity" of an "index" (measure) of these goods could be specified. This would seem to ensure that the index would advance conceptions of good by doctrines and hence help ensure an overlapping consensus. But, this is not the approach of justice as fairness. Rawls hopes that via fair social cooperation an index of primary goods is found. Citizens holding different views that together support the political conception of justice "will not withdraw support for it if the relative strength of their view increases and becomes dominant" (the political conception is not affected by the distribution of political power).

Finally, Rawls feels that there is a relation between citizens seeing their political society as good, and its stability. If they view political society as good for themselves both taken as a whole and as individuals, they appreciate the political conception of justice. Also, they will then not be encouraged by envy, spite, the desire to dominate, and "the temptation to deprive others of justice."

### 2.3.2 Amartya Sen's Idea of Justice and Development as Freedom

Amartya Sen is from India (Delhi University), but has lived in England (Cambridge University) and the US (Harvard University). He was the winner of the 1998 Nobel Prize in economic systems. He is a prolific author; here, synthesis and summary of the books (Sen, 2000, 2011) is provided (the main things left out are the examples and many comparisons he makes between his approach and others, often arguments to justify his approach). Quotes in this section are from (Sen, 2011), unless otherwise specified. Some section headings come from (Sen, 2011).

Generally speaking, there are two types of theories of justice. In the first type, the focus is on defining an ideal just system (e.g., ideal just society). An example of this is the Rawlsian "justice as fairness" (which is called "transcendental institutionalism"). In the second type, there are "comparative" theories of justice. Sen's approach is one of these. In a comparative theory of justice the focus in on formulating a theory in terms of how to make changes to increase justice and remove injustices. Sen's comparative theory is a "realization-focused comparison," based on what actually happens in lives and institutions. The aim is to use practical reasoning and scrutiny about how to proceed in improving justice. There may be divergent conclusions (e.g., lack of agreement on priorities or obligations) in how to improve justice, and this will be discussed more below. Sen highlights a number of advantages of a comparative over a transcendental approach, including: (i) there may be no agreement on what is ideal, (ii) the ideal may not be realizable anyway, (iii) knowing the ideal does not necessarily tell you how to improve justice when you are in a non-ideal state, and (iv) you

do not need to know the ideal in order to make incremental improvements in justice or avoid injustices for current conditions. Rawls's focus was on ideal just institutions in a single country; Sen's considers institutions and includes the behavior of people living their lives. He points out that in early Indian jurisprudence, there are two concepts of justice, and he discusses these throughout his book: *niti*, is about organizational propriety (rules of behavior considered conventionally to be correct) and behavioral correctness, and *nyaya* is about what emerges and how, and the lives people are actually able to lead. Sen seeks a global theory of justice, not just one for, for instance, a country or region.

### The Demands of Justice

Sometimes the smart thing to do is to help others (e.g., if it helps you). There may also be good reasons, other than personal gain, to help others. Being smart helps you understand how your actions can affect the lives of others. Quite a few people reject the notion that it is irrational or stupid to do good things for other people. "What we owe each other is an important subject for intelligent reflection." Sometimes we may rationally decide to allow others to try to achieve their goals by restraining ourselves in the pursuit of our own. These issues are discussed in the next section, while here we discuss the issues of public reasoning and justice, and the importance of global rather than just local perspectives on justice.

### Public Reasoning and Social Choice:

**What is the role of broad public reasoning in justice?** Free and open public reasoning and debates are critical for democracies and the pursuit of social justice. In public reasoning, Adam Smith (father of modern economics and author of The Wealth of Nations (1776) and The Theory of Moral Sentiments (1759)), felt that we need to have a variety of viewpoints developed from a diversity of experiences "from near and far," rather than those from only some narrow local group (with entrenched tradition and culture), to perform public reasoning. Adam Smith introduced the notion of the "impartial spectator," a person who would provide a non-biased perspective and inputs to (local) public reasoning. Such a concept helps to add fairness to a system of justice, and has a number of beneficial features:

*Public reasoning promotes social justice in democracies.*

1. It helps deal with comparative assessment of how to promote justness;

2. It can identify features of social realizations (what is actually happening);

3. May provide an incomplete assessment, but guidance on achieving social justice, and in particular avoiding injustices; and

4. To help others avoid being locked into their own local, traditional, or cultural viewpoints.

Moving beyond local perspectives and opinions, global perspectives matter too. The world outside a country's borders must enter into the assessment of justice for a country. First, what happens in a specific country (e.g., institutions) can have a significant impact on other countries (e.g., decisions to go to war). Second, local tradition and beliefs need global examination and scrutiny to make sure the right questions are asked, to critique assumptions, and to consider (perhaps) widely divergent views.

Sen feels that impartiality pays a central role in the public reasoning and evaluation of social justice. He discusses two types of impartiality. First, "closed impartiality" where no person outside (e.g., a country) enters into the public discussion (as in Rawlsian justice, even though he uses the veil of ignorance). Second, "open impartiality" involves persons from outside the focal group (e.g., country) to avoid "parochial bias;" this can be achieved by Adam Smith's notion of an "impartial spectator."

**What is the role of social choice theory in justice?** Next, Sen identifies the aspects of "social choice theory" (in addition to the focus on social realizations) that he feels are useful for his theory of justice. Summarizing the above discussion, these are (quoting):

1. Focus on the comparative, not just the transcendental;

2. Recognition of the inescapable plurality of competing principles;

3. Allowing and facilitating re-examination;

4. Permissibility of partial resolutions;

5. Diversity of interpretations and inputs;

6. Emphasis on precise articulation and reasoning; and

7. Role of public reasoning in social choice.

**Local vs. global view of justice?** Should justice only focus on a country and leave the rest to humanitarianism? Sen discusses two issues in connection with this question:

1. Ideas of obligation are important to justice. "To argue that we do not really owe anything to others who are not in our neighborhood, even though it would be very virtuous is we were to be kind and charitable to them, would make the limits of our obligations very narrow indeed." If we have concern for all people in the world, even if it is vague, then a theory of justice must include all of humanity, and not just from a humanitarian perspective.

2. Actions in one country can significantly impact other countries (e.g., via war, trade, and commerce). Hence, shouldn't the inputs of other countries be sought?

**Forms of Reasoning:**

**In evaluating injustices, how should we reason?** When reasoning, each person does this from a "positional perspective" ("position means where you live, language(s) you speak, conditions under which you live, education, culture you live in, etc.). Sen says that there is a need to break away from the limitations of our positional perspectives to assess justice. These limitations include what we can observe and what we can comprehend, and can affect our beliefs, understanding, and decisions. A change in positions can clarify an issue or distort it. Objectivity depends on position; hence true objectivity is position independent. Sen uses an illustrative example of women scientists. He says that a positional observation that there are few women scientists in a country may not be mistaken, but the conclusion that women are bad at science is erroneous. The position must be changed to draw proper conclusions. In other countries where women have more opportunities and facilities, there may be more women scientists and the new positional observation may lead one to conclude that women are just as good as men at science. The need for such alternative positional observations is especially acute in traditional societies where there is "protest-free tolerance social asymmetry and discrimination." An "objective illusion" is "a positionally objective belief that is, in fact, mistaken in terms of transpositional scrutiny" (that is, if a different position is taken, the belief is found to be wrong). As an example, illusions can occur when trying to do self-assessments (e.g., low-income people's self-assessment of the overall health status of low-income people); this teaches us that to assess justice problems positional variation is important. Understanding positions and illusions is important in assessing and promoting justice.

Who should we be concerned about when it comes to injustices? In reasoning about justice, there is a need to think about who to be concerned about, in general. There is a long history of feeling that it is most important to help your "neighbor" where that meant someone living close by. Sen points out that Jesus did not agree with this point of view, as witnessed by his story of the good Samaritan (someone from far away) helping a wounded man where others would not, whereupon he asked a lawyer who was the injured man's neighbor? The lawyer had to say that the Samaritan was his neighbor. When the Samaritan found themself in a new location, he defined it as his neighborhood. In the modern world we are linked in many ways (not just via physical travel), including global communications, political relations, and trade. Our increasing human-to-human interconnections widen the boundaries of justice and force us to all look at each human in the world as their neighbor.

**Is it rational to help remove injustices?** Rational choice theory, as studied today, typically says that people choose rationally if they intelligently seek to maximize their self-interest (a very narrow view of rationality). Sen has fundamental disagreements with this standard definition of rationality. He says "if a person finds it painful to live in a society with large inequalities, and that

> Your positional perspective affects how you reason about justice.

is the reason for his trying to do something to reduce those inequalities, then his self-interest is clearly mixed up with the social goal of reducing inequality." But, if "a person wants to lessen inequality, not for diminishing one's pain at seeing it, but because it is judged by him to be a bad thing for society (whether or not he is also pained at the sight of inequality), then the social arrangement must be distinguished from the personal pursuit of private gain" (this is a departure from self-interested behavior). That is, Sen says it can be rational to want to help reduce inequality. Sen proposes a different view of rational choice, where choices are based (implicitly or explicitly) "on reasoning that we can reflectively sustain if we subject them to critical scrutiny." Choices, actions, objectives, values, and priorities must be subjected to reasoned scrutiny (and not just a "gut feeling"). Rational choice as "critically scrutinized choice" allows for the possibility that more than one choice could survive the scrutiny (in this sense it is "permissive"). A person can be more altruistic than another and not be irrational, so long as they have critically scrutinized this choice. Adam Smith felt that there were reasons for acting outside of only self-interest, such as in areas of sympathy, justice, generosity, and public spirit. Sen says that a person may simply enjoy helping others and that is a good reason to do so. He also says that even if you do not agree with the goals of another person, that many not give you the right to place obstacles in the way of them achieving their own goals, but it may prompt you to be considerate of their goals though it may not prompt you to help them achieve their goals. It may be best to simply let them be.

> It can be rational to help reduce inequalities.

**Does everyone have an obligation to work to remove injustices?** While we may have rational concern for others, it is more difficult to argue "that there is some necessity or obligation to have such concern on grounds of rationality alone." When it comes to fairness to other people, Sen says that we must consider the demands of "reasonable conduct" towards them, including considering their perspectives and concerns, and consider these in scrutinizing our own decisions. He says that what is right and wrong for us to do depends on Scanlon's idea of what other's "cannot reasonably reject." He discusses public reasoning and the importance of having involvement of anyone with relevant interests, not just persons from one country. In public reasoning he agrees with Scanlon's "idea of a shared willingness to modify our private demands in order to find a basis of justification that others also have reason to accept." The principle of "non-rejectability" can lead to pubic reasoning that does not identify a unique set of principles of justice (like in the Rawlsian framework). There can be a "plurality of robust and impartial reasons" that result from each individual's scrutinized reasoning. Individuals may have their own priorities and viewpoints (e.g., feel that everyone has an obligation to reduce injustices), but not everyone will agree and it may be difficult to completely reject what are possibly their well-defended reasons.

**Cooperate to reduce injustices?** Assuming rational self-interest, it can be good to cooperate because there can be "mutual benefits" for all parties to

the cooperation (also, recall the central role of cooperation in Rawlsian justice). Moreover, parties to the cooperation may recognize that what is to be achieved is too big to achieve individually without cooperation of a group. Cooperation is sometimes essential to solve problems (e.g., with the environment, to avoid the "tragedy of the commons," work ethics in production processes, and "civic sense in urban living").   To enable or encourage cooperation there may be a need for enforced contracts (e.g., via laws) or promotion of social norms of behavior. There is a debate on which is needed, and when. But, what if someone has the power to reduce an injustice in the world? Are they obligated do to it? There is a strong social argument for them to use their power to reduce the injustice. However, this obligation stands in contrast to the mutual obligation for cooperation in terms of justification of motivation to reduce injustices. If a person is free to take an action, and the person assesses that the action is justice-enhancing, then that is a sufficient argument for taking the action. It need not be the case that mutually beneficial cooperation based on symmetry and reciprocity is the only motivation to address injustices.

*Cooperation is one approach to reducing injustices.*

**Realizations, consequences, and outcomes matter in determining what to do?**  Through reasoning via an example of moral issues surrounding war in Indian history (Arjuna and Krishna), Sen makes the points that (i) "what happens to the world must matter and be significant in our moral and political thinking" (you cannot just follow *niti* and ignore what will happen); (ii) when a decision has serious consequences one must take personal responsibility for choices; and (iii) when a decision has serious consequences for people you have an affection for (e.g., your children, spouse, or friends) it is natural that this "positional concern" is significant. Sen argues for the use of "consequence-based reasoning" (i.e., reasoning taking into account consequences) and the consideration of general "outcomes" of actions when reasoning about how to act justly. "The outcome" is "the state of affairs that results from whatever decision variable we are concerned with, such as action or rule or disposition." Sen says "comprehensive outcomes" "include actions undertaken, agencies involved, processes used, etc. along with the simple outcomes seen in a way that is detached from processes, agencies, and relations–what I have been calling "culmination outcomes."" "Agencies" are actions or interventions to produce a particular effect. So, comprehensive outcomes include everything, process and results whereas culmination outcomes are only what happens (results). This distinction will be used below.

**The Materials of Justice: Freedom and Capability:**

**How do we measure human advancement?**  For many years, economic measures have been used to measure human advancement (e.g., gross national product or individual income level); however, such measures can only be justified by what they do for human lives that they influence. More people, however, are increasingly recognizing the importance of using direct indicators of the quality

of human life, well-being, and freedoms in order to measure human advancement. It is important not to confuse "means" with "ends:" income and wealth are not important by themselves, but only "for what they help people to achieve, including good and worthwhile lives." Indeed, economic opulence and freedom are connected, but sometimes diverge. For instance, if you consider living a long life to be a freedom, length of life in economically deprived disadvantaged groups in rich countries (even if they are relatively wealthy compared to a low-income country) can be the same as that in a developing country (even if people there are much less wealthy as in the rich country). It seems that it is not the absolute level of income that determines length of life, but economic inequality in the country in which you live (see Problem 2.19). Increasing your income does not necessarily increase your length of life.

**What does freedom mean?** "In assessing our lives, we have reason to be interested not only in the kind of lives we manage to lead, but also in the freedom that we actually have to choose between different styles and ways of living." For instance, given freedom, we may choose to try to reduce injustices to others that have no apparent connection to ourselves. So, freedom is valuable because:

Freedom is the ability to choose between different styles and ways of living.

1. "Freedom gives us more opportunity to pursue our objectives" (what we value), and this is called the "opportunity aspect of freedom;" and

2. Freedom is important in the process of choice, what is called the "process aspect of freedom."

Above, what does "opportunity" mean? The freedom to put yourself in a position to choose between just two alternatives? Or more? What about the quality or type of the alternatives? Sen's distinction between a comprehensive and culmination outcome is relevant here. The opportunity aspect of freedom can be defined only in terms of the opportunity for culmination outcomes ("what a person ends up with"); if opportunity is seen that narrow way, then existence of options and freedom of choice is somehow unimportant. However, opportunity can be defined more broadly (and with greater plausibility) in terms of achievement of comprehensive outcomes by "taking note also of the way the person reaches the culmination situation (for example, whether through his own choice or through the dictates of others)." The breadth of the definition of opportunity is central in moving from freedom to the idea of a person's capabilities. Is the capability to lead the kind of life you want to assessed only on culmination outcomes, or also the process of choice, the choices available, and the ability to choose these?

Freedom has an opportunity aspect and process of choice aspect.

**The capability approach to assessing justice and injustice:** It is important to establish an "informational focus," that is, to decide which features to consider in evaluating whether there are justices or injustices. In utilitarianism, the informational focus is on, for example, individual happiness or pleasure,

to assess how advantaged a person is, and to compare to the advantages of others. That is, only a single feature is used. The libertarian information focus is on rights (e.g., property rights) and liberties (e.g., unrestrained capitalism); hence, their conclusions about justice are very different. The libertarian information focus does not include happiness or desire fulfillment like utilitarianism. Libertarianism's sole focus on (and prioritization of) procedures for liberty and entitlements has a deliberate neglect of derived consequences, including "rather terrible results" (Sen, 2000) (an exceptional exemption to the libertarian prioritization of liberties is given by what Nozick, a leading libertarian theorist, calls "catastrophic moral horrors"). Another common approach in economics is to assess people's advantages via their income, wealth, or resources (i.e., using say 1-3 features). This information focus results in the "resource-based approach" to assessment. In Sen's "capability approach" (which does not deny the importance of income, wealth, and resources) individual advantage is assessed "by a person's capability to do things he or she has reason to value." Hence, someone's opportunity advantage is judged to be lower than someone else's if she has less capability (less real opportunity) "to achieve those things that she has reason to value." The assessment focus is on the freedom that an individual actually has, given their capabilities. What we value the most is especially important for us to be able to achieve. But, the idea of freedom explained above respects that we are free to choose what we want, value, or decide to choose. Hence, capability is closely linked with the opportunity aspect of freedom viewed in terms of comprehensive opportunities and not just what happens at culmination.

What types of "capabilities" are important to our lives? Building on Sen's work, in (Nussbaum and Glover, 1995) the authors claim that a life that lacks any one of the following capabilities, "no matter what else it has, will fall short of being a good human life" (list quoted, items 1-12):

1. Being able to live to the end of a human life of normal length, not dying prematurely, or before one's life is so reduced as to be not worth living.

2. Being able to have good health; to be adequately nourished; to have adequate shelter; having opportunities for sexual satisfaction, and for choice in matters of reproduction; being able to move from place to place.

3. Being able to avoid unnecessary and non-beneficial pain, so far as possible, and to have pleasurable experiences.

4. Being able to use the senses; being able to imagine, to think, and to reason–and to do these things in a way informed and cultivated by an adequate education, including, but by no means limited to, literacy and basic mathematical and scientific training.

5. Being able to use imagination and thought in connection with experiencing and producing spiritually enriching materials and events of one's own choice; religious, literary, musical, and so forth. They believe that the protection of this capability requires not only the provision of education,

In the capability approach to assessing justice, individual advantage is assessed by a person's capability to do things he or she has reason to value. Assessment is based on an individual's freedom, given their capabilities.

There are essential capabilities that are important to people's lives.

but also legal guarantees of freedom of expression with respect to both political and artistic speech, and of freedom of religious exercise.

6. Being able to have attachments to things and persons outside ourselves; to love those who love and care for us, to grieve at their absence; in general, to love, to grieve, to experience longing and gratitude. Supporting this capability means supporting forms of human association that can be shown to be crucial in their development.

7. Being able to form a conception of the good and to engage in critical reflection about the planning of one's own life. This includes, today, being able to seek employment outside the home and to participate in political life.

8. Being able to live for and to others, to recognize and show concern for other human beings, to engage in various forms of social interaction; to be able to imagine the situation of another and to have compassion for that situation; to have the capability for both justice and friendship. Protecting this capability means, once again, protecting institutions that constitute such forms of affiliation, and also protecting the freedoms of assembly and political speech.

9. Being able to live with concern for and in relation to animals, plants, and the world of nature.

10. Being able to laugh, to play, to enjoy recreational activities.

11. Being able to live one's own life and nobody else's. This means having certain guarantees of non-interference with certain choices that are especially personal and definitive of selfhood, such as choices regarding marriage, childbearing, sexual expression, speech, and employment.

12. Being able to live one's own life in one's own surroundings and context. This means guarantees of freedom of association and of freedom from unwarranted search and seizure; it also means a certain sort of guarantee of the integrity of personal property, though this guarantee may be limited in various ways by the demands of social equality, and is always up for negotiation in connection with the interpretation of the other capabilities, since personal property, unlike personal liberty, is a tool of human functioning rather than an end in itself.

The capability approach says what types of features to focus on, and does not specify a formula on how to use or combine information. Inequality of capabilities is quite relevant in assessing social inequalities, but again, it does not specify a formula to quantify this (e.g., to set policy). There is no implicit assumption that equality of capabilities must be sought. When assessing justice or injustice at a society level, the capability approach would draw attention to "expansion of human capabilities of all members of the society," but does not say how to deal with conflicts between accumulation of many capabilities by few

people (i.e., "aggregation") versus the spread of capabilities across many or all people (i.e., "distribution"). Yet, the capability approach can be quite useful in the assessment of institutions and societies, and for subsequent setting of policy.

The capability approach is concerned with many different features of human lives. Attainments of "human functioning" that we value are diverse, from being well nourished, being healthy, avoiding premature mortality, taking part in the life of the community, having shelter, to developing skills for work. "The capability that we are concerned with is our ability to achieve various combinations of functionings that we can compare and judge against each other in terms of what we have reason to value." Rather than just income or resources, the capability approach focuses on human life–it is a departure from focusing on "means" (e.g., via a resource-based method or as found in the Rawlsian use of "primary goods") to "actual opportunities of living." Sen feels, however, that the capability-based assessment approach could replace the Rawlsian primary goods; Rawls's focus on human freedom is quite compatible with Sen's ideas.

Some people feel that the focus should be on assessment of the actual achievement of human functionings, rather than the capability to choose between what to achieve. We can identify the value of a human's capability set (which is based on human functionings) with the value of the human functioning combination and this allows the capability approach to heavily weight achievement as measured by achieved human functionings. But, the capability approach is more general than a focus only on achieved functionings. Importance is also given to opportunities and choices. There are three additional issues: (i) "Even an exact "tie" between two persons in achieved functionings may still hide significant differences between the advantages of the respective persons which could make us understand that one person may be really much more "disadvantaged" than the other" (e.g., comparing a poverty-stricken person who is malnourished to a person who is fasting, we would say that their under-nutrition (achieved functioning) may be the same, but the capability of the well-off person who chooses to fast may be much greater); (ii) "The capability to choose between different affiliations in cultural life can have both personal and political importance," and there is a difference between "doing something and being free to do that thing" (e.g., for immigrants there is a decision as to whether to follow their old traditions and culture or to adopt those of their new country–the freedom of them to choose is central to the capability method, not what is achieved in the end); and (iii) "There is also a policy-related question that makes the distinction between capabilities and achievements important for a different reason" (e.g., in deciding about whether to provide some basic guarantee of healthcare, the central issue is providing humans the capability to improve their health–if they choose not to use the opportunity, then that deprivation is not as much of a "burning social concern" as the failure to provide the healthcare opportunity in the first place).

"Functionings and capabilities are diverse, as indeed they must be since they deal with different features of our life and our freedom." Capabilities are "non-commensurable" since it is not generally possible to judge and compare capabilities (e.g., by putting them all in the same units of measure–coming up

> Human functionings are valued attainments such as being healthy, participatory, and educated; capability focuses on attainment of valued functionings.

with a single numeric measure assessing "overall level of capability" based on a set of capabilities). But, to make decisions about justice and injustice, you do not need capabilities to be commensurable; we make decisions all the time based on non-commensurable objects (e.g., when we shop).

Public reasoning, involving scrutiny and critical assessment, is important in social evaluations that need good information and arguments to move beyond the reasoning of a single individual. For instance, public reasoning can result in a better understanding of (i) the "role, reach and significance of particular functionings and their combinations;" and (ii) "the choice and weighting of capabilities." The agreement on use of weights may not be complete; there may be a need to use some range of weights and partial orderings. But, we can still assess justices and injustices in this case.

Sen thinks of capabilities of individual humans, not groups of humans (e.g., communities or societies), but one can think of capabilities of groups also (e.g., a sports team). Should assessments of justice and injustice take into account capabilities of groups? First, capabilities do include social influences (e.g., the capability to participate in a group) and influences of public reasoning on their own lives. Groups have a deep influence on an individual's "thinking, choosing, and doing." Sen says "since groups do not think in the obvious sense in which individuals do, the importance of capabilities that groups have would tend to be understood, for reasons that are clear enough, in terms of the value that members of the group (or for that matter, other people) place on the proficiency of that group." Moreover, people are in many groups (e.g., gender or profession) and should not be thought of as only in one group.

**How to define sustainable development?** Some see the environment as a static state of affairs of nature that will stay pure so long as we do not pollute it (hence interfere with it as little as possible). This view is, however, defective for two reasons: (i) The value of the environment is not just based on the current state of affairs in nature, but also on what opportunities it offers people and how it impacts people; and (ii) We must engage in the active pursuit of preservation of the environment (e.g., via education and purification of water). The Brundtland Report says "sustainable development" is "development that meets the needs of the present without compromising the ability of future generations to meet their own needs." Solow defines sustainability as "the requirement that the next generation must be left with whatever it takes to achieve a standard of living at least as good as our own and to look after their next generation similarly." His focus is on sustaining living standards, which goes beyond "needs." But are sustained living standards enough? Sen says we need to sustain, and when possible expand, freedoms (including the freedoms to meet our needs and to live our life according to certain standards) and capabilities, and what humans value and have reason to think are important, without compromising these for future generations.

Sen says that sustainable development is a focus on sustaining or expanding freedoms and capabilities without compromising these for future generations.

**How are capabilities and resources related?** Income and wealth are not good indicators of the kind of life you can achieve (e.g., a disabled person may need a lot more income to achieve the same standard of life). The resources of income and wealth are often used as criteria for poverty. It is well-recognized that there are problems with the use of only such criteria. Rawls use of primary goods extends the traditional definition of poverty to include general means to live a good life, but his definition also has limitations. Different people have different abilities (that also depend on the environment in which they live, both natural and social) to convert income or primary goods into good living and valued freedoms. Variability in the ability to convert income into the kind of life people want to lead depends on:

1. *Personal heterogeneities:* Disabilities, age, gender, proneness to illness, etc.

2. *Diversities in the physical environment:* Climate, temperature ranges, flooding, pollution, depletion, etc.

3. *Variations in social climate:* Social conditions such as healthcare and epidemiology, public educational opportunities, prevalence of crime and violence, etc.

4. *Differences in relational perspectives:* Traditional patterns of behavior in a community (need to dress nicely) may affect the ability to transform income into social functioning (e.g., ability to appear in public and participate in a meeting).

There may be coupling between different sources of deprivation. Disabilities impair the ability to earn income, and make it more difficult to convert income into capability. Hence, real poverty, if you view "poverty as capability deprivation," can be more intense than a traditional income-based view of poverty. Distribution of resources and opportunities within a family creates even greater concerns with defining poverty in terms of income level. For instance, if girls are given less than boys, a measure of income of the family does not adequately characterize poverty of the individuals of the family (i.e., capability deprivation of each family member).

*Poverty is capability deprivation.*

Some of the most deprived individuals in the world are those with physical and mental disabilities (Sen says that more than 600 million people in the world, about one-tenth of all humans, have a significant disability–and 400 million of these live in the developing world), often having the lowest incomes and abilities to earn, but needing more income to achieve the same things as able-bodied people. Many of the tragic consequences "of disability can actually be substantially overcome with determined societal help and imaginative intervention" (e.g., many disabilities can be prevented). "If the demands of justice have to give priority to the removal of manifest injustice (as I have been arguing throughout this work), rather than concentrating on the long-distance search for the perfectly just society, then the prevention and alleviation of disability cannot but be fairly central in the enterprise of advancing justice." Sen feels

that the predominate focus on income levels (e.g., $1/day-2/day$) significantly mismeasures deprivation, with adverse effects on understanding what it means to be disabled, and feels that the capability approach provides a much better understanding in this case (which is important for policy considerations).

Since there are significant differences between primary goods (general means) and capabilities, Sen is skeptical of the difference principle. Rawls does, however, "recommend special correctives for special needs like disabilities" (at the legislative stage) even though this is not a part of his principles of justice. Rawls does not, however, concern himself with the differences in converting primary goods into opportunities (as discussed above). Sen feels that to adequately use "humane and sympathetic reasoning" those conversion issues must be taken into consideration. This impacts institutional structure and functioning.

**What is the relationship between happiness and capability?** Recall that if someone has the power to reduce an injustice, then there is a strong and reasoned argument for doing so. Does this power imply an obligation? Happiness does not generate obligations like capability does. Indeed, there is a major difference between well-being and happiness, and freedom and capability, with respect to obligations. Next, note that increased income does not necessarily improve happiness. Happiness is not the only thing we value, and not a good measure for other things we value. The capability to be happy is to be valued. Achievement of things we value often results in happiness, and unhappiness can result from a failure to achieve. Deprived people (income, gender discrimination, etc.) often adjust to their situation and modify their expectations and perceptions in light of a hopeless situation; thus they seek to build some joy into their lives. But, this self-generated happiness should not be used to judge this life conditions in the sense of underestimating injustice since they may be happy. Happiness is not a good measure of (capability) deprivation.

> Happiness is not a good measure of capability deprivation.

**How do we assess health and its impact on capability?** There are generally differences between a person's view of their own health and a doctor's assessment of the person's health based on observations and examinations. Pain and suffering may be poorly understood by a doctor, and hence the doctor may not understand its impact on a person's capabilities. On the other hand, a person's perception of their health is limited based on their knowledge and social experience. If a person lives in a low-income community with many illnesses but few medical facilities, then the person may view their illness as normal when it could be preventable. This is "adaptation to social circumstances" and it masks real problems and makes a person's assessment of the impact of their health on capability problematic. Due to these problems with assessments of persons and doctors it is difficult to assess the impact of health on capability and opportunity.

**What is the relationship between capability and well-being?** Capability is an aspect of freedom that focuses on opportunities. A person may

have a number of goals (agency), some of which correspond to their well-being. There are four ideas of human advancement and how it can be measured: well-being/agency achievement and well-being/agency freedom. "A person's capability can be characterized as well-being freedom (reflecting the freedom to advance one's own well-being), and agency freedom (concerned with the freedom to advance whatever goals and values a person has to advance)." Goals may be set by a person that have nothing to do with their well-being (e.g., if they have great capabilities and power they may set a goal of helping others that will not help their own well-being) so "capability seen as agency freedom can diverge from both the perspective of well-being achievement and that of well-being freedom."

**Does Sen support paying special attention to the most capability-deprived humans?** Per Rawls's total priority of liberty (his first principle of justice) over the second principle Sen says: "Why should we regard hunger, starvation and medical neglect to be invariably less important than the violation of any kind of personal liberty?" Sen is clearly concerned with the ordering of the first principle of justice before the second; hence, in this case he seems to indicate that top priority should be given to the second (opportunity and the difference principle), though he does not explicitly say that, in general. Next, Sen asks the following question: "Why must any violation of liberty, significant as it is, invariably be judged to be more crucial for a person–or for a society–than suffering from intense hunger, starvation, epidemics and other calamities?" Sen is essentially arguing that there are good reasons (at times) to consider Rawls's second principle of justice, and in particular, the role of the least-advantaged in the difference principle, as more important than the first principle (liberties). Overall, however, Sen agrees with Rawls that liberties have the first priority. Next, Sen says that assessment of aspects of justice need not be "totalist" (i.e., prioritized, certain, or complete). He says that Rawls's ranking of his two principles of justice "gives total priority to the minutest gain of the worst-off group even when this entails huge losses for groups that are not worst-off but are very badly off, on which quite different reasonable positions can be taken by impartial observers. There may also be varying reasonable compromises in balancing small gains in liberty, which is given priority in Rawls's first principle, against any reduction in economic inequality–no matter how large." It is interesting that Sen is perhaps most passionate in the whole book about doing something to help in the worse case–very low-income people who are also disabled. Finally, Sen says that while reduction of capability inequality deserves our attention, but so does increasing the capabilities of all.

**Equality of what?** Do we need equality of incomes? Of capabilities? Seeing people as equals relates to a demand for impartiality and objectivity. It is possible to view equality of capability as important without demanding it, possibly at the expense of other considerations that may be in conflict with it. Capability is a single aspect of freedom related to (substantive) opportunities but does not pay attention to fairness and equity of processes or "the freedom

of citizens to invoke and utilize procedures that are equitable." The capability approach just assesses the advantages and disadvantages of a person. But, justice must be concerned with more than that. Issues of fair process and fair deals go beyond a person's advantages. Returning to the issue, Sen says that he is concerned that there is no one demand for equality (e.g., along the lines of incomes, wealth, or capabilities). Considering equality of capability, there are many types of capability, so what type of equality of a single type of capability should be used (providing an incomplete picture)? Ranking of capabilities is not possible, and impartial rankings are possible. There are significant variations in specific capabilities and the choice of weights on specific capabilities (if one were to aggregate them to try to find a basis for quantifying equality). But, all this does not mean that it is not worthwhile to pay attention to reducing inequalities in capabilities. Again, Sen says that reduction of capability inequality deserves our attention, but so does increasing the capabilities of all.

**What is the relationship between capability and liberty?** Suppose you replace in Rawls's justice as fairness framework, primary goods by capabilities to assess the advantages and disadvantages of individuals. Recall Rawls's two principles of justice, the first of which had to do with liberties and the second of which had to do with opportunities and the difference principle. Recall that Rawls gave first priority to the liberties. As mentioned above, Sen asks the following question: "Why must any violation of liberty, significant as it is, invariably be judged to be more crucial for a person–or for a society–than suffering from intense hunger, starvation, epidemics and other calamities?" Sen is essentially arguing that there are good reasons (at times) to consider Rawls's second principle of justice, and in particular, the role of the least-advantaged in the difference principle, as more important than the first principle (liberties). Overall, however, Sen agrees with Rawls that liberties have the first priority.

**What are freedom and liberty?** Some types of ("instrumental") freedoms include political freedoms, economic facilities (e.g., to engage in the market), social opportunities (e.g., education and healthcare), transparency guarantees, and protective security (Sen, 2000). "Unfreedoms" include famines; undernutrition; lack of access to healthcare, sanitation, or clean water; susceptibility to disease; and denial of political liberty and basic civil rights (Sen, 2000). Freedoms are related to one another; having one can enhance another. Freedoms help people help themselves, a central issue in development. Sen views freedoms as the "means" and "ends" of development (Sen, 2000). Earlier, the process and opportunity aspects of freedom were discussed. "The question of whether a person can bring about the objects of her reasoned choice is crucial to the idea of freedom of which the notion of capability is a part." A person can bring about the objects of her reasoned choice through her own actions (call this "direct control"). But there is also "indirect power" where others act on her behalf (e.g., a lawyer, doctor, or relative), using what Sen calls "effective power," to bring about the objects of her reasoned choice. An example of use

of effective power by another person, that does not violate a person's freedom, is when a doctor saves a severely injured and unconscious patient from death. In this case, the patient's freedom has been affirmed since the doctor is guided by what the patient would have wanted. In this case, Sen says the patient has "effective freedom." This idea arises in other contexts, for instance, when health officials seek to avoid or eliminate regional epidemics (what the people are known to want), the people in the region still have effective freedom though none of them have control over decisions about management of the epidemic. Next, note that bringing about the objects of a person's reasoned choice may involve neither direct control nor indirect power, it may simply be due to luck.

Some people consider freedom and liberty to be the same and hence use them interchangeably. Rawls has concern with freedom of personal lives, and freedom from interference by others (e.g., the state). Rawls is also concerned with people's freedom to live their lives as they would like; liberty not to be interfered with by others. In the "republican" theory of freedom by Pettit, "liberty is defined not just in terms of what a person is able to do in a certain sphere, but also includes the demand that others could not have eliminated that ability of this person even if they wanted to do so." Hence, liberty is compromised even by the threat of hindering freedom, even if the threat is not carried out. Pettit is opposed to the view of freedom as capability, "since a person may have the capability to do many things that are dependent on the favour of others, arguing that to the extent the person's actual choices (or achievements) are dependent in this way, he is not really free." "Dependence" here means, for instance, how a physically disabled person may need the help of others (who are available and willing) for mobility. The republican approach would say that such a person is not free, while the capabilities approach would say that they are (since their freedom is reliably enhanced by others). Sen says that living completely independent of others is difficult, and may not even be important. He acknowledges that the republican view of freedom adds to the capability perspective, but does not eliminate it. He feels freedom has aspects of capability, lack of dependence, and lack of interference.

Some have viewed liberty as only the individual's right to the choice of an action. Others recognize the social setting, interdependencies between humans, and outcomes. Sen feels that "liberty and freedom are not concerned only with the respective actions, but also what emanates from those choices taken together." He feels that both equality and liberty have several dimensions, that we should not adopt a narrow view of either, and that both, in their full complexity, should be a part of any theory of justice.

### Markets, State, and Social Opportunity

This entire section is based on (Sen, 2000) where Sen argues that a balanced outlook on markets is needed: the market may be essential, and may have benefits, but it also has defects.

**What are the adverse impacts of not using the market?** Since freedom is of basic importance, freedom of market transactions is of basic importance. Humans "have good reasons to buy and sell, to exchange, and to seek lives that can flourish on the basis of transactions." It is well-known that markets are efficient; however, this does not mean anything about equity of outcomes or equity of distribution of freedoms. Many of the restrictions on the market in developing countries today (and supposedly socialist countries of yesterday) are of the "pre-capitalist" type: prohibition of some types of domestic or international exchange or preservation of antiquated techniques and production methods (e.g., businesses owned and operated by the rich), that both result from a "restricted competition" mindset. In such cases, public discussion on these issues (via political freedom) can result in securing the freedom of economic openness.

Free markets have both benefits and defects.

**What market restrictions, if any, should there be?** Adam Smith argued that there should be a restriction against usury; he wanted legal restrictions on maximum interest rates on loans. He was also concerned about the possibility of social loss when persons only pursue self-interest (e.g., effects on the environment). Sen argues against a single-faceted approach to development (e.g., "open the markets"), and for a multi-faceted, integrated, and comprehensive approach that tries to make progress on all fronts.

It is standard that the market approach assumes that all commodities ("private goods," everything on which our welfare depends), can be bought and sold in the market and its efficiency is based on this. But, key contributions to human capability can be difficult to sell to one person at a time and hence the market does not apply. Consider "public goods" that people consume together rather than as individuals. Examples include the environment, defense, policing, epidemiology, and public health care. For instance, if one individual buys a malaria-free environment, his neighbor gets it also without having to pay. Education has a mixed private-public nature: purchasing an education can benefit an individual, but if many do that it can facilitate social change and economic development in a whole area so that others benefit also.

**Should public provisioning be provided?** The implication of the above discussion is a support for "social provisioning" (public expenditures) to meet basic capabilities like elementary health care and educational opportunities. But, will public support provide proper incentives, encourage initiative, or distort individual efforts? Does free public education incentivize people to get an education, encourage them to take the initiative to go far in their education, or discourage efforts to get a private education? Frequently, people see many reasons to get a good education (including fulfillment), not just economic reasons. One can also ask if such social opportunities are needed, and whether individuals should just pay for them by themselves rather than via public provisioning. Some see education and healthcare as a basic right; however, they can only be provided in light of availability of a limited amount of resources.

World-wide "means-testing" based public provisioning is often used where the rich pay more than low-income people ("targeting") to stretch resources further. This raises issues of assessment of capabilities, and economic conditions (to determine if they can pay). Ambitious targeting can result in distortions including an "information distortion" since there will be miss-assessments of poverty and richness levels resulting in errors; "incentive distortions" that result from targeted support affecting a person's economic behavior (e.g., prospects of loosing public support if you earn too much); "disutility and stigma" that result from identifying someone as "poor" resulting in lack of self-respect and respect by others; "administrative costs, invasive loss, and corruption" that result from needing to target, the resulting violations of privacy, and the power relationship that administrators have over applicants that can result in, for instance, bribery; and "political sustainability and quality" can become a problem since targets of social support are typically weak politically.

### Public Reasoning and Democracy

Democracy is often thought of as a Western idea and approach (e.g., what has happened over the past few centuries in the US and Europe), but there were earlier experiments with democracy in, for instance, some areas in India. Democracy can be seen as "government by discussion" and hence it gives a central role to public reasoning in a society. Central to democracy are political participation, dialogue, and public interaction. As discussed earlier, the demands of justice can only be assessed via public discussion so there is a central connection between democracy and justice.

**What is the role of the press?** A free and independent press is very important for the promotion of public reasoning. Free media, and the free ability of people to communicate with each other, enhances quality of life. The press helps inform the people about the issues. The press has a "protective function" in being a voice for the neglected and disadvantaged. Investigative journalism can uncover problems. While leaders may be insulated from the problems of the people (e.g., their misery and effects of famine or disaster), the press provides criticism that provides motivations to leaders (e.g., in getting elected) to address problems. Indeed, "no major famine has ever occurred in a functioning democracy with regular elections, opposition parties, basic freedom of speech and a relatively free media (even when the country is very poor and in a seriously adverse food situation)." There is extensive evidence that democracy, political rights, and civil rights enhance human security. Also, democracy gives the opposition to current leadership the opportunity to push for policy changes in the face of chronic problems, not just acute and sudden ones (e.g., a famine).

**Is democracy good for development?** Or, is an authoritarian approach better? Focusing on human lives, rights, and freedoms, democracy certainly fairs better. In terms of economic growth, there is no empirical evidence that an authoritarian approach does better (considering cases of fast economic growth

of several countries). "Democratic freedom can certainly be used to enhance social justice and a better and fairer politics."

**Does democracy, based on majority rule, respect the rights of minorities?** Will a ruthless majority abuse the minority? What about sectarian strife and inter-community hostilities promoted by extremists? First, "formation of tolerant values is thus quite central to the smooth functioning of a democratic system;" the political process itself must promote tolerance. Second, broader values that cross divisive borders must be promoted. People have many affiliations (religion, region, language, profession, etc.) and democracy provides a way to highlight these affiliations and "their rival claims over religious divisions." Democracy, by uncovering the plural identities of humans, promotes tolerance. Of course, the press plays a very important role in this process; it makes everyone (each group) aware of "the problems, predicaments, and humanity" of everyone else (every other group).

**Human rights?** Intellectuals have doubts about, and criticize them, but activists promote them in trying to solve urgent world problems of severe deprivation. One set of human rights is given in the United Nations Universal Declaration of Human Rights (1948). Such lists of human rights are ethical assertions, not propositions about what are currently protected by law. Rights, however, can serve as a basis for establishing new legislation. Sometimes, however, the reach of human rights is not advanced via law, but via non-governmental organizations (NGOs) seeking to promote human rights via their defense or via eliminating capability deprivation. Human rights are ethical affirmations of paying attention to freedoms (process and opportunity aspects), and for including a freedom as a human right. For instance, by affirming the right not to be tortured, the importance of the human freedom not to be tortured is acknowledged. What freedoms should be codified into rights, ones for all people in the world? Certainly, each right must survive reasoned scrutiny to be judged as a human right, but is full universal agreement needed to adopt a right (e.g., a racist or sexist person might not agree)? The answer to this question may depend on "agreements" (e.g., majority opinion) within a democratic society when the rights proposal is subjected to full public reasoning.

**Duties and our perfect and imperfect obligations?** What are the duties associated with each right? What should we do to help each other to defend and promote our freedoms? Sympathy is not the only reason to help. Sen agrees with Raz's view that "rights ground requirements for action in the interest of other beings." Sen says that: "the basic general obligation here must be to consider seriously what one can reasonably do to help the realization of another person's freedom, taking note of its importance and influenceability, and of one's own circumstances and likely effectiveness." Not everyone must rise to help everyone else meet their human rights; however, if you "are in a position to do something effective in preventing the violation," then there is good reason to

do that. While the nature of your obligations, and of others, is often ambiguous, this does not mean there is no obligation at all. Kant says there are two types of obligations: "imperfect obligations" and "perfect obligations" which can be thought of as clarifying the meaning of "duty" to meet a human right with an underlying freedom. If a group of people watch a terrible crime (assault) against a woman (a violation of her freedom and her right not to be injured by others), then the person committing the assault has a "perfect obligation" not to do that, but the persons in the group watching each have an "imperfect obligation" to help. A similar scenario with the focus person being severely low-income (severely capability deprived) can be constructed. The (ambiguous) imperfect obligation can be avoided only if the rest of humanity (except those directly involved) is "exempted from any responsibility to try to do what they reasonably can to help" (i.e., in the example, all members of the group cannot reasonably do anything to help).

**Should there be economic, social, and welfare rights?** These are sometimes called "second-generation rights." Is there an entitlement to subsistence and medical care? Viewing poverty's connections to human rights has made changes in policy. Sen points to Crocker's work, in which he says "the long-term goal of good and just development–whether national or global–must be to secure and adequate level of agency and morally basic capabilities for everyone in the world–regardless of nationality, ethnicity, religion, age, gender, or sexual preference." Inclusion of second-generation rights makes such a proposal possible.

There are two types of critiques of rights: "institutionalization" and "feasibility." The institutionalization critique focuses on economic and social rights and is concerned with identifying the corresponding duties for these. They say there is no right unless the duty is institutionalized. Social organizations can satisfy imperfect obligations for social rights. Next, in the related feasibility critique, it is argued that even with great efforts some economic and social rights cannot be realized for all. In Sen's view, just because rights are not fully realized for all, does not mean that we cannot make further progress toward their realization; hence, it is unfair to reject some rights based on an assessment of infeasibility now. Lack of achievement motivates further social action.

**Justice in the world?** Injustices often relate to social divisions, linked to "divisions of class, gender, rank, location, religion, community" it is often difficult to overcome such barriers to get an objective analysis of what is really happening, and what could have happened, something needed to advance justice. "Resistance to injustice typically draws on both indignation and argument." Frustration and outrage over injustices may motivate us, but reasoned scrutiny and assessment of injustices, along with public reasoning in the presence of plurality, are needed for addressing underlying problems to remove injustices, even though more than one course of action may be suggested. It is important that decisions are just, and are seen as being just; otherwise, implementing a

solution is adversely affected and its soundness is problematic. Broad public reasoning about justice, including impartial observers "at a distance" (e.g., in other countries) is of significant importance to justice (e.g., to avoid parochialism). Also, doing what is just in one country may adversely impact other countries (globalization of trade and communications has brought us all closer). We need a global view of justice. As Sen points out, Dr. Martin Luther King, Jr. said in 1963 in a letter from a Birmingham jail, "injustice anywhere is a threat to justice everywhere." He also points out that in 1651 Hobbes noted that the lives of people were "nasty, brutish, and short," and that it is largely the same today; his theory is concerned with rectifying that problem. Indeed, in spite of the world's deep problems, in the end Sen holds out hope for justice since humans can understand, sympathize, argue, altercate, communicate, cooperate, and respond.

### 2.3.3 Engineering Ethics and Social Justice

Here, the basics of engineering ethics are discussed, then these are related to social justice in the context of humanitarian engineering. This results in a call for reconsideration of conventional engineering ethics content when it is used in a global context.

#### Basics of Engineering Ethics

Engineering ethics and professionalism are important enough to be required in many university educational programs (e.g., in all US engineering programs via ABET requirements), and are in some ways even more important for the field of humanitarian engineering. The standard approach to engineering ethics is to learn the principles, then to discuss or debate "case studies" that illustrate the main concepts. There is a wide range of case studies that are available, for example, via the National Society of Professional Engineers (NSPE) "Board of Ethical Review" cases, or the Online Ethics Center. The key concepts from engineering ethics from (Martin and Schinzinger, 2005; Harris et al., 2014) are outlined next.

**Professionalism:** Historically, engineering has had a significant impact on the welfare of humanity through the technologies engineers have created, ones that have driven economic development, alleviated toil and suffering, and enhanced health and education. This forms the basis and justification to call engineering a "profession." Being a professional means having competence, integrity, good conduct, and some feel that it also requires "service," broadly defined (e.g., to the profession, colleagues, or community) while others reject such a notion. Engineering is a profession, but different from other professions (e.g., medical ones) in that it is sometimes said to be "invisible" in the sense that it often operates in the background and most people do not know about engineers' role in technology that greatly impacts their lives (e.g., engineers create new medical technology, such as a for EEG/EKG, or diagnostic equipment, but medical

doctors use these with patients, and typically the patient knows nothing about how those technologies came to be via engineering efforts). To understand engineering professionalism, it is indeed good to compare to other professionals like medical doctors and lawyers, the nature of their "direct-contact" professions compared to the "invisible profession," and the impact of that, and the pro bono (free) work they often do for clients (e.g., at free medical and legal aid clinics), on perceptions of their professions relative to engineering (Passino, 2009).

**Codes of Ethics, Ethical Dilemmas, and Decision Making:** Codes of ethics exist for the NSPE, each engineering discipline in the US, and also for many international engineering organizations. Every engineer should read their own code of ethics at least once. A key statement in several codes of ethics is that engineers must "hold paramount the safety, health, and welfare of the public" (or a similar statement). While codes of ethics provide inspiration and broad guidance in ethical decision making, they are typically not helpful in solving basic ethical problems that are encountered in the daily life of an engineer. Indeed, there is no way to codify solutions to all the possible cases and eventualities; hence generic approaches to ethical decision making are applied to specific cases that are encountered. The key issue to be addressed in ethical decision making is the moral dilemma, and not cases that are obviously immoral (e.g., stealing from a company). There are two common strategies for confronting moral dilemmas and making a choice about what to do: (i) gain moral clarity on the issues, know the facts, consider options (e.g., a creative middle solution), and make a reasonable decision (Martin and Schinzinger, 2005); and (ii) "line-drawing" where features of a case study in engineering ethics are placed, one per row, in a left-hand column of a table and in the adjacent column place a label "completely unethical," and next, a column labeled "fully ethical," with a line drawn from one extreme to another for each case study feature; then, an "X" is placed where you assess the case feature to be on the scale from completely ethical to fully unethical (and a "bold X" for a really important feature), and, finally, considering all the X positions on the lines, make an assessment of the balance between unethical and ethical to make a decision about the overall case (Harris et al., 2014).

**Moral Frameworks:** These are used to make connections between engineering codes of ethics and morality as it is used in everyday life. There is utilitarianism ("do the most good for the most people"), which is different from engineering "cost-benefit analysis," rights ethics (human rights), duty ethics, virtue ethics (which emphasizes character), self-realization ethics and personal commitments (e.g., "community-oriented self-realization ethics where you pursue self-realization and try to enrich the community), and aspirational ethics which encourages behavior like an "exemplary" engineer (Martin and Schinzinger, 2005; Harris et al., 2014).

**Engineering as Social Experimentation:** Technology development by engineers involves a process over many iterations of a technology (versions) where after the initial design and manufacturing, a product or process is released and used (tested) by the public. Sometimes, injuries or deaths occur that were unanticipated by the engineers, but they get customer data and for the next version try to improve the technology to make it safer, and the process repeats (Martin and Schinzinger, 2005). This happens not just with respect to safety, but also health, the environment, and other aspects of a solution's impact in a social setting. Often, engineers make decisions about how to design technologies in the face of significant uncertainty, and quickly provide a technological solution that may have many negative consequences, especially in cases where testing the technology before release is impossible.

**Safety and Risk:** Safety almost always costs money, and if you invest more money, a product is often safer, or there is less risk associated with its use. However, absolute safety is never attainable: the key question for the engineer is how much to spend to achieve an acceptable level of safety. When is it acceptable to cut cost, for example, to lower a product's cost to get more sales, but injure or kill more people (e.g., for an automobile)? For some products or technological systems, engineers spend a significant amount of time on "risk-benefit analysis" to assess the trade-offs.

**Engineer's Rights and Responsibilities:** There are certain standards of professionalism in the workplace including competence, conduct, and commitment. Teamwork is important, as is loyalty to a company, and collegiality. It is important for both managers and engineers to be professional and set a professional tone in a workplace. Confidentiality issues (e.g., proprietary information) and conflicts of interest (e.g., issues of bribes and kickbacks, or having interests in other companies, or insider information) arise frequently and must be dealt with in an ethical manner. Engineers have important rights, which include a "right of professional conscience" (moral autonomy), a right of conscientious refusal, a right to recognition, and a right to fair pay. Clearly, engineers have a right to equal opportunity, nondiscrimination, not to be sexually harassed, etc. Under certain conditions, an engineer has a right to "whistle-blow," that is, take information outside an organization, or around organizational channels, in order to alert the public to a serious issue that might affect their safety, health, or welfare. Justification and motivation for whistle-blowing may come from the profession's code of ethics via, for instance, a statement like "hold paramount the safety, health, and welfare of the public."

**Honesty:** There is a very high standard for truthfulness in engineering; dishonesty about a technology, in particular its performance or safety features, and impact on health and well-being, are serious issues. It is simply highly unethical to lie about (e.g., distort) such issues due to the ramifications for the public. Credit must be given where it is due, for example, on an engineering

team. Trustworthiness is important to clients, and so that the public learns to trust engineers so when they make recommendations in order to improve safety, health, and welfare, they are trusted. As an example of honesty issues, normally academic integrity among engineering students is addressed (e.g., cheating on tests, plagiarism, or fabrication of experiment results) in class. Research integrity is discussed with a focus on graduate students in the university. Issues there include honesty in reporting results, conflicts of interest, protecting human and animal research subjects, failure to give credit, and misleading listing or ordering of authorship. Special issues arise for consulting engineers including deceptive advertising in order to get business, and allowing the funding of the project to impact professional technical judgment. Expert witnesses and advisors are hired to represent one "side" on an issue (e.g., in court) yet they must give a balanced objective technical judgment, without undue influence from the persons paying them or their personal ideology.

**Environmental Ethics:** If the technology or technological process you create destroys the environment, then it impacts the health of humans and hence goes against the mandate to "hold paramount the safety, health, and welfare of the public." Self-interest of companies (in making money) cannot be relied on to preserve the environment. Indeed, the principle of the "tragedy of the commons" (e.g., air and oceans) says that unregulated commons will be over-exploited and hence ruined if self-interest rules the day (see Section 1.6.7). The UN World Commission on Environment and Development, in "Our Common Future," 1987, (BC, 1987), "sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (see Section 1.3). For engineers, "sustainable design" often involves "life-cycle design" or "end-to-end design" where every aspect of the process, from materials selection to product end-of-life and recycling the disassembled pieces, is considered from the perspective of how it affects the environment (see Section 4.7.9). There are a number of versions of environmental ethics that are typically discussed, ranging from concern only for humans, to include animals, plants, or all living beings. Religious/faith perspectives are sometimes considered (e.g., as in systems of social justice).

**Global Issues:** Issues of multinational corporations performing technology transfer give rise to ethical issues (Martin and Schinzinger, 2005), and the need for "appropriate technology" (most suitable technology for the country it is to be transferred to–sometimes simpler, easier to maintain with local services, easier to fix with local materials, more rugged, etc.), as discussed in Section 4.6.3. Engineer's moral responsibilities on a global scale give rise to a range of ethical issues including the "when in Rome, do as the Romans" problems: (i) Whose environmental/disposal rules to follow?, (ii) What should workers be paid in a manufacturing facility ("fair wage")?, and (iii) What degree of safety is acceptable when operating in another country (Martin and Schinzinger, 2005)? Other global issues arise, including whether engineers should unionize, and computer

ethics (privacy, privacy vs. security, free speech, pornography, and hate speech) (Martin and Schinzinger, 2005). Engineer's involvement in weapons development raises ethical issues: Are all types of weapons good? Land mines? Cluster bombs that do indiscriminate killing of civilians also? Weapons of mass destruction, including nuclear, chemical, and biological weapons? Almost always, engineers cannot control what is done with the weapons they create, even in a democracy. Trade policies are set by others and often dictators are sold weapons (simply to make profits) to enable oppression of their people. Yet, most feel that defense of your country is honorable, military humanitarian intervention is needed at times, and if done properly, counter-terrorism efforts are needed. But, often such issues are not even discussed in engineering ethics classes/treatments, or at least not to any level of depth. For a brief treatment of some of these issues see Problem 4.56 on engineers' involvement in weapons development and law enforcement, and also Problem 4.57 on humanitarian military intervention.

### Infusing Engineering Ethics With Social Justice

Apparently, there has been little work done on explicitly connecting social justice and engineering ethics, though one could argue that principles of social justice are naturally infused into engineering ethics via culture, and dominance of a religion or philosophy in a country. To start to more firmly connect social justice to engineering ethics, consider that the statement "hold paramount the safety, health, and welfare of the public" should be different for humanitarian engineering since the clients are not the standard ones in the developed world where this statement came from. There are many differences: socio-economic, cultural, environmental (importance of sustainability), and an especially low "welfare" (well-being). Yet, there are also many aspects that are the same between the "public" in developed and developing countries: fundamental value of human life (the same value for someone making $1 per day PPP as someone making $100,000 per year), concerns about safety, health, and environment, though such concerns may be accentuated as the lives of the public may be more fragile in the developing world. Moreover, the humanitarian engineer who is trying to do something "good" may be especially concerned that only bad things are achieved (e.g., a technology having some positive impact in one respect, but a significant unforeseen negative side effect on people's lives, as discussed in Section 4.9). While the principles of engineering ethics clearly apply, the above differences and similarities between the "publics" result in a number of changes in how to view the principles and topics in engineering ethics for humanitarian engineering. Changes in how to view the basics of engineering ethics are covered below, in the order that the basics were presented above.

**Existence and Projection of Professional Image:** The key aspects of being a professional, such as competence and conduct, remain in force, but a humanitarian engineer may emphasize the importance of directly helping (e.g., helping a community) by the actions they take, more than a typical engineer (see Section 4.1). They will often "project" the image of the profession in the

direction of "service" just like a medical doctor does who works in a free medical clinic. The humanitarian engineer, cannot however, deny the fundamental importance of competence and conduct. The more (technically) competent you are, the better you will be able to help. Your conduct has a fundamental impact on the process of helping with integrity. By saying that a humanitarian "emphasizes" the service aspect of professionalism, does not imply that other aspects of being a professional are allowed to be substandard. If a large group of engineers project an image of service to the public, the reputation of the profession of engineering will change, hopefully for the better. There is also a problem identified in (Harris et al., 2014): not all cultures even have a conception of the notion of "professional." If you do not have such an idea, much of engineering ethics is different.

> The professional humanitarian engineer has excellent competence and conduct.

**Changing the Fundamental Ethical Dictate in Engineering:** While the systematic approaches to analyzing ethical dilemmas may remain the same, the details and conclusions at each step of those methods will clearly change for the "public" of humanitarian engineering. Basically, the impacts and trade-offs are different, so conclusions reached can be different. This can change the very way that codes of ethics for engineering are stated and applied. To give an example, consider what is arguably the most fundamental dictate (mandate) in engineering ethics: "hold paramount the safety, health, and welfare of the public." In humanitarian engineering, the level of emphasis on these three issues may change for the developing world, relative to the developed world. Moreover, it is easy to conclude that the statement itself is not satisfactory. How? Would a better statement be: "hold paramount the safety, health, and welfare of the public, and give special attention to these for the least advantaged (or privileged)." That is the basic mode of thinking of many humanitarian engineers, and is fully justified by many perspectives on social justice discussed earlier in this chapter. But, since this statement would apply to each individual engineer, some would argue that a better statement would be:

> The most fundamental mandate in engineering ethics, "hold paramount the safety, health, and welfare of the public," needs to be reconsidered to make it more compatible with principles of social justice.

> "hold paramount the safety, health, and welfare of the public, and encourage engineers to pay special attention to least advantaged (or privileged)."

In this way, individual engineers are not required to help the least advantaged (e.g., ones who have other responsibilities to a severely ill family member), but in a sense the profession is. See Problem 2.25. Another possible approach to restating the fundamental engineering ethics dictate would be to use the "inequality of technological capacity" idea earlier in the chapter (Section 2.1.2), coupled with the systems of thought on social justice. Clearly, the appropriateness of the fundamental dictate needs to be seriously considered by the profession, along with the wording of other aspects of codes of ethics, to reflect changing conditions in the world, especially the globalization and inclusiveness of engineering. It is time to admit that engineering ethics, at least in the US, has only a limited perspective, not a global one, and this is highlighted by many systems of social justice.

**Inclusive Moral Frameworks and Social Justice:** While the moral frameworks considered in engineering ethics (e.g., "common morality" (Harris et al., 2014)) are certainly representative of how many persons reason about moral issues, there should be cause for concern about whether they are inclusive at a global level. For instance, how does the emphasis on the individual in Western cultures change reasoning compared to some Eastern cultures where the group is emphasized? Cultural differences do matter. For instance, in (Luegenbiehl, 2004) it is claimed that people in Japan either do not value, or discourage, the notion of "moral autonomy" (Martin and Schinzinger, 2005) which is one of the most basic and important ideas in engineering ethics as it is taught in the US (moral autonomy says that you have the right and responsibility to use your best technical knowledge combined with your own moral reasoning–perhaps also religious–and make conclusions on ethical issues); such a change is very basic and impacts many issues in engineering ethics. Moreover, the moral frameworks currently used need a heavy infusion of ideas from social justice above along the following lines: (i) connecting standard statements in engineering ethics about "human welfare" with the capabilities approach of Sen, human dignity, human rights, and human fulfillment; (ii) rethinking basic issues in the university, workplace, and profession from a human rights perspective (e.g., equality, discrimination, and solidarity); (iv) rethinking technological policy (e.g., intellectual property and trade policy) at the economic and political levels and infuse this into the treatment of engineering ethics; (v) rethink a number of the "global issues" (Martin and Schinzinger, 2005) and enrich their analysis with a social justice perspective (e.g., technology transfer, development of manufacturing sites so that they are not "sweatshops," a more comprehensive treatment of environmental ethics by infusing social justice perspectives, a much more detailed analysis of the role of engineers in weapons development using ideas from social justice like the "just war doctrine" as found in Section 2.2.2). While most often micro and macro level engineering ethics issues are discussed in engineering ethics, if time is limited, typically only micro-level issues are discussed (e.g., safety). Social justice can be used to enrich both the micro and macro issues in engineering ethics. There is also a clear need for infusion of social justice principles into the most basic part of engineering ethics, which is moral reasoning. The above points simply provide examples of what could be done, in order to make the argument that something needs to be done; clearly, additional details/aspects will also need to be addressed. This point is further underlined if you consider statements on engineering ethics from around the world, and consider the differences from the ones in the US (e.g., via a search of the internet).

> More inclusive moral frameworks need to be incorporated into engineering ethics.

**Special Responsibilities Due to Engineering as Social Experimentation:** The basic concept of engineering as social experimentation is just as relevant to humanitarian engineering, however, there can be additional difficulties in applying the idea to the "public" typically encountered in humanitarian engineering. If you deploy a humanitarian technology, it is important to assess

its performance and impact on safety, health, and welfare not only immediately, but over what is sometimes a long time period. Will there be people that can gather information on these issues over a long time period and give feedback? Even without a good communication infrastructure, or good incentives to provide this information? Will your engineering team make a long-term commitment to a technology and iteratively improve it over many years, especially after key information on safety, health, and human welfare impacts comes in? Of course, no engineer would take the attitude that the value of human life is less in a developing country, so irresponsible social experimentation with technologies could be done in a developing country (because laws there may allow it), and perhaps then the results could be gathered to improve the technology for a developed country. Unfortunately, there are examples of this approach in history, for example via medical experimentation on an oppressed/controlled subpopulation.

*The role of engineering as social experimentation needs to be reconsidered for a global audience.*

**Safety, Risk, and Local/Global Ethics/Laws:** One reason for an engineer in a developed country to make sure that a product is safe, is simply to follow the laws in that country so as to avoid punishment for creating technologies that injure or kill people. The laws support the ethics, at least to some extent; sometimes, the law lags good ethical practice–"minimal compliance" to law is often not ethical. What happens, however, if you are in another country where there are weak laws, no laws, or laws that are not enforced with respect to safety, health, and the environment? Do you follow the local laws so that you can create lower-cost products, but at the expense of safety, health, and the environment? In this case, either you feel that human life is of less value in the developing country, you are simply trying to make more profit since you can get away with it, or at best you are simply considering changed cultural constraints and the desires of their public. Yet, you always have a responsibility to safeguard the public, no matter where you are at, in spite of lax laws. But, will your competitor not respect principles of engineering ethics, and subsequently be able to produce a lower cost product, and thereby drive your company out of business or at least capture significant market share from you? Is adhering to ethical principles always profitable? Perhaps in the long-term, but the reality is that there are some cases where, via exploitation, a company can profit in the short term by ignoring engineering ethics. For example, consider the prevalence of sweatshops with terrible working conditions in the developing world as discussed in Section 4.6.6, and seen in Problem 4.51.

*The core subjects of safety and risk need to be expanded to include international realities.*

**Engineer's Rights and Responsibilities on a Global Scale:** Many issues in engineer's rights and responsibilities change in different international settings. Some of this is driven by culture, laws, and traditions. It should be more heavily driven by principles of social justice and in particular, equality, human rights, and duties. There needs to be a heavier emphasis on equality/discrimination in engineering ethics, for example, via a social justice perspective (e.g., to promote women or minority engineer's rights and improve the treatment of these people).

This is especially the case due to the typical male "dominance in numbers" in various disciplines in engineering, and lack of presence of under-represented minorities. There is evidence that the area of humanitarian engineering attracts women at higher rates than men, and some evidence that this is also the case for minorities (specifically, persons motivated from a social justice perspective to get involved) (Colledge, 2012; Bixler et al., 2014). Moreover, social justice has many implications on how to structure engineering businesses (e.g., that the structure should focus on the fulfillment of the engineers and their clients and not only profits). Also, principles of social justice may tilt the balance in an ethical decision away from company loyalty to whistle-blowing and public welfare.

*There needs to be a heavier emphasis on discrimination and social and economic inequalities in engineering ethics.*

**Honesty and Tendencies Toward Dishonesty:** All the issues on honesty discussed above are important for humanitarian engineering; however, there are cultural differences on this issue, that are difficult to identify and discuss (how could you, with certainty, accuse a country of having uniformly less honest people?). Many people recognize that a government may be perceived as more corrupt in some country than another, and this may impede development, but to say that people in a country are less honest than another country would be very difficult to scientifically justify. You may have anecdotal evidence along these lines, but one should be careful not to over-generalize. You certainly should not go into a humanitarian engineering situation with a prejudice that the clients are more or less honest than you. Of course, you may find for a specific person or persons you are working with that this is the case. If you find yourself in a corrupt situation, the best approach is probably to try to set an example of good behavior; trying to change a country by working at an individual level is futile and likely to cause you many problems. Personally, I have found that humanitarian engineering situations demand a high level of honesty on the part of the engineer. For instance, in working with clients, if you are wrong on some point, freely admit that to the clients in a fully honest, open, and truthful manner; do not act like you do not make mistakes or that you cannot learn from them. Such raw honesty is humble and ultimately greatly respected by clients, and respectful to them. It makes you human to them.

*A greater emphasis on corruption is needed in engineering ethics.*

**Environmental Justice:** Typical treatments of engineering ethics may include sustainable design and perhaps environmental ethics. There is a clear need for a broader and deeper treatment. First, the current state of the polluted environment needs to be covered to convince engineers that there is indeed a problem that needs to be addressed (e.g., as in Section 1.3). It makes little sense to talk about ethics of an issue without defining the issue. Second, there is a need for a broader/culturally more inclusive treatment of the environment and sustainable design via the infusion of social justice concepts (e.g., Sen's definition of sustainability from a capabilities perspective in Section 2.3.2 needs serious consideration from a general engineering perspective and a specific humanitarian engineering perspective). There also needs to be a deeper under-

*Engineering ethics needs to expand its treatment of environmental ethics, including the perspectives from social justice.*

standing of the impact of the environment on various engineering problems, the impact of technologies on environmental problems, and the differences between conventional engineering and humanitarian engineering on these issues. Is sustainability more important when engineering humanitarian technologies? Many humanitarian engineers think it is, but there are always trade-offs in design where in some cases you may need to accept more pollution in order to help with human welfare! It is a matter of (typically complicated) interconnected priorities between humans and their environment.

**Lack of Deep Treatment of Global Issues and Social Justice:** The global issues discussed in engineering ethics that are outlined above are social justice issues. Yet, the typical textbook treatment is not very sophisticated. For instance, the interconnection of issues is not treated properly (e.g., coupling between economic/political systems, human rights, and the environment) and the issues are not studied deeply (e.g., the weapons development issue). There is no treatment of issues of technologies for fighting corruption or encouraging political participation. There is typically no treatment of issues of setting science and technology policy and its coupling to human rights issues. There is, indeed, a tendency in classroom treatments to focus on micro rather than macro issues. Moreover, it is rare that "activism" in engineering is discussed in class, for example, the need for protest against unfair engineering organizations and practice (Riley, 2008).

> Global issues, including war and multinational corporations, need to be addressed in engineering ethics in the context of global social justice.

### The Globalization of Engineering Ethics Education

Personally, I view the profession of engineering as being in a state of on-going development. For example, engineering ethics education has evolved some over the last 25 years that I have been teaching the subject; above is a call for consideration of more significant changes via the infusion of social justice perspectives; such changes could help advance the profession of engineering in the modern world by providing a more global/international viewpoint on engineering ethics. However, it is challenging to develop and disseminate engineering ethics education in the world. There needs to be more work on development of country-specific versions of engineering ethics, cross-cultural engineering ethics, comparative engineering ethics, and development of approaches to teaching engineering ethics in many countries, ones that respect local traditions, religions, philosophies, industries, and curricular and faculty constraints.

To be concrete about what is needed to globalize engineering ethics education, consider one issue. There is a significant need for development of engineering ethics case studies that are relevant and important for specific countries trying to introduce engineering ethics into their curricula. Experience by many educators has shown that case studies are a crucial part of teaching engineering ethics, especially in-class discussion/debate on cases. To make cases interesting for students they should be: (i) well-known in their country as having terrible consequences (with engineers behind the problems); (ii) connected to at least one key idea in engineering ethics (e.g., safety or conflict of interest) so it pro-

vides a concrete example and teaches the principles; and (iii) of a sufficient number that all the key ideas in engineering ethics, infused with social justice, are illustrated in at least one case that is discussed. This is basically the background that the key textbooks, (Martin and Schinzinger, 2005; Harris et al., 2014), provide in order to facilitate teaching and learning. Clearly, however, in some ways, these two very nice books are deficient if one tries to use them on a global scale as they do not (cannot) properly cover local cases for every country (e.g., they might discuss the Challenger disaster case for the US but not issues of corruption or nepotism in engineering companies in Latin American countries). Generic/theoretical cases, ones not naming real people or situations, are sometimes used (e.g., by the NSPE), but these are naturally more abstract and not as engaging for the students. Engineering ethics and social justice are highly engaging, and sometimes controversial, subjects; it will clearly degrade the educational experience to divorce cases from concrete reality.

## 2.4 Models, Dynamics, and Analysis of Social Justice

Here, we study several types of models of social justice, including influence diagrams and dynamical models. First, influence diagram models of social justice "systems" ("systems of thought" or "representations of all the interacting pieces of a theory or doctrine of social justice"), in particular, the Catholic and Rawlsian cases, are covered. Distributive justice is modeled using influence diagrams, first by viewing Sen's capabilities as basic features of an individual's advantage, and ideas about redistribution of these features. More detailed influence diagrams are provided for the case where only a single feature is considered, wealth. A range of distribution strategies (policies) is considered, specifically, how these affect dynamics of redistribution and the ultimate distribution. Ideas of distributive justice are used in a low-income community to study how "mutual cooperation" between individuals affects those individuals' well-being. In this approach, the model of individual poverty from Section 1.6 is used, along with a wealth distribution strategy that fits several systems of social justice in this chapter. Also, a model of democracy is introduced and used to adjust, via voting, the wealth distribution strategy to make it more or less generous per what the majority of people in the community want. Finally, a model and computational analysis of an environmental justice policy, whose aim is to avoid the tragedy of the commons, is provided. In sum, three key issues in social justice are modeled and analyzed: distributive justice, participatory justice, and environmental justice.

### 2.4.1 Influence Diagram Models of Social Justice Systems

Suppose social justice is viewed as a dynamical system, an interacting group of humans, with interactions that are in some sense just, and which obeys constraints to ensure justness, and that promote human development. To model

such systems, first, influence diagrams are used to provide a model of Catholic social justice and in Problem 2.32, Rawlsian justice. The models are simply another way to understand these systems of justice, one that provides a visualization of their viewpoints. It is possible to produce very detailed influence diagram models for these systems of justice, but here diagrams that fit into less than one page are produced even though many details are left out (that is the models are far from perfect). The intent is only to represent some key entities, ideas, and their interactions. For homework, in Problem 2.31, the reader will be asked to make the diagrams more accurate by adding on other parts of the relevant social justice systems.

The standard influence diagram, first introduced in Section 1.6.1, is extended in the following ways:

1. *Multiple node types:* Here, we will often assume that nodes represent humans and arcs represent interactions between humans. Some node types will be used to represent concepts that connect humans or groups of humans. Humans sometimes work in groups (e.g., a community, city, institution, or government) and nodes representing humans can be placed in "super-nodes" that represent groups of humans (more than one). There can be multiple types of "sub-nodes" inside nodes representing, for instance, features of nodes, that can be influenced, or influence, other nodes in the graph or sub-nodes in a graph. Nodes are sub-nodes of super-nodes. Various other node types could represent concepts or entities.

2. *Multiple arc types:* An arc from one node to another means that the node at the root of the arrow can "sense" (e.g., via seeing the person or hearing about them on the news, or if the root node is a super-node perhaps via a survey) and the node at the arrow-end of the arc can be influenced by the root node in some way, perhaps with the level of influence quantified via an arc's strength. The meaning of strength depends on the arc type. Similar statements about interconnections and strengths can be made about arcs to and from super-nodes, sub-nodes, nodes, or other nodes.

As with the influence diagram models in individual poverty in Section 1.6.1, the influence diagrams here do not provide a clear picture of dynamics; a more detailed picture will emerge from the mathematical and computational models presented after the influence diagram models.

### Catholic Social Justice Model

Using the discussion on Catholic social doctrine in Section 2.2.2, a simple (incomplete) influence diagram model of Catholic social justice is presented here. Consider Figure 2.1.

First, let a node represent a single human. Inside the node is human dignity, human rights ("basic" or otherwise), and human fulfillment (which could be viewed as "sub-nodes"). Different types of arcs, nodes, and interactions include:

Abstract models of systems of social justice help clarify relationships between parts of a theory.

Influence diagrams can be used to represent abstract systems of though on social justice.
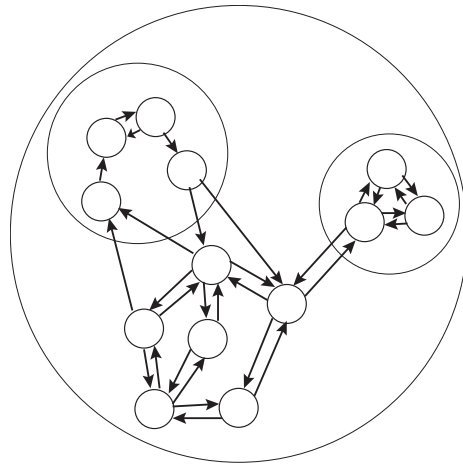
Figure 2.1: Influence diagram model of *some* key aspects of Catholic social justice, with representations of deviations from the doctrine.

- The common good is represented with the super-node that encircles all the humans in Figure 2.1. This means that every human must contribute to the common good ("according to their possibilities") and every human deserves to benefit from the common good. All interactions between humans are governed by the common good. In this case an arc type is not needed for everyone's contribution and benefit from the common good; it is assumed that influences from/to the common good exist for each human.

- Solidarity is represented by an arc from one individual to another, where the root node person has solidarity for all people pointed to by arcs emanating from the root. Arc strength here is magnitude of solidarity, perhaps influenced by how much you know about the person and their situation. One person can have solidarity for only some other people, but Catholic social doctrine demands a type of "graph connectivity" along the lines of what is inherently present for the common good super-nodes: "complete connectivity" so that from every human node there is an arrow to every other human node for all human nodes. The doctrine says that all humans must have concern for all other humans. This is not the situation shown in Figure 2.1 as the graph is not completely connected. The upper right super-node of three people may represent a family that is fully-connected, but they only interact via one person in the family to one other person in a distant community, which implies that the family only has information about the well-being of one other person. The super-node in the upper left side of Figure 2.1 could represent some type of governing body. It is only concerned with a few people, and only influences a few people, far

from the ideal situation that the doctrine requires.

- The universal destination of goods principle (property rights regulated by universal ownership that leads to the preferential option for the poor) is represented first by an arc between one human node and another. The root node person must consider what the human that the arc points to has (they must sense them), and if there is inequality then the advantaged person must give to the disadvantaged person if they are very bad off (an interpretation of the meaning of the Catholic approach to inequality reduction). Strength of arcs for this case may represent the strength of moral mandate to give (e.g., which may be higher for more inequality). In a sense, there should be a completely connected graph, that is, every human must know every other human's condition and respond accordingly. Figure 2.1 does not represent an ideal situation. For instance, the government super-node only listens to some people and only helps some people.

- The doctrine's principle of "participation" essentially says that every person has a right and duty to participate. Arcs can represent strength of participation (e.g., a human's ability to influence their government). The doctrine indicates that complete connectedness of the graph is mandated, and in particular has implications for how super-nodes interact with humans outside the super-node (e.g., when the super-node is an institution or government).

- The doctrine's principle of "subsidiarity" has implications for both the pattern of interconnections in the graph, and the strengths on the arcs as it dictates that in an association of humans one should not do things for the others that they can do for themselves. For instance, this limits the strengths on arcs from the government super-node to individuals outside that super-node.

**Participatory Justice Models**

Participation in the life of a community is both a human right and duty. Participation means that a person contributes to their community's cultural, economic, political, and social life. It applies to many groups. For instance, persons living in a small community (e.g., village) have a right to be involved in decision making on important matters that affect the community. None should be discriminated against by not letting them have "voice" and influence on group decisions (e.g., women or racial minorities). Similarly, citizens in a country have a right to be heard with respect to the choices that a country makes (e.g., in an election of a leader or in the decision about a new law or policy); all persons are equal and hence deserve to be heard. Moreover, no one person, no matter how wealthy or powerful, should have more influence on decision-making than any other person.

To model an election in a democracy (small community or country) with an influence diagram, see Figure 2.2. The principle of participation says that everyone has a node in this diagram and a non-zero strength of influence on others and the final choice. They have a duty to enter into the process and not ignore it entirely. There are two candidates shown by the two nodes at the top. The groups of interconnected nodes at the bottom represent the set of voters that the arcs between them represent communications (e.g., persuasions, opinions, and arguments) about the candidates. The circle around the group of voters represents the media (internet, television, etc.) that the candidates provide information to, and who get information about, the candidate and provide it to the electorate. Candidates try to persuade the electorate to choose them, and may even try to change their positions on issues to capture more votes.
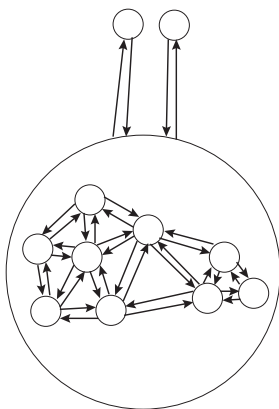


Figure 2.2: Influence diagram model of an election.

The group of voters typically have a priori tendencies to choose one candidate over the other (e.g., liberals go with the liberal candidate and conservatives with the conservative one), but there may be a group (e.g., "independents") who start out with no biases. Some persons do not listen to the opinions of their neighbors, and evaluate the candidates on their own, while others can be easily persuaded in one direction or another by the way the whole group of voters is "leaning," or will simply vote with their group of neighbors to choose one candidate over another simply to conform.

Group selection of a policy is similar to choice of a candidate. If there is only one policy being chosen, then the vote is "yes," "no," or "abstain" for a total of three options to be considered (rather than the two options for candidates considered above) where "abstain" is a choice to let others decide. If $N$ different policies are considered in the same group choice problem, then there can be $3N$ different choices for the voters, "no," "yes," and "abstain" for each choice. It is also possible to have a choice where voters can only pick one of say three options, and only one. For instance, for $x > 0$, voters could choose among the options "increase taxes by $x$," "decrease taxes by $x$," or "leave taxes the same,"

which in some cases can represent a vote to let others decide. Choices about policies can be more complicated. For instance, the choice can entail changing a healthcare system or broad changes in tax policy.

## 2.4.2   Distributive Justice Models

A central idea in social justice is inequalities (e.g., social and economic) and how, if at all, they can and should be reduced. Distributive justice focuses on various type of inequalities, their distributions, and strategies for redistribution (e.g., laws or moral dictates on who should give what to others). This section is based on the ideas of distributive justice earlier in this chapter and the overview in (Lamont and Favor, 2013). The objective here is not to model the distributive justice portion of some specific system of justice (e.g., Rawlsian or Islamic justice), but to represent the range of possibilities for modeling distributive justice from several different perspectives.

### Influence Diagrams for Humans With Features

Suppose in this section that nodes represent humans. Suppose that each human has a number of "features," each of which is represented with a different sub-node type. These features can be used to characterize human well-being, human welfare, or human fulfillment, if they are fully or adequately achieved. Different perspectives on social justice define these sub-nodes differently:

Influence diagrams can be used to represent, at an abstract level, difficult-to-quantify aspects of human inequalities.

- *Human rights as features:* The UN provided its Universal Declaration on Human Rights, and each of those rights could be considered a different sub-node type in a node representing a human. The Catholic social doctrine states that basic human rights arise from the equal dignity of every human and has a different list of rights, even considering rights that they list in other parts of their doctrine (e.g., worker rights). Other religions have some related views on equality and rights. Rawls and Sen have views on what constitutes a human right and its primacy, as does engineering ethics. Rights could be represented as sub-nodes of a human node.

- *Duties and responsibilities as features:* Individuals or groups have duties corresponding to rights of others. Or, some would call these responsibilities. Sub-nodes could be used to represent these.

- *Capabilities as features:* Amartya Sen's capabilities approach would represent the features of a human in a system of justice as humans' capabilities and Nussbaum and Glover provided a list of "essential" capabilities in (Nussbaum and Glover, 1995), though others could have disputes with that list and invent their own. Sub-nodes could represent each of these capabilities, no matter what one felt needed to be included in the list in order to characterize human well-being.

For each case, it is natural to think of each feature as having a "level" that somehow represents how well that feature is achieved. In some cases, people try

to numerically quantify the level of achievement with a single number, either negative or positive or always positive (e.g., on a range of 0 to 1, with 0 representing that the right is not met and 1 representing that it is fully met). A single human may have a mix of rights, duties/responsibilities, and capabilities. The basic influence diagram for a human with features is shown in Figure 2.3.
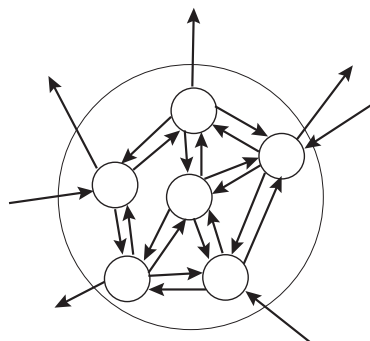


Figure 2.3: Influence diagram of a human with features.

An arc from one sub-node to another sub-node represents that one feature can influence another feature (e.g., by increasing or decreasing it), perhaps with some strength. As an example, consider the income-health-education influence diagram of Section 1.6.1. Arcs coming from outside the human node within which sub-nodes lie, and pointing to a particular sub-node, represent that another outside entity (e.g., a "provider") can perhaps sense and help improve that feature of the human (this may be the other's duty or responsibility). As an example, consider sub-nodes representing income, health, education, and technological capacity, and the influences between these four features, and provides for income (workplaces), health (healthcare), education (educators), and technological capacity (engineers). Of course, others may provide in these categories also. Arcs starting at sub-nodes and pointing outside the human node in which they reside can represent the influence of one human's feature on another human's feature. For instance, in some cases, improvement of one human's health means that another human's health will not decrease (e.g., due to disease transmission) or improvement of income level may result in improved income for another (e.g., if the "breadwinner's" income increases, then effectively the income of that person's family members may also increase assuming the breadwinner shares). Similar examples can be given for education and technological capacity.

### Influence Diagrams for Human Groups With Features

Suppose now that a super-node represents a group of humans. There are many types of human groups including families, teams, clubs, communities, cities, countries, the world, institutions, governments, professions (educators, doctors,

nurses, engineers, scientists, etc.), and others. There can be more than one group of one type; hence, there are multiple types of super-nodes. The features of groups can have the following characteristics:

- *Aggregation of human features:* In some cases, the sum (appropriately defined) of all features of all humans of like type in a group is the feature of the group. Other times, such a simple concept will not hold. It can be that the "sum is more than that of the parts" in the sense that features can combine via mutual enhancement of each other (e.g., on a sports team). For instance, in the group of scientists there is significant open collaboration via publications on scientific advancements; no one person could achieve what the group can achieve as a whole. The same remark holds for other professions such as engineering. But, it could be that there is a type of mutual inhibition of talent due to poor interactions such that the feature of the group is less than the sum of the human group's individual's features. For instance, it may be that due to bad practices or corruption the actions of a government are less effective than they could be considering the individual talent in the organization.

- *Features of groups interact:* Analogous to how individual human features interact, a group's features do also and this can be represented with an influence diagram. One feature can enhance or impede another feature. These interactions are represented with arcs as before. For instance, software like Matlab, or technologies like the computer or internet, that are developed by engineers and scientists, speed the rate of scientific discovery and engineering advancements. Corruption by a scientist or engineer (e.g., falsifying data) slows advances.

- *Features and arcs:* Arcs can represent different types of interactions with other groups' features and individuals' features who are outside the group, or inside the group. For instance, the group of healthcare experts can monitor an individual's health, and via healthcare help improve their health. A profession like engineering has a profound impact on the medical profession by collaborating to develop technologies to help with healthcare (e.g., electronic monitoring devices and scanners).

Via a simple re-interpretation, Figure 2.3 represents a human group. The large circle is a super-node representing one type of group, individual humans are assumed to be in the group and therefore not explicitly represented beyond their representation via an influence diagram for each human, and the subnodes of the super-node (nodes) represent now the features of the group. Arcs coming in, and going out, of the group represent the group's influence on other groups' and individuals' features.

A complete influence diagram for distributive justice is a "composition" (connecting together) of many humans with features and many groups with features. Social justice dictates how the interconnections should be specified. Ignore the issue of births and deaths (appearances of new nodes with new interconnections,

and disappearance of nodes along with their interconnections). Also, ignore the fact that in real life the presence of arcs changes over time (e.g., due to marriage, moving to a new city or country, or joining an organization).

To be more concrete about the meaning of such a complicated influence diagram, consider next the example of economic distributive justice.

**Example: Influence Diagram for Distributive Justice**

Suppose, for simplicity, that we consider economic distributive justice in the case where only wealth held by individuals is considered (that includes the dollar value of all resources and assets). Assume initially that no individual gets additional income, or spends, during the redistribution (such additions and subtractions can be represented with arrows going into nodes and coming out of nodes and are discussed below). The structure over which wealth distribution will occur is shown in Figure 2.4 for a simple case. Other formulations would use income or expenditures and also include aspects of trade, the market, business, etc. In the diagram, the fact that humans exist in the super-node is ignored, as is the fact that these individuals are part of the group among which wealth is redistributed (in this sense the large circle always encircles some individual nodes). The only capability of the group is that it senses the amounts of wealth of connected nodes, collects money, determines who gets what, and redistributes it.

*Influence diagrams help us think deeply about issues in distributive justice.*
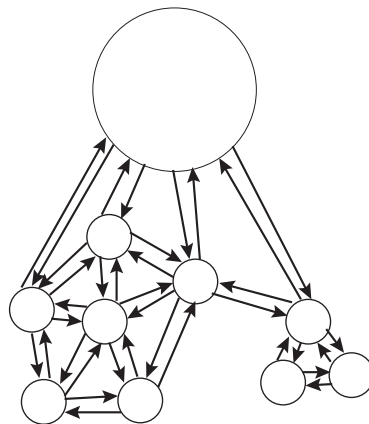


Figure 2.4: Influence diagram model of distributive justice, the case for one group and a set of other individuals not in the group.

Suppose that there is a set of humans with only one feature, how much wealth they have and their capability to manage that wealth (e.g., to decide about giving donations). Hence, each human is represented by a stack of money at a node, an ability to sense the wealth of connected neighbors, some rules for finance management, and an ability to transfer funds. Suppose that we call the "neighbors" of a node (or super-node) the set of other nodes that it can sense

wealth in (that is, the set of other individuals whose wealth is known by the individual) and transfer wealth to. Next, assume that an arc that originates at one node and ends at another node means that the root node can sense wealth of the node it points to and can transfer wealth to that node. It is possible that there will not be transfers in both directions between two nodes. Assume that there is only one super-node that represents some type of authority (e.g., government or moral leadership) that implements or suggests the "policy" on what wealth transfers should occur (of course, there could be more than one, like a government and charity, that senses, collects, and redistributes wealth). The super-node can take wealth from individuals (by force of law or moral mandate) and give it to others. Individuals that are connected directly to one another can transfer wealth to each other if appropriate arcs represent that this is possible (e.g., charity or providing for individuals in your family). The "topology" (pattern) of arcs connecting nodes to each other, and nodes to the super-node, represents a number of possibilities: (i) a set of nodes with a high number of arcs connecting them may represent a family or close-knit group of some sort, (ii) people that are not linked to the super-node in any way are hiding from the super-node to avoid transferring wealth to others (e.g., being taxed) or are ignored by the super-node so no transfers will go to them (e.g., in cases of individuals who are marginalized or discriminated against).

**Sensing, Policy, and Wealth Transfers:**  Suppose that a "policy" by an individual or group is based on their knowledge of those whose wealth they can sense, and specifies a recipe for what the individual or group will transfer to another individual or group. Such a policy will depend on what is sensed:

- *Available information:* There are cases along a spectrum between all "neighbors' wealth can be perfectly sensed" and "very poor accuracy in sensing neighbors' wealth." Sensing accuracy can depend on a neighbor's willingness to share information about their wealth (e.g., if they hide wealth) or their accuracy in estimating their own wealth. It can also depend on your ability to estimate their wealth, without their help (e.g., based on their public spending actions). Below, we will assume that a neighbor's wealth can be sensed perfectly, but only a neighbor's wealth; it is assumed that you have no information whatsoever about a person's wealth who is not a neighbor. Assume individuals do not hide wealth (which can be viewed as a type of corruption in some settings), or that in the discussion below, it is only "known wealth" that is considered in all distributions so that the true distribution is not known.

- *Sensing delays:* You may know their wealth, but only up to a random but bounded delay into the past. For example, a government may know their wealth some months into the past, but not at the present time when wealth redistribution decisions are made. Similarly, an individual may have old information about a neighbor's wealth and not know about their recent fortunes or misfortunes.

Of course, social justice principles would typically dictate that individuals should honestly share information in a timely manner about their wealth so everyone can make just decisions about wealth transfers.

Consider the following policies for wealth transfer, implemented at either individual nodes or a super-node, and the resulting distributions:

- *Wealth redistribution policy based on religion:* Charity is donations by individuals or groups, not government enforced, but encouraged or required by a number of religions (e.g., in Islam, one of their five pillars) if the transfer of funds is directed to the least disadvantaged groups or individuals, however that is defined. Donations are not connected with any expectation of anything in return, and altruistically people simply seek to help others. Stated slightly differently, Catholics are also asked to contribute to the "common good" which in the case of money can be thought of as a "common bank" that everyone must contribute to (according to their possibilities); some may make withdrawals from that bank, but not all need to or choose to. Catholic doctrine says that the principle of the universal destination of goods regulates private property to result in the preferential option for the poor. This could be interpreted as a moral dictate that the richest must give to the lowest-income people (but the exact meaning of the word "regulates" is not clear, probably it is left intentionally vague to allow for a variety of interpretations). This could be thought of in more than one way: for individuals it means that you should share with your neighbor if you are rich and they are low-income. It also means that in seeking the common good, a government must follow this mandate in wealth redistribution. Catholic social justice sees charity as only part of the solution to inequalities; it has a heavy focus on changing the rules (e.g., policies of governments) so that there are fewer inequalities that demand charity. They seek systemic change.

- *Wealth redistribution policy based on political philosophy or governments:* Rawls's political conception of justice identifies the "difference principle" as a principle of justice that a society will agree on. That idea says that the most advantaged must give to the least advantaged (since the only inequality that is allowed is one that reduces the inequality). Rawls implies that this principle only applies to the government redistributing wealth, and unlike religions, not individuals, as his is a political conception of justice. Of course, adherence to such a principle may depend on what is happening between individuals (e.g., due to transfers motivated by adherence to religions) as this interacts with what happens in the government requiring transfers (e.g., if someone feels that the government does enough redistribution to take care of the disadvantaged, they might not be willing to do anything more for their neighbor, and vice versa). In practice, some governments use redistributions of *income*, rather than wealth, based on "progressive taxation" where the rich must pay in taxes a higher percentage of their income than low-income people ("regressive" is the opposite). This bears some relationship to what religions and Rawls are saying, but

it is not the same as it allows for arbitrarily high accumulations of wealth and arbitrarily high levels of spending by individuals.

Debates over whether to try to equalize wealth, income, or spending occur, and sometimes practical trade-offs have to be made in terms of what is possible to reliably measure (e.g., in some cases is may be easier to accurately measure income) and notions of fairness (e.g., is it fair to equalize incomes when there may be good reasons for one individual to need more income, e.g., if they have medical conditions that are expensive to treat).

Wealth redistribution depends on implementing transfers of wealth between individuals, either via direct transfer from one person to another, or via a group like a government transferring from one group to another. Who gets what, and gives what, depends on what is sensed and the policy. Moreover, it depends on the nature of the transfers themselves. First, the only persons wealth is transferred to are those defined by the topology (nodes that arcs are pointing to), and not others. Second, there may be a cost to transfer and who should incur that cost, the donor or recipient? Third, will the transfer be deviously intercepted, with all or part of it stolen by a third party? Fourth, there is the very common problem of a delay (often random) occurring in doing the transfer that occur for a number of reasons: (i) it may take a while to decide what to transfer to whom due to deliberations or bureaucracy; and (ii) it may take a while to get the money from one individual to another, or from the government to an individual, based on the need to withdraw and send money. Clearly, delays can have an important adverse impact on the least advantaged, and slow down equalization. They also have the impact of interacting with the delay in sensing the wealth of an individual (is money sent, but not received, actually owned if another transfer is being considered?). Clearly there can be a complex interactions between sensing and transfer delays. If the government has already sent the check, is charity needed from a neighbor?

**Ultimate Wealth Distributions: Equality or Fairness**   There are a number of issues to consider in whether, after many transfers, will there be a perfectly equal distribution across all humans, or at least deviations from equality that are in some sense acceptable? Some issues are as follows:

- *Wealth quantization:* The nature of how wealth is quantified affects distributions. For instance, if wealth comes in different sized pieces ("chunks"), this will affect an ability to redistribute it equally. Wealth most often comes in discrete blocks. Money is not infinitely divisible in practice; there is always a minimal unit like a dollar or penny. Other wealth may be represented by ownership of a second home, or one share of a stock, that is not really easily divisible unless it is sold and the resulting money is divided. These facts affect how equally wealth can be distributed. Moreover, it implies, in the presence of a topology, that wealth differences over, for example, a line topology, can accumulate along the line, with significant inequalities between the two ends of the line as there can be a block

of inequality between each two nodes along the line. This may not be a problem if a government steps in and is connected to everyone in that they can sense everyone's wealth and transfer between any two individuals, but having discrete wealth always implies, even in that case, some level of deviation off a perfectly equal wealth distribution. Yet, if everything is reduced to money, then the inequality that results from quantization is typically quite low.

- *Interconnectedness and topology:* The interconnectedness of the people and super-node per the topology of the graph will influence the sensing (see above), wealth redistribution policies, and the "ultimate achieved wealth distribution" (that is after many redistributions, what the final distribution across the human nodes, not the super-node, is). If every node (including the super-node) is bidirectionally connected to at least one other node in the graph, then wealth can be transferred throughout the graph so equalization becomes easier. If some set of nodes is not connected to the graph, then it is normally is not possible that equality in a distribution is achieved (that "island" of disconnected nodes may achieve its own distribution independent of the other nodes). Generally, increasing some measure of connectedness (e.g., the minimum number of distinct neighbors each node has) will result in faster redistributions of wealth for many transfer policies, and hence faster achievement of the ultimate distribution. The systems of social justice in this chapter do consider topology (e.g., some make no distinction about giving based on only who you know or interact with or can sense wealth of–in a sense they *require* a fully connected topology).

- *Effect of wealth distribution policy:* Many policies that result in some level of persistence ("aggressiveness") in reducing the maximum inequality between all humans will result in a fair distribution. This reduction can be achieved in many ways: (i) systems of social justice generally say that it should be via the rich giving to low-income people (persistent reduction of inequality from both ends); (ii) someone, not necessarily the richest, giving to the lowest-income person (persistent reduction of inequality from the bottom side up); or (iii) anyone that is richer than anyone else giving money to them (persistent reduction from the top), which could ignore the lowest-income people. The first option seems to many people to be the most fair one as the rich are thought of as not being hurt by giving something away, and this clearly can significantly help low-income people. There is, however, a principle at work here: assuming that everyone is connected to the government, then it should be that at each step a transfer is decided upon, at least the person with minimum wealth of everyone should gain more wealth and the richest person will lose some wealth. If the person of minimum wealth always gets more wealth (of course, the person with minimum wealth is likely to change over time), then the level of inequality across all humans will decrease. But, what about the case when there is not such global information known by the government (e.g.,

what wealth everyone has)? Consider the case where there is no government, and only individuals with local distribution policies on what wealth their neighbors have, and perhaps a religious mandate. Suppose that the mandate is that the richest have to give to the lowest-income people. Suppose, for convenience that humans are always "bidirectionally connected" (so arcs are in both directions between them) and call this combined interconnection an "edge." Suppose that in the resulting graph, that could be sparsely interconnected, there is a "spanning tree" (a tree that includes all nodes). One logical way to interpret the policy over such a graph is that if I am wealthier than all my neighbors, then I must give something to the lowest-income persons of my neighbors. There are two very important facts that result from this assumption of spanning tree connectedness and policy: First, somewhere the richest of all humans will give something to their lowest-income neighbor (who may have relatively high wealth compared to non-neighbors) making the richest person give away some wealth (reduction from the top). Second, the lowest-income person will have a neighbor who is richer than them and hence that person will give them some money, increasing their wealth (reduction of inequality from the bottom). Hence, even without the global information that the government has, if everyone is generous enough, then *global* wealth inequalities can be reduced (even without perfect information), though possibly not as fast (indeed, in the completely connected graph case, it is as though each person is a government with good information, and hence redistribution can be faster–this is likely why systems of social justice require things like "solidarity" and the "common good" a type of requirement for bidirectional connections between all humans). It seems as though some systems of social justice try to specify the least restrictive rule to achieve reduction of inequality; clearly, more aggressive strategies could be used, but may require more generosity that could be expected. The question is whether the decrease is fast enough, and will the inequality go to zero if that is what is desired (not explicitly called for in, for instance, the Catholic, Islamic, Jewish, Rawlsian, or Sen cases discussed earlier). It is not clear what some systems of social justice require in cases when a human group becomes relatively equal: Is anyone over the mean income of the group considered "rich" and hence must give to anyone below the mean, who are "low-income"? Or are only such transfers needed to persons below some fixed amount below the mean (as is required by some governments)? Or, should an absolute measure of poverty be set, and donations only be required from everyone else not in that group? Statements from, for instance, Rawls and the Catholic church, are not perfectly clear on this point, though for either case you may be able to argue that a person somewhat below the mean, provided that mean is high enough, will have their human dignity respected (and subsidiarity would demand not to give when it is not needed) or not be considered "disadvantaged" by Rawls, so giving may not be necessary or appropriate (i.e., it could be considered unfair). It seems that a policy that ignores relatively small inequalities

is considered fair by many people. Of course, Karl Marx demanded that there be no private property, so he clearly demanded full equality of wealth distribution, which, strictly speaking, meant that if I had one more dollar than you, I would have to give you $0.5. Finally, there are two things to note: (i) there is a highly unlikely, but theoretically possible dynamic where many people could have a neighbor who is very low-income, and all these neighbors could *simultaneously* donate enough to that individual so that the low-income individual's wealth goes up so much that they are richer than even some of the people that donated to them after all the donations are made. This case, however, under the appropriate wealth distribution policy, will still result in a decrease of the maximum inequality and will not destroy the ability to achieve fair distributions as the low-income person who suddenly got wealthy will likely later be required to donate themselves; and (ii) the above policies about transfers (based on (Passino and Burgess, 1998), the "generalized" case) assume no delays in sensing and transferring money. If there are delays, then random but bounded delays are allowed in both cases. More restrictive policies are needed to ensure progress toward an equal distribution in the presence of random but bounded sensing/transfer delays (Bertsekas and Tsitsiklis, 1989; Passino and Burgess, 1998). Similarly, transfer policies have to be modified for quantized load, sensing uncertainty, or other cases (Passino and Burgess, 1998).

- *Frequency of redistributions:* If the super-node is a government, then it could be that redistributions may only take place once per year through that super-node. However, if transfers are due to charity or some other aspect of a religious mandate, the frequency of transfers from individual to individual may be daily. Generally, for many policies for wealth redistribution, high frequency transfers to redistribute wealth will result in faster achievement of the ultimate distribution. Moreover, the "aggressiveness" of the policy, combined with this frequency, dictates (along with topology) how fast wealth is redistributed. Clearly, slow redistribution strategies can be considered unfair (e.g., by low-income people), as can very fast ones (e.g., by the rich). If there are significant inequalities, then it is not clear that redistributions of wealth will occur fast enough to significantly help the disadvantaged (e.g., avoid suffering) and significantly reduce inequalities in a life time. The systems of social justice in this chapter do not *explicitly* consider rate of redistribution; it is only considered as a separate issue in statements about, e.g., respecting dignity at all times, which inherently demands a relatively high rate of redistribution, fast enough so that people will not, for instance, starve to death.

- *Influence of income and expenditures during redistributions on ultimate distribution:* All of the above discussion assumed, as stated at the start of this section, that all individuals did not get any new income or make any expenditures that would change their wealth. There are significant changes if such incomes and expenditures are allowed, as they must be, of

course. In reality, the wealth redistribution process must occur simultaneously with the processing of gaining income and making expenditures, that is, when wealth of each individual is fluctuating. Individual humans may have income and expenditures, or just expenditures and no income (e.g., if they do not have a job or are severely mentally or physically disabled); everyone has expenditures assuming they are alive for long. Of course, transferring wealth from one individual to another is increases expenditures of the donor and increases income of the recipient. The frequency of redistributions affects the frequency of such expenditures and incomes. Of course, the topology can have significant influences on the pattern of expenditures and incomes. Persons with lots of arcs pointing to them may get lots of income infusion, whereas individuals with lots of arcs pointing away from them can have more expenditures due to donations to more people. But, there can be an income of wealth from outside the group of humans (e.g., via farming) that requires no human to give you money, and expenditures on oneself (e.g., for healthcare or education) that do not entail necessarily giving money to anyone else, though they may. How do these effect redistribution policies and ultimate distributions? View incomes as a *sources* of wealth for the group of humans, and personal expenditures as *drains* to that wealth. The ability to achieve equality of wealth distribution, or even something close to it, is significantly affected by large variations in income and expenditures. Essentially, to have a chance at some level of equality the wealth redistribution, the frequency must be faster than the changes in incomes and expenditures that generally create inequalities. Considering the problems with implementing fast wealth distribution strategies, the effects of delays, uncertainty in wealth levels, and effects of topology, it is certainly practically impossible to achieve an equality of wealth distribution. It is clear that all that can be hoped for is oscillations within some inequality bound; however, considering the above discussion, if such a bound were known, this may be acceptable to many people ("fair").

The Gini (Equation (1.3)) or Atkinson (Equation (4.25)) indices could be used as measures of inequality of wealth distribution (even thought, traditionally, they are not used for that), both at each point a transfer is done, and after many transfers are done to measure the inequality in the ultimate wealth distribution if the distribution converges to a specific value, or a range of Gini/Atkinson indices if the distribution ultimately, for instance, oscillates. Generally, inequality in distribution can also be thought of as a sum of the differences in wealth, squared, along all arcs of the influence diagram between humans. If all wealths are equal, then this will be zero and if there is more inequality, then that sum will be higher.

### Distributions Across Other Features

There are some very basic differences in distributive justice when other features of humans are considered in isolation like wealth distribution was considered

in isolation above (e.g., mostly independent of health and education features, except via the discussion on income and expenditures near the end of the above section). Two cases will illustrate the point, what could be called "health justice" and "education justice," each from a distributive justice perspective only:

- *Health distribution:* "Native endowments" such as inherited tendencies toward illness, disease, and disorders, along with unpredictable life events (e.g., an accident), essentially good or bad luck throughout a life, imply that there is an unequal health distribution across all people at all times. Health is inherently different from money as we are born with no money. Health also does not "transfer" like money. A doctor may get sick from a patient in trying to cure their illness, but this often does not happen, especially in a wide array of noncommunicable health problems. Healthcare experts, can up to a point, improve someone's health, and hence change the overall distribution of healths. It makes sense to try to take care of the worst cases. Such a "maximization of the minimum health" approach (with some relationship to the wealth distribution policies) will not always work of course as some serious health problems simply cannot be fixed. Social justice might say that those with good health, and expertise, a should help those without good health (but health that can be improved), and a lack of ability to fix their health themselves (see quote by Dr. Paul Farmer at the start of this chapter). There is sensing uncertainty ("noise") in health related to the difficulty of individuals and experts to diagnose health problems, there could be a quantization issue as it seems that some illnesses are either present or not, there can be delays in using sensed health information (e.g., due to a busy healthcare staff) and in delivering healthcare and having it work (some medicines simply do not work immediately), and there are certainly topology issues related to whether someone has access to medical experts (both in terms of expert's ability to measure their health, and deliver healthcare). While for simple issues, another non-expert human could help improve your health (e.g., simply by making you food while you recover), some improvements are clearly not possible by a typical "neighbor." This makes the topology more sparse, which naturally can hinder quick resolution of serious health problems in some cases. The analogous frequency of application of healthcare solutions and the rate at which people get sick and well due to external influences can significantly impact the ability to achieve a just health distribution of solvable health problems (the only feasible goal). There are interactions between a wealth distribution and a health distribution as healthcare often costs money, and since improving/degrading health can result in an increase/decrease in income. Such interactions are coupled together for each human. Also, there are interactions between a health distribution and an education distribution, since education often costs money, and since higher educational attainment often leads to a higher income. In a sense, both health and education can be considered a financial investment; however, social justice demands that we see health and education as basic

rights that significantly contribute to our well-being. The basic couplings imply that general distribution policies must consider many features of a human, and not just those associated with money.

- *Education distribution:* Education comes in several forms: (i) simply by living life, observing, and learning (i.e., learning via life experiences); (ii) informal education from other humans (e.g., parents and siblings); and (iii) formal education, typically in a school, from a trained teacher. Native endowments connected with intelligence (e.g., memory and cognition ability) imply that two people with the same amount of education will not have the same level of knowledge. Moreover, people are educated differently since they live different lives and have different teachers and this too implies that even people of the same age and education in terms of number of years in school will not only have a different level of knowledge, but knowledge about different topics or processes. Hence, there is a natural inequality in the distribution of knowledge across humans that is in some sense just, at least in some cases (but perhaps not just if a good teacher cannot be afforded). Sensing a level of knowledge of an individual is regularly done with tests. Transfers are education, for example done by experts. However, transfer of knowledge from a teacher to a student *does not* imply that the teacher loses knowledge, indeed, most often teachers gain knowledge by teaching. The only knowledge loss is due to natural loss of memories over time (assuming no mental illnesses or disfunctionalities). Issues of uncertainty in sensing, quantization, sensing/transfer delays, topology, and impacts of education distribution policies, all apply. Moreover, there are intimate couplings between income, health, and education in each human (all can positively or negatively impact each other) which implies that good distribution policies must all consider all three features simultaneously. Clearly, equality of knowledge across all individuals is not achievable, but great inequalities can be significantly reduced by educating those with the least knowledge assuming the availability of funds and their health (mental and physical), along with an educational expert who helps.

A similar analysis can be generated for "technological capacity distributive justice." In a number of ways technological capacity inequalities are reduced via a combination of ideas from health and education (it is not always the same as the educational case, e.g., part of technological capacity is owning and using technologies analogous to how humans may own a bed net and use them to avoid malaria).

**Measuring Inequality in Multiple Human Features**

Quantitatively measuring inequality when there are multiple features (sometimes called "dimensions") of human well-being is not simple, and some feel that it is impossible. It is difficult enough to believe that one number can represent the level of attainment of one feature. It is much more difficult to believe

that there is a way to combine two or more features via some formula to obtain one number representing human well-being. Some would say that the goal is to simultaneously maximize levels of attainment of all features, but this is difficult since the features are coupled (but the idea of "Pareto optimality" at least provides a way to think about such an approach).

Others insist on the clarity that a single number provides in comparing the well-being of two or more individuals. This is why the UN, World Bank, and others use the HDI, discussed in Section 1.1.2. Recall that this is a measure that takes into account three features: income, health, and education. But, these features, when measured for many people (e.g., a sampling of people in a country) are often averaged, then combined in the formula in Equation (1.4) to obtain the HDI. Essentially, variance is not taken into account in the measurements of each feature. Hence, a society could appear to be more developed on average, than another due to higher averages, but have even more inequalities; many feel that such inequalities represent a significant lack of development. This led to the inequality-adjusted HDI, IHDI, in Equation (1.5) that uses the Atkinson measure of inequality that accounts for variations within dimensions via Equation (4.25). The IHDI is defined in a way that when there is no inequality in and between dimensions, the IHDI is the same as the HDI. To achieve human development, this perspective says that you need good levels of income, health, and education, and no/low inequalities in, and between these. When there is more than one feature, it is more difficult to agree on what equality means, and to come up with strategies that will effectively reduce measures of inequality when there are inter-dimension dynamic and uncertain couplings that significantly impact holistic distribution policies.

### 2.4.3 Wealth Distribution Policy to Promote Distributive Justice

The organization of the wealth distribution strategy, which is a distributed feedback control method, is shown in Figure 2.5. Here, three people are shown as boxes, and each person has their current wealth, a PID spending advisor (see Section 1.6.4), and a *local* wealth distribution policy (to be explained below) that is parameterized by a "generosity parameter." This policy will capture the notion of how individuals give and receive "donations," that are represented by the arrows in the figure. Of course, giving a donation corresponds to spending by an individual, and receiving a donation corresponds to an increase of income for the individual. The wealth distribution policy is based on feedback loops between individuals that try to reduce local wealth inequalities and the result can be that global inequalities are thereby also reduced. It is a feedback controller that tries to reduce inequalities of wealth.

Modeling and analysis of the dynamics of wealth distribution provides a sophisticated view of dynamic distributive justice.

**Wealth Distribution in a Small Low-Wealth Community**

In this section, a very small community is considered, one with only three people (some may even view this as not fitting some definitions of a community, but
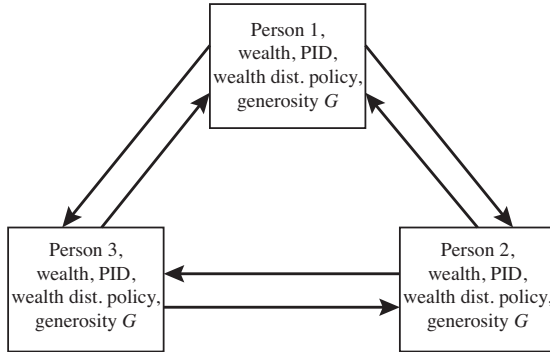
Figure 2.5: Wealth distribution strategy as a distributed feedback control system for inequality reduction.

strictly speaking a community only needs two or more people). We assume there is no group (e.g., government) that collects and redistributes wealth; only individuals contribute to each other, if they do at all. We consider a "low-wealth community" where persons are making around an average of $1 per day, and there are no donations from outside the community, or payments to outside the community. Why consider wealth redistribution in such a community as such persons likely do not have much to give, but only need to receive? If, perhaps via suffering as seen in Section 1.6.3, people can save money and if one person has saved $25 and another has absolutely no money, then one person looks quite rich compared to the lowest-wealth person. It is, however, questionable to some whether it is fair for the richer person in this case to have to give to the person with lower wealth.

Different assumptions will be made about the average income levels of each individual, and their desired wealth (i.e., what they are trying to keep in reserve to avoid the risk due to unexpected emergencies like health problems). It is assumed that each person gets $1 at the start of their life as inheritance, but the effect of this is unimportant. It is assumed that a PID spending strategy, the same one, is employed by each individual in the community simply to try to represent that each individual is doing a relatively good job at managing their own expenses, and to at least partly remove the issue of individual poor finance management influence from the problem (this could be viewed as a technology that extends human capability to do finance management per the discussion in Section 1.6.6). The PID spending strategies are not re-tuned for each individual, even though that could improve the performance of the strategy if, for instance, one person makes on average more money than another individual. The PID strategy is set to never recommend that the person spend less than $0.95 per day, and never more than $15 per day (the upper limit is normally not achieved). The lower limit is set higher than in Section 1.6.3 to represent that all individuals in this community want to avoid what happens when they spend very little money (e.g., they go hungry that day); this does not guarantee that they will spend

at least \$0.95 per day as they cannot spend what they do not have; hence you will see in the simulations times when they spend amounts less than \$0.95 in one day. It is assumed that the desired wealth profile of each individual is in the form, from Section 1.6.3, of an initial ramping up of wealth, then a holding of wealth constant at some level throughout their life. The impact of the levels of constant desired wealth will be adjusted to see their influence.

It is assumed in this community that every person can perfectly sense the true wealth of every other person with no delays and pass them donations (i.e., the topology is fully connected). It is assumed that each day each person looks at their income that day, the donations they received from others in the community from yesterday, and their wealth that day, and adds the three and subtracts the recommendation of the PID spending strategy in expenditures and spends that amount if possible (i.e., if they have enough funds in their pocket). Only after spending on themselves, will they consider donating to others depending on what their "remaining wealth" is after spending on themselves. First, however, the person needs to determine what they "want to donate" to others. To do this, each person in the community uses the following policy:

> *Community wealth distribution policy:* Each individual in the community looks at their own wealth today, and if it is greater than all their neighbors' wealths today, then since that individual is the richest of his neighbors (before any spending by anyone that day), s/he donates some percentage (denoted by $G$) of the difference between their wealth and the lowest-wealth neighbor's wealth to the lowest-wealth neighbor each day (that donation is actually received by the person they give it to tomorrow). S/he donates nothing to the other neighbor(s) who have less wealth than themselves, but more than the lowest-wealth neighbor (if in the rare case where two neighbors have equal wealth, then the donation is not split and it does not matter which person gets the donation so the one arbitrarily numbered lower (e..g, person 1) gets the donation).

A community can design their own wealth distribution policy; here, however, the policy is based on basic ideas from social justice.

Of course, as discussed above, this represents a number of ideas from religious and secular views of social justice; independent of topology, it tries to reduce global inequality by both raising the wealth of the lowest-wealth person in the community and reducing the wealth of the richest. For now, we assume that everyone in the community has agreed to this policy and will adhere to it every day and this sets the frequency of redistribution. For simplicity, it is assumed that money is infinitely divisible. There is a one-day delay in everyone getting donations from their neighbors, but the approach could be reformulated to remove that delay. It is not clear that humans will obey the above wealth distribution policy, in spite of what many systems of social justice say people ought to do. Yet, considering the "game of the Dictator" from behavioral economics, wealthy people do tend to give a portion of their wealth to someone who does not have any money (pp. 143-144 of (Toyama, 2015)).

The parameter $G$ has a significant influence on the community. Consider

$$G \in [0, \frac{1}{2}]$$

The lower limit of zero represents that no one donates to anyone else no matter what the wealth differences are, that is, that there is no wealth redistribution policy. Setting $G = \frac{1}{2}$ means that the richest neighbors will give half the difference of wealths between her/himself and their lowest-wealth neighbor, if they are richer than all their neighbors. Yet, from the perspective of the rich person, the worst case is if their neighbor has zero wealth and they will then give away exactly 50% of their wealth if $G = \frac{1}{2}$. This is quite generous in many cases as it equalizes the wealth of what was the richest and lowest-wealth individuals, perhaps driving the wealth of the individual to be lower than that of some of her/his other neighbors. Hence, the higher the $G$ value is the more "aggressive" the wealth distribution policy is. Moreover, it is important to consider the effects of even small values of $G$ over time: if someone gives 5% of the difference each day ($G = 0.05$), then this will still reduce the difference in wealths relatively fast (e.g., in the case where one individual keeps giving to their lowest-wealth neighbor they could quite quickly give *near* 50% of their wealth), but of course $G = 0.1$ will reduce wealth faster over time. The rate of redistribution is dictated by the value of $G$, the frequency of redistribution, and the interconnection topology between people.

In assessing what happens in a community with such a wealth distribution policy several issues will be considered: how much each individual spends on themselves, how much they donate to others, how much is donated to each individual, how well they can maintain their desired wealth (to avoid risk), and how often they spend a very low amount, or have a relatively low amount of wealth (the number of times they are at significant risk in coping with an emergency).

### Mutual Cooperation in a Low-Wealth Community

Suppose that all three persons in the community have the same average income of $1 per day (same as in Section 1.6.3, each day a uniformly generated random number in $[0, 2]$) and try to maintain a constant wealth of $25 per day (after an initial ramping up to this value). Also, all members are equal in the sense that they are "equally connected" to all other members of the community in terms of sensing wealth, passing donations, and receiving donations (i.e., it is a fully connected topology).

**No Wealth Redistribution Vs. Generous Wealth Redistribution:** In the case of no wealth redistribution between individuals, when $G = 0$, the results are shown in Figure 2.6. This is simply a simulation of three people living financially independent lives. Spending by persons 1, 2, and 3 are shown in the left column, top to bottom. Notice that spending is typically above $0.95, the lower spending limit set on the PID spending strategy, but sometimes it is

even lower (e.g., see persons 2 and 3, just after time is zero, as each person is struggling to save in order to match the desired wealth). The second column plots simply show that no one donates anything to anyone, or gets donations from anyone. The column on the right shows the error, the difference between desired wealth (ramp up to $25 dollars where it is held constant) and the actual wealth. Notice that due to the demand of the individual in the PID spending strategy to try to spend no less than $0.95 (high relative to the cases considered in Section 1.6.3), the individual finds it difficult to regulate wealth at the desired wealth. For all three individuals, deviations above the desired wealth occur (i.e., errors less than zero), but are limited in magnitude since in that case the person quickly spends the "extra" money to reduce wealth to the desired wealth. However, deviations of significant magnitude, above $10 for all people, appear, which corresponds to their wealth frequently going below $15 per day, which is judged to be a risky situation. Of course, if the PID spending strategy were adjusted by increasing the lower recommended spending limit above $0.95, better desired wealth tracking can be achieved as shown in the last chapter, but of course this comes at the expense of quite often spending less, which corresponds to more individual suffering to pay for the reduced risk.

Next, consider the case of a generous wealth redistribution strategy, one where $G = 0.5$, with results shown in Figure 2.7. First, in column 1 of the plots, notice that there is little, if any, very low spending; this due to the wealth distribution policy dictating that low-wealth people are given funds and this avoids them having to spend very low amounts. In the second column of plots, for each of the three individuals, it appears that the individual donates about as much has s/he gets (just as many times the red is behind the blue as it is in front of it), but it is not clear if one person is more generous than another in terms of average or total donations to others, or from others. The column of plots on the far right shows that, relative to the no-wealth distribution strategy case in Figure 2.6, much better wealth regulation is achieved. In particular, while wealth does sometimes go above desired wealth, it never goes below $25-$8, or $17 per day, which is then quite a bit less risky for everyone in the community every day of their lives than the no wealth distribution strategy.

Comparing Figure 2.6 to Figure 2.7 you may *suspect* that it is possible that the wealth distribution strategy may help, and not hurt, everyone (e.g., at least in terms of improving wealth regulation so risks are avoided); however, it is not possible to make such a conclusion from only two cases, especially considering how "noisy" the time sequences of data are in the plots, which arises from the random sequence of incomes of the three individuals. Next, we seek to confirm our suspicions about this wealth distribution policy.

Mutual cooperation can emerge in a community with no inequality.

**Average Effects of Generosity Level Considering Many Equal Communities:** Consider 100 communities of three persons each, with all identical parameters, as above (i.e., income and desired wealth equality among the three people), but with a range of 10 different values linearly spaced between $G = 0$ to $G = \frac{1}{2}$ (so, 100 communities for each of 10 different $G$ values, for a total of
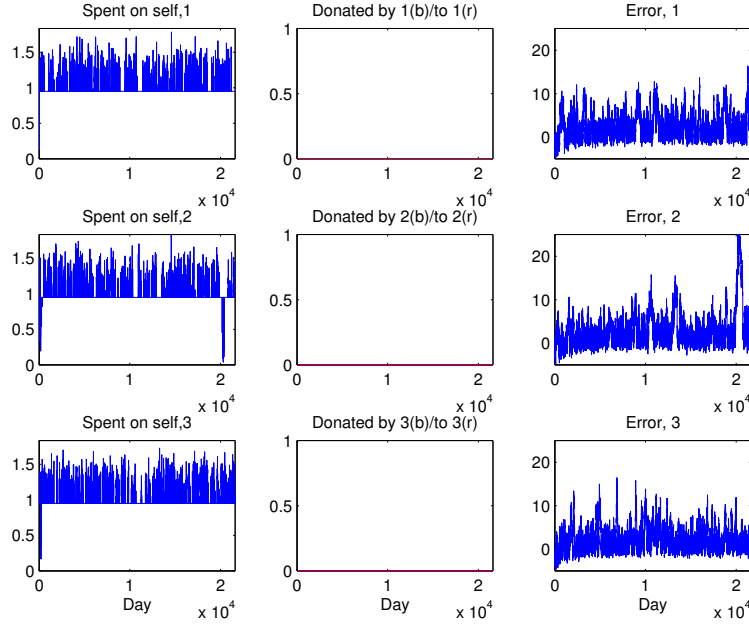
Figure 2.6: Community spending per individual (left column of plots), donations by (blue) and to (red) individuals (middle column of plots), and errors between desired wealth and actual wealth (right column of plots) for each individual, for individuals numbered 1, 2, and 3 per row of the matrix of plots. Case where $G = 0$.

1000 simulations of three-person communities). Means and standard deviations of various values will be computed over the 100 communities and used to represent average effects of the generosity level, $G$, for each of its values in the range from no generosity to high generosity.

Figure 2.8 shows the results in an array of plots analogous to what was produced in the last subsection, but the axes are all different. First, in the far-left column the mean and standard deviation of the total spending by persons 1, 2, and 3 are shown for values of $G \in [0, \frac{1}{2}]$. Notice that for each person, the mean total spending on themselves is close to \$21,600, the number of days in their 60-year life, since they spend on average of \$1 per day, the amount they make. The standard deviations in all cases are quite small. Hence, even with wealth transfers, including their own donations to neighbors which are expenditures but not on themselves, all people are spending as expected, and no matter how generous everyone is. The second column of plots shows the means and standard deviations of the total amount donated by each person (blue), and total donated
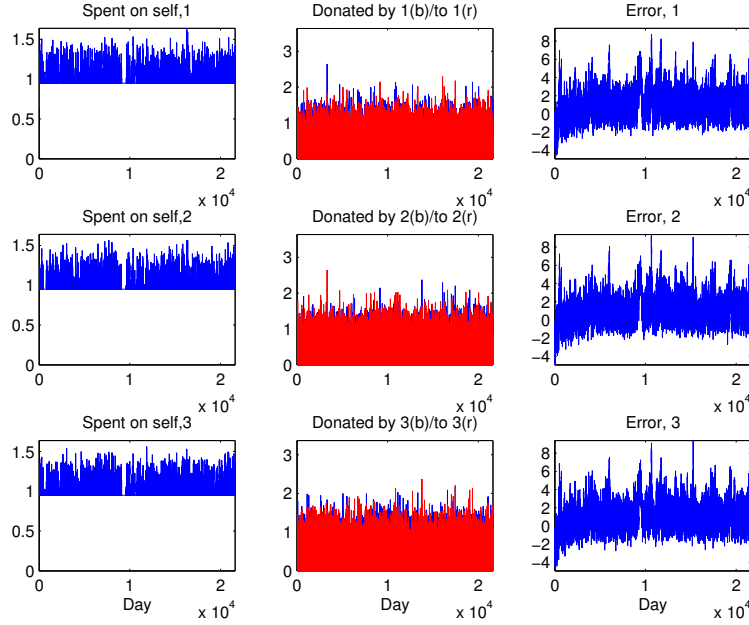
Figure 2.7: Community spending per individual (left column of plots), donations by (blue) and to (red) individuals (middle column of plots), and errors between desired wealth and actual wealth (right column of plots) for each individual, for individuals numbered 1, 2, and 3 per row of the matrix of plots. Case where $G = 0.5$.

to each person by all other persons (red). With very small standard deviations, the means for the two cases (donated and received) are virtually identical (red lines are on top of the blue lines) showing that on average all three people receive as much as they donate. This is why the donations by an individual do not, on average, reduce the spending plots in the first column. Does this indicate that the donations and receptions of donations have no effect on average? To answer this question, consider the last column of plots which shows the mean (over 100 communities) of the mean (over a life time) of the error, and the mean of the standard deviations, which illustrates that: (i) the mean errors for all three people decrease as $G$ increases (though do not go to zero due to the effect of the relatively high lower recommended spending limit of \$0.95 in the PID spending strategy that makes it difficult for the individual to save money when wealth goes below desired wealth so it can be driven back up to the desired level; put another way, notice that the mean of mean errors for all individuals is about one for high $G$ values), (ii) the mean standard deviations of the errors also decrease for all

three people as $G$ increases, and (iii) these means and standard deviations for all three people are basically the same for all values of $G$ (in this sense the wealth distribution strategy, on average, "equalizes" wealth across the community and hence could be viewed as successful in one way). Also, by both measures, as generosity increases, these mean and standard deviations of error measures of risk decrease, for every member of the community; however, successive increases of $G$ above about $G = 0.1$ generally give diminishing returns.

Next, Figure 2.9 shows, in the left-column of plots, the mean and standard deviation of the total number of times each person spends less than \$0.5 in a life time. For no wealth distribution strategy, there are times when a person spends such a low amount, but the number of such times generally decreases with generosity. A similar statement can be made with respect to the right-hand column of plots that show the mean and standard deviations of the number of times that wealth for a person goes below \$15. The wealth distribution strategy is clearly beneficial to all persons by these two metrics. However, it does not take a great amount of generosity to get the desired effects. Values of $G > 0.1$ seem to work equally well. It appears that most advancements are obtained via relatively low amounts of generosity. This is simply due to the fact that such low values of $G$ applied daily have a large impact relatively quickly, and in a sense correspond then to a high amount of accumulated generosity.

So, how can it be that average net donations/receptions are zero, and average spending by each person on themselves does not degrade for anyone, but the benefit of reducing risk and the benefit of not spending very low amounts (extreme suffering) is accrued by everyone? Does everyone not pay, but still win? On average, yes! To understand this phenomenon, the key is to realize that the high variances on the error seen in Figure 2.6 ($G = 0$) but lower variances in Figure 2.7 ($G = 0.5$) are important. Basically, assuming no wealth redistributions, all three people experience random times at which they are at more risk, but the likelihood of these occurring *at the same time by all three people* is relatively low. So, the effect of the wealth distribution strategy is summarized by: "Someone helps you when you are not doing well and you help someone when they are not doing well." Also, the benefit of reducing the number of times anyone in the community spends a very small amount of money is simply due to a similar effect (i.e., someone else is likely to have some money to give you in this situation).

It is the case, then, that this wealth distribution policy, under the assumption of equals, is a "mutually beneficial cooperation." If you enter into the agreement to join this community under these conditions (only if you are an equal), then it benefits both you and the others; hence, you will want to join, and the group will want you to join. Is there then a need for a law or moral mandate that generous sharing of wealth occur within this type of community? It depends on whether the individuals can understand (predict) the benefits of the cooperation. Of course, if the PID spending strategy is on an available electronic device it could keep track of the all the data in each row of plots in Figure 2.8 and this would encourage the individual to keep cooperating as they will see that "they are essentially getting something for very little if any cost." Does this seem
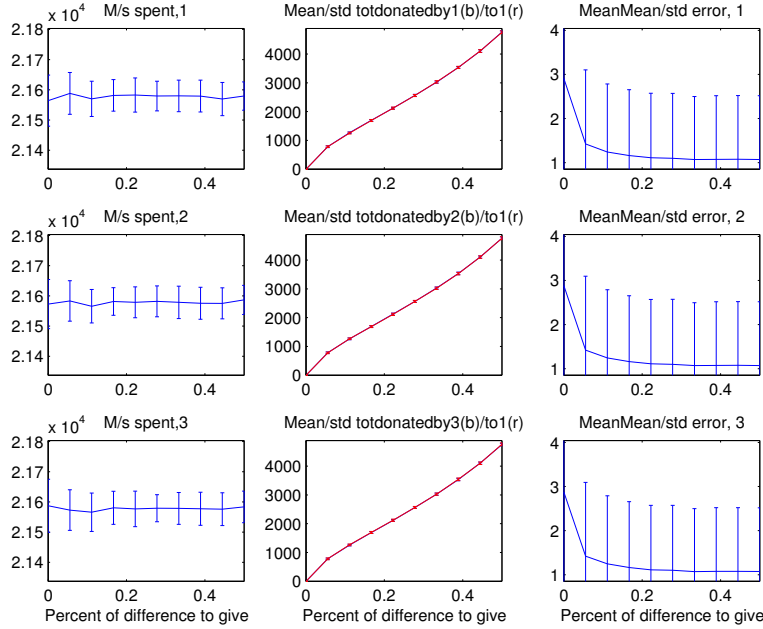
Figure 2.8: Community of three people making an average of $1 per day, effect of wealth distribution strategy on spending by each individual, donations to/from each individual, and the errors between desired wealth and actual wealth for each person. Horizontal axes are $G$ values (the explicit range is 0 to 0.5, meaning 0% (no giving) of difference to 50% of the difference (generous)). Vertical axes for the three plots on the far left, top to bottom, correspond to persons 1, 2, and 3, with values showing the means and standard deviations of the total amount these individuals spend on themselves. Vertical axes for the three plots in the middle, top to bottom, correspond to persons 1, 2, and 3, with values showing the means and standard deviations of the total amount these individuals donate (to any individual) and have donated to them (by any other individual). Vertical axes for the three plots on the far right, top to bottom, correspond to persons 1, 2, and 3, with values showing the mean (over all simulation runs) of the mean error in a life time, and the mean (over all simulation runs) of the standard deviation, of the difference between the individual's desired wealth and actual wealth.

too good to be true? Well, these effects clearly depend on the assumption of equality, an "ideal" case, as will be seen next.
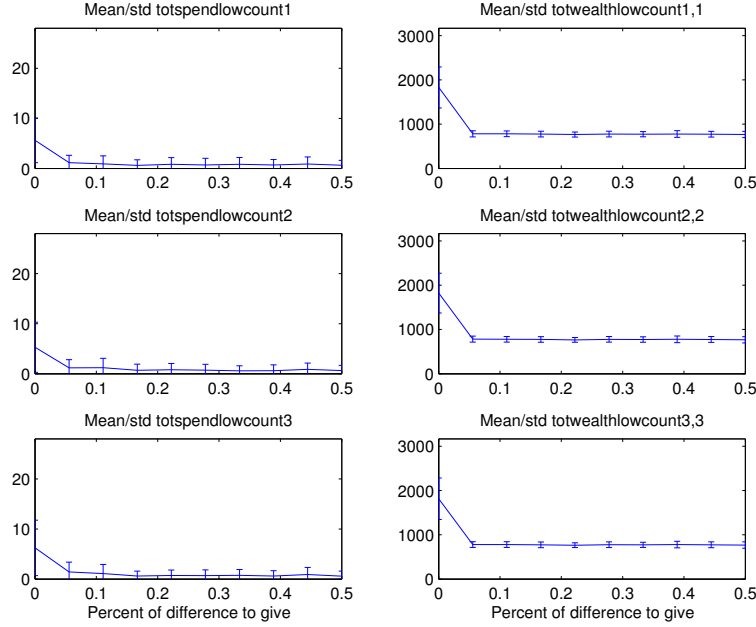
Figure 2.9: Community of three people making an average of $1 per day, effect of wealth distribution strategy on the number of times each person spends less than $0.5 per day and the number of times each person's wealth falls below $15. Horizontal axes represent a range of values of the percentage of the difference of wealths between the richest person and lowest-wealth person that the rich person gives the low-wealth person (explicit range of $G$ is 0 to 0.5, meaning 0% (no giving) of difference to 50% of the difference (generous)). Vertical axes for the three plots on the left, top to bottom, correspond to persons 1, 2, and 3, with values showing the means and standard deviations of the total number of times the individual spent less than $0.5 per day. Vertical axes for the three plots on the right, top to bottom, correspond to persons 1, 2, and 3, with values showing the means and standard deviations of the total number of times the individual's wealth fell below $15.

### Communities With Inequality in Individual Incomes

The same approach as in the last section is used, but only for five values in the range $G \in [0, 0.25]$ as the important effects can be seen in that range, and person 1 is given a raise by adding a constant of $0.25 per day to their uniformly distributed random income on $[0, 2]$ so that their average income is $1.25 per day. The others' incomes remain the same. Hence, there is income inequality

in the community in this case; however this is the only type of inequality.

Figure 2.10 shows, using the same format of plots as in the last section, the effects of income inequality in the community. In particular, first consider the left-hand column that corresponds to the mean total of spending on themselves for each of the three persons (and standard deviations which are very low). Keep in mind that the two low-wealth people should spend on average $21,600 in their life time, and with no wealth redistribution ($G = 0$) this is roughly the case. The first person, however, should be able to spend $1.25 \times \$21,600 = \$27,000$ on average in their life time and this too is roughly the case when there is no wealth redistribution. Notice that as $G$ increases, the mean total spending of the first person decreases (due to expenditures on donations to others) and the spending of the two low-wealth persons correspondingly increases (at the same levels) above the average of $21,600 due to these donations. The person with the higher income has clearly helped the two others at her/his own expense. Next, consider the middle column of plots that shows the means and standard deviations of the total donations by each person, and to each person, for different levels of generosity. As generosity goes up, the person with more income makes more and more significant donations to her/his neighbors, but does also get some donations also as shown by the red line for person 1, which occur when person 1 is having more difficulty regulating his wealth due to his reduction in spending due to providing so many donations. The two other people clearly get more donations than they give, but do indeed also provide some donations, including to the person with the *higher* income and spending. The first person regulates their wealth to the desired wealth quite well due to their higher income, and even has less variance around their desired wealth than the other two lower-income persons. As generosity increases: (i) the two lower-wealth persons can regulate their wealth closer to the desired wealth and with less variance, and (ii) the wealths of the three individuals are tending toward equalization for higher values of $G$ (the highest value of $G = \frac{1}{2}$ was not tested so the plots could focus on the lower $G$ values). In summary, as generosity increases, the higher-income person helps the others more, but the two lower-wealth people also help each other and the rich person (since everyone has variance on their wealth errors).

Figure 2.11 shows that the person with higher income never, for any value of $G$, spends less than $0.5 in a day, and that changing $G$ does not change the number of times the person's wealth goes below $15 (it does always go below that value about the same amount as when $G > 0.1$ for the two people with lower incomes). Having $G > 0.1$ ensures that the two individuals with lower income almost always avoid spending less than $0.5 per day. Hence, with enough generosity, more from the higher-income individual, but some from others too, the two low-income individuals do better by all measures considered, but the higher-income individual pays the price by spending less on her/himself than they could have, and donating more than the others.

Why would the high-income individual want to enter into an agreement on this wealth distribution strategy with a community? There could be several reasons. It could be that there are close family and friendship ties or it simply
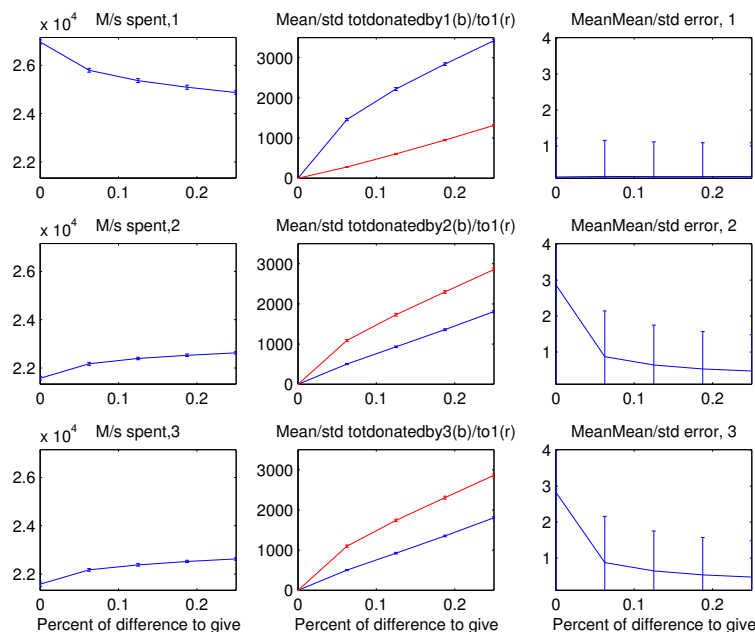
Figure 2.10: Community of three people, with one making $1.25 per day, and two making $1 per day, with a wealth distribution policy. See Figure 2.8 for a description of the meaning of the plots.

could be "where my family has always lived," or some similar reason that would put pressure on them to agree. Of course, the individual may have a certain degree of altruism, or may feel that the "pay back" for being viewed as a good person (i.e., reputation) for helping the community is worth it. Or, it could be that there are other pay back mechanisms that the person values, such as more power or leadership in the community that may come with helping out more. In terms of strictly financial reasons, it could be that they believe that there is no other deal that is better in a nearby community, and that they would not want to suffer the social isolation that would result in them not agreeing to this in their own community. Alternatively, they may listen to what their religion or moral philosophy is saying and simply agree based only on that.

Finally, could an electronic device of some sort (e.g., personal hand-held device with radio-frequency communications ability, one that extends the approach in Section 1.6.6) be useful to help implement the wealth distribution policy for the group? Via "reminders" (recommendations) on who should give whom what? Via keeping track of who gives whom what, to try to provide a clear picture of how fairly each person is treated? Modern devices can form local wireless networks so it certainly would facilitate implementation of the policy
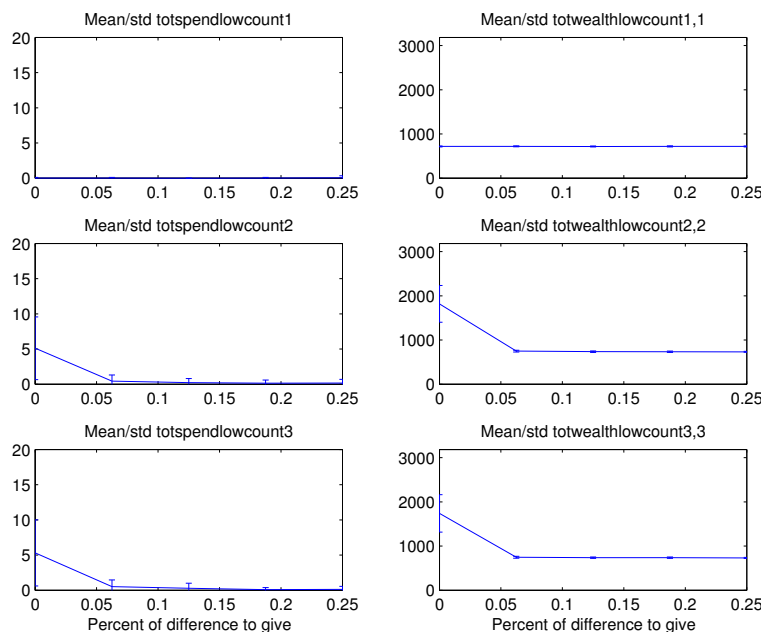
Figure 2.11: Community of three people, with one making $1.25 per day, and two making $1 per day, with wealth distribution policy. See Figure 2.9 for description of meaning of plots.

for the community. Of course, the same types of problems exist with such a technology as were discussed in the last chapter (e.g., will people really listen to donation suggestions, or what happens if the communications between devices temporarily fails and the wealth of the neighbors is not known?).

### Community With Inequality in Incomes and Desired Wealths

Suppose that everything is the same as in the last section, including the elevated income of person 1, but now also suppose that person 1 tries to regulate her/his wealth to $30, rather than the $25 that the other two persons with lower income try to achieve. This seems reasonable: if you have more income, your raise your target wealth held in savings to try to fix even larger emergencies. Figure 2.12 shows that while there are some similarities to the last case, there are important differences also in this case of greater inequality. First, notice that in the far-left column of mean/standard deviation plots of total spending that the richer person spends less and less on her/himself as generosity goes up, and the two lower-wealth individuals' spending on themselves goes up as they get more donations. But, it is important to note that at some relatively low $G$ value the average spending of the rich person goes *below* the average spending

of the two low-wealth people, and for higher $G$ values than that point there is a growing difference in the average amounts the rich person spends on her/himself relative to the two low-wealth people. Indeed, for the highest level of generosity considered, $G = 0.25$, the rich individual is spending on average *less than* $1 per day, the salary of the low-wealth individuals with no wealth distribution (i.e., $G = 0$). Clearly, the rich person is suffering to some extent to help the others, even when they are doing better in terms of how much they are spending for low $G$ values. The middle column of plots shows why this happens: the richer person is making most of the donations for any $G > 0$. The column of plots on the right shows, for the two low-wealth people, that the richer person's donations help them regulate their wealth and hence avoid risk. However, interestingly, this comes at a cost to the rich person of an increase in their own risk (increase in mean and variance) as $G$ increases. Also, as $G$ increases, wealth *across all three individuals* equalizes to a certain extent (for higher $G$ values it will get even closer as the mean error for person 1 is tending to $5, corresponding to mean wealth of $25). Considering all the plots at once, you see an interesting feature that as there is more generosity, wealth is equalized better, which actually tends to drive everyone to cooperate more by giving money to each other (that is, the equality case). Finally, Figure 2.13 shows that the mean total number of times that spending is below $0.5 (first column) is zero for the first person, and decreases as generosity increases for the two low-wealth people. A similar effect is seen in the column of plots on the right.

Returning to the discussion at the end of the last section, you may wonder why a rich person would want to join, or stay in, this community as they are giving more than they get, especially when there is more inequality, this time not just in income, but also in accumulated wealth. The difference in desired accumulated wealths here, assuming honest reporting of wealth, creates a significant problem for the richer person since decisions about donations, though made after spending on oneself for the day, are based on wealth. Success of the richer person in maintaining their desired (higher) wealth basically comes down to having to take on the challenge of helping others while trying to save money and that is generally difficult under the set of assumptions we have made. Clearly, different dynamics will arise if income or expenditures are used to make decisions about donations, that is, if a redistribution strategy focused on trying to equalize incomes or expenditures.

Finally, it should be noted that the wealth distribution strategy is quite simple and more sophisticated ones will clearly change the redistribution dynamics and how well everyone does in the community. The policy used here has one tunable parameter, $G$, but is dynamical in the sense that the error is multiplies is the difference between your wealth and the lowest-wealth neighbor's wealth (which changes over time) only if you are the richest of your neighbors (and is also influenced by the lower limit saturation nonlinearity that dictates that you cannot donate what you do not have). So, assuming the saturation limit is not hit, the policy is basically based on a linearly entering gain, multiplied by an appropriate error, that changes over time (that is, how the error is formed based on which neighbor is now the lowest-wealth). A logical strategy to try to im-
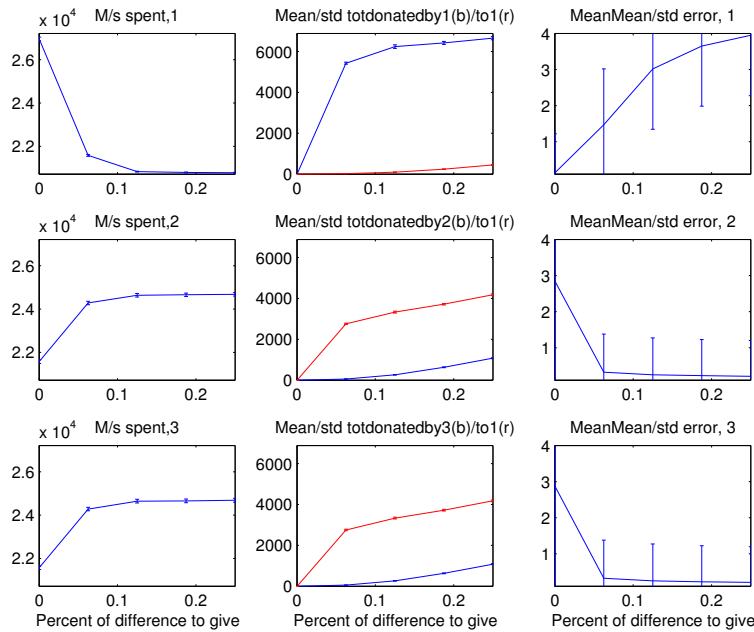
Figure 2.12: Community of three people, with one making \$1.25 per day and trying to maintain desired wealth at \$30 per day, and two making \$1 per day each trying to maintain desired wealth at \$25 per day, with wealth distribution policy. See Figure 2.8 for description of meaning of plots.

prove performance of wealth regulation is to change that proportional gain into a "PID donation strategy." While there may be benefits to such an approach, it is difficult to escape two facts: (i) inequality reductions seem to *always* require more of the richest in realistic cases; and (ii) it is likely going to be increasingly difficult to get richer people to agree to, and follow, any redistribution strategy that is increasingly requires more of them. Perhaps the question is "what will they live with."

Finally, there is the issue of whether an electronic device would be useful and acceptable to implement more complex strategies for donations, and that ultimately may depend on various persons perspectives, the engineering team deciding it, versus the community, versus the rich persons in the community who may have the power to get it accepted or not. Clearly, the human side of such technology is very complicated, and likely dominates the complexity of the technology design itself and demands for "robustness," i.e., so the same PID strategies, combined with wealth distribution strategy, will work for a wide range of financial conditions the individual clients encounter within one community,
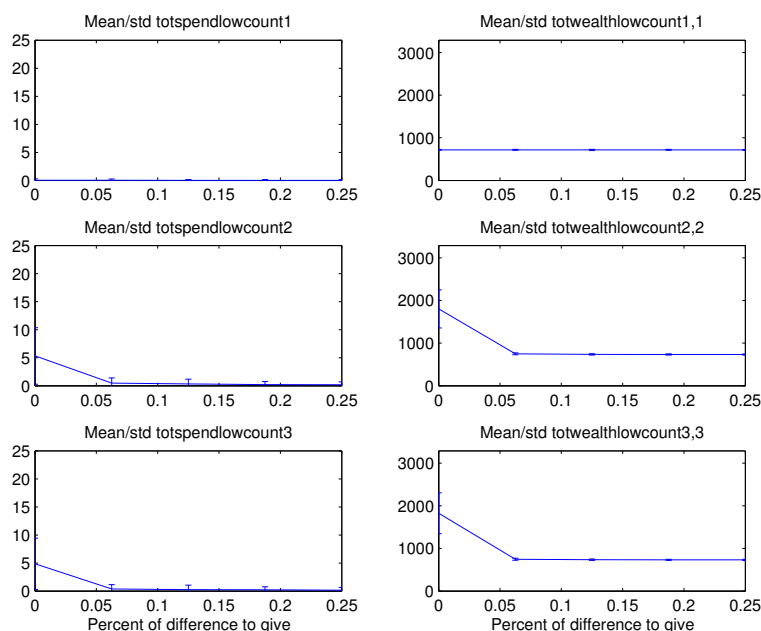
Figure 2.13: Community of three people, with one making \$1.25 per day and trying to maintain desired wealth at \$30 per day, and two making \$1 per day each trying to maintain desired wealth at \$25 per day, with wealth distribution policy. See Figure 2.9 for description of meaning of plots.

*and* the wide range of different communities that a "social version" of the basic PID spending strategy technology would have to cope with in order to gain broad acceptance.

### 2.4.4   Democracy for Wealth Distribution Policy Choice

Here, concepts from participatory justice and distributive justice are combined. Consider a very simple form of democracy (what you might call "social choice" or "group choice"), where the individuals in a small community of three people collectively choose the wealth distribution policy for the community. Assume that the wealth distribution policy of the last section is used, but that the generosity parameter $G$ is selected via voting by the community. Normally, you would think of such voting occurring once a year. Here, for convenience, such voting is going to take place each day when donations from others, income, and expenses are known, and the generosity parameter chosen is used that day in deciding what donations to make, ones that others will receive the next day.

The organization of the combined democracy and wealth distribution strat-

Democracy adjusts the wealth distribution policy to adapt it to local desires.

egy, which is a distributed feedback control method, is shown in Figure 2.14. Notice that this figure builds on Figure 2.5 in two ways: (i) it adds for each person a process of personally assessing how well they are doing under the current generosity parameter $G$ and then specifying a vote on whether to increase or decrease the generosity parameter; and (ii) a model of democracy at the upper level collects the votes, determines the majority vote, and adjusts the generosity parameter $G$. While the wealth distribution process at the lower level is distributed, the upper level democratic strategy (controller) is centralized in the sense that it is assumed that all votes can be gathered from all people and that the updated generosity parameter $G$ can be broadcast to all people. The democracy adds an *adaptive* feature to the feedback system so that the democratic wealth distribution policy adapts to local conditions according to the wishes of the community. Of course, just like any controller, the democratic strategy could be designed (changed) to improve overall performance.
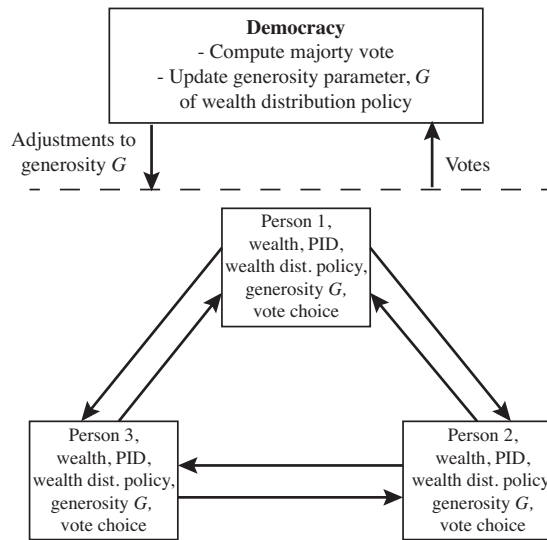


Figure 2.14: Democracy for adjusting a wealth distribution strategy viewed as a distributed adaptive feedback control system.

There are a number of types of feedback in this system. At the lowest level there is the personal spending advisor PID feedback loops for each person. Next, there are feedback loops between individuals that try to reduce inequalities. Then, the votes from individuals provide the democracy feedback information that it uses to adjust generosity. Everything is coupled, nonlinear, stochastic, and dynamic. Yet, you will see that the system behaves in predictable ways.

**Voting on Wealth Distribution Policy Changes**

Suppose the three people cast votes from the set of three different options

$$\{-P, 0, +P\}$$

where $P$, $P > 0$, is the amount to change $G$ and $-P$ means the person votes to *decrease* $G$ by $P$ compared to yesterday, 0 means the person votes to keep $G$ the same as yesterday, and $+P$ means the person votes to *increase* $G$ by $P$ compared to yesterday. Here, choose $P = 0.001$, or a change of 0.1%. This formulation could be easily changed to disallow the "0" vote so that there are only two choices, or at the other extreme, allow for each individual to pick each day along a continuum of $[0, \frac{1}{2}]$ as their vote. Suppose that the value of $G$ used on day $k$, $k \geq 0$, is denoted by $G(k)$. Here, we force $G(k) \in [0, \frac{1}{2}]$ based on ideas above, so that even if voters vote for it to go above or below these endpoints, it will be kept at the endpoints. Here, $G(0) = 0$ is used, that is, it is assumed that the community starts with no generosity.

How does a voter $i$, $i = 1, 2, 3$, determine how to cast a vote? The voter needs to somehow determine which option will help them the most. Suppose for the moment that any one voter is considered and we act as though they are the only voter picking $G(k)$ (that is, consider how votes are determined by individuals; later we will consider how to combine the votes). Suppose the measure used by each voter to determine how well they are doing financially is denoted by $J^i(k)$, $i = 1, 2, 3$, on day $k$. Suppose that from the voters' perspectives, they want to pick $G(k)$ so that it benefits them the most, that is to increase $J^i(k)$; so, *greed* is assumed of each voter in casting their vote (ignoring that some individuals might have at least a slight amount of altruism, often found in humans).

The problem is that $G(k)$, $k > 0$, is not known. Assume that at some point in the day, the voter knows her/his own income, expenses, and wealth for the current day. They also know (if they can remember it) the total they have given to others and received from others over their life time up till yesterday (but not today as that is what they are trying to determine). A voting strategy can only depend on current information the voter has. Hence, choose $J^i(k)$ to be sum of (i) the total amount received in donations minus the total amount given in donations to others over their whole life time, up till yesterday (the sum of the difference, something that voter $i$ would like to be large so that the voter receives without donating, and that can be computed incrementally at each step); and (ii) added to a constant $S$, $S > 0$, times the amount that the person decided to spend on themselves today. Choose $S = 10$, but we will discuss this value below. Clearly, the individual wants to either increase $J^i(k)$ via increasing donations to themselves, decreasing donations to others, or increasing spending on themselves, or all three (income is not included in $J^i$ since changing $G$ in our model does not affect income). It would also be natural to include an absolute value of the wealth error as a term in each person's $J^i(k)$. The values of $G(k)$ will affect values of these components of $J^i(k)$ as was seen in the last section.

To maximize $J^i(k)$, for each $i$, by adjusting $G(k)$ consider the "update equa-

tion" for $G(k)$

$$G(k) = G(k-1) + \alpha \left[ \frac{J^i(k) - J^i(k-1)}{G(k-1) - G(k-2)} \right] \tag{2.1}$$

(in simulation, a small positive number is added to $G(k-1) - G(k-2)$ to make sure there is never a divide-by-zero error). This equation implements "hill climbing," where climbing up the hill ($J^i$ function) represents that the individual is doing better off. To climb this hill, the individual must vote for either increasing or decreasing $G(k)$; the update equation shows how to update $G(k)$ to try to increase $J^i(k)$. In Equation (2.1), $\alpha$, $\alpha > 0$, is called the "step size" (how big of a step to take up the hill) and $\frac{J^i(k) - J^i(k-1)}{G(k-1) - G(k-2)}$ is the "update direction" (which direction to move order to increase $J^i$) To see how this works, first note that the value of $G(k-1)$ produces $J^i(k)$ and $G(k-2)$ produces $J^i(k-1)$. This means that

$$\frac{J^i(k) - J^i(k-1)}{G(k-1) - G(k-2)} \tag{2.2}$$

can be interpreted as a slope of $J^i$ between $k-1$ and $k-2$. It is a measure of how changing the generosity parameter *of the group* will affect whether you go up or down the hill at the next step, $k$. That is, adjustments to $G(k)$ depend on whether this slope is positive or negative. First, consider two cases:

1. *Positive slope:* If $G(k-1) - G(k-2) > 0$ and $J^i(k) - J^i(k-1) > 0$, then Equation (2.2) is positive which represents that an increase in the generosity parameter resulted in an increase in the person's measure of how well they did under that generosity parameter. So, Equation (2.1) indicates that $G(k)$ should be increased as its right-hand-side term is positive. In this case, the person wants to increase generosity more since it worked well for them the last time it increased.

2. *Negative slope:* If $G(k-1) - G(k-2) < 0$ and $J^i(k) - J^i(k-1) > 0$, then Equation (2.2) is negative so Equation (2.1) indicates that $G(k)$ should be decreased as its right-hand-side term is negative. In this case, the person wants to decrease generosity more since it worked well for them the last time it was decreased.

There are two other cases, ones where $G(k-1) - G(k-2) < 0$ and $J^i(k) - J^i(k-1) < 0$ and $G(k-1) - G(k-2) > 0$ and $J^i(k) - J^i(k-1) < 0$; however, these are similar to the above two cases and also result in hill-climbing if Equation (2.1) is followed. There is also a fifth and sixth case that result from whether $J^i$ unexpectedly increases or decreases, but each results in switching to one of the above cases. Of course, in Equation (2.1) if $J^i(k) - J^i(k-1) = 0$, the voter keeps the generosity value the same, that is, $G(k) = G(k-1)$ representing a way to vote for no change.

This provides the basic idea for how a single voter would like to set the $G(k)$ value. Next, suppose individual "votes" are represented by $+1$, $-1$, and $0$, for increase, decrease, and do not change $G(k)$. To set the vote by the $i^{th}$ voter:

1. *Individual vote for more generosity:* Vote increase, $= +1$, if

$$\left[ \frac{J^i(k) - J^i(k-1)}{G(k-1) - G(k-2)} \right] > 0$$

2. *Individual vote for less generosity:* Vote decrease, $= -1$, if

$$\left[ \frac{J^i(k) - J^i(k-1)}{G(k-1) - G(k-2)} \right] < 0$$

3. *Individual vote for same level of generosity:* Vote no change, $= 0$, if

$$\left[ \frac{J^i(k) - J^i(k-1)}{G(k-1) - G(k-2)} \right] = 0$$

To determine a "majority vote" for the group, an aggregation of the individual votes, compute the sum of all the changes voted on by all individuals (i.e., the sum of the $+1$, $-1$, and $0$ values), then simply test if this sum is above, below, or equal to zero and adjust $G(k)$:

1. *Majority vote for more generosity:* If the sum is above zero, let

$$G(k) = G(k-1) + P$$

2. *Majority vote for less generosity:* If the sum is less than zero, let

$$G(k) = G(k-1) - P$$

3. *Majority vote for same level of generosity:* If the sum is zero let

$$G(k) = G(k-1)$$

In summary, Equation (2.1) guides each individual on how to vote, a majority vote is made, and then everyone has to live under the conditions created by the choice of $G(k)$ that the group makes until the next iteration.

### Emergence of Mutual Cooperation in a Low-Wealth Community of Equals

Suppose that the three individuals all make an average of \$1 per day and try to have stored wealth, after ramping it up, of \$25. A typical life of a community is shown in Figure 2.15 where the left-hand column shows the spending by the three individuals which is roughly the same. The middle column of plots shows the money donated by each individual (blue) and to each individual (red). Notice that donations increase in the beginning; this is due to the initial wealth for all individuals being set at \$1 (a low value so no one has much to give away), and the ramp up in desired wealth requiring savings by each individual,

A low-wealth community of equals can promote sharing and achieve mutual cooperation.

so that each individual has little to share at the start, then as they accumulate wealth they can share more. Below, you will also see that this increase in donations is due to an increase in the generosity parameter that is voted on by the community. Notice that donations to and from each individual are roughly the same overall. The errors between desired wealth and actual wealth for each individual are shown in the right-hand column of plots, where on average it appears that wealths are equalized. Also, compared to the $G = 0$ case in Figure 2.6 the variances on the errors are significantly less (you will see next, that relatively quickly the $G(k)$ value was increased enough so the behavior becomes somewhat like the generous case in Figure 2.7). Figure 2.16, the top plot, shows the voting by all three individuals (total vote count up till today), where increases in the plots show times where the individual voted for increasing $G$, days where it does not change is when the person votes to keep generosity the same, and decreases in the plots show times where the individual voted for decreasing $G$. The effect of the community voting on $G(k)$ for each day $k$ is shown in the plot on the bottom. Clearly, in this community of equals, in a type of participatory democracy, all typically vote for more generosity and this results in a mutually beneficial cooperation that benefits the entire community in terms of risk reduction (see discussion above). The community essentially collectively figures out that cooperation is to all their benefit via a democratic process.

### Low-Wealth-Skewed Unequal Community

Suppose that person 1 makes and average of $1.25 per day ($0.25 constant guaranteed income, and a random amount uniformly distributed on $[0, 2]$) and that person 1 tries to have stored wealth of, after ramping it up, $30. Suppose that persons 2 and 3 make an average of $1 per day and try to have stored wealth of, after ramping it up, $25 each. Hence, we think of person 1 as rich relative to persons 2 and 3, but person 1 tries to save more money and persons 2 and 3 are equally low-wealth. This community is "low-wealth-skewed" since there are more low-wealth people than rich people.

Figure 2.17 shows that spending, donations received, and error are basically the same for the two low-wealth people. However, the rich person donates more than receiving, spends less than the others after a short period, and their wealth is higher than the others but person 1 does not meet their savings goal on average. At first, everyone is donating to everyone else; this is due to the fact that all are frequently saving (which lowers their spending) to track the ramp increase in desired wealth and need help from each other to do that, but the low-wealth persons more than the rich. This ramp is the same in all three cases up till the time when the desired wealth of all three people reaches $25 where then the desired wealths for the two low-wealth people stay constant and the desired wealth for person 1 continues to increase linearly to $30 (i.e., person 1 is given a longer time period to save since s/he has to save $5 more). That extra time where person 1 is trying to save, but the others are just trying to maintain, drives person 1's spending down since s/he is donating more than the others

A low wealth skewed community adversely affects a rich person if the wealth distribution policy is chosen via democratic majority voting.
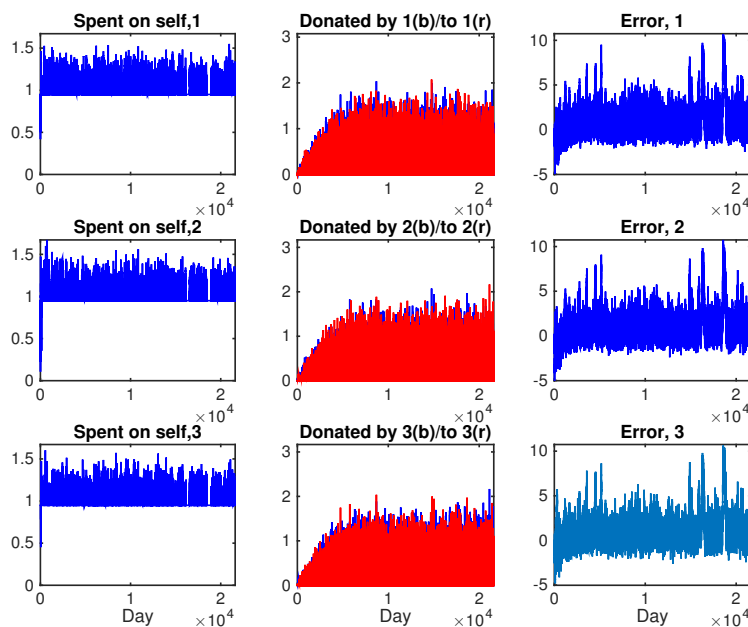
Figure 2.15: Voting on a wealth distribution strategy in a low-wealth community of equals: spending, donations, and desired wealth minus actual wealth per day.

*and also needing to save.*

The voting pattern at the top of Figure 2.18 is for the case in Figure 2.17, and connected with the generosity parameter dynamics at the bottom, it means that after the initial period, the two low-wealth persons are not *always* voting to increase $G$, and the rich person more frequently votes to reduce $G$, and these competing forces result in a type of *compromise* at the relatively constant value of $G$ seen in the bottom plot. The relatively low values of $G < 0.2$ are able to maintain sharing high enough to keep the variances on the errors in the right side column of plots relatively low for all people. This community is working together to try to meet the demands stated by the different desired wealths for each person and trying to balance everyone's interests; essentially, it picks a type of compromise dynamically over time under different conditions. Clearly, however, one could argue that the richer person is contributing more and suffering somewhat for it, even though the rich person has more wealth.

So, considering all the above analysis, is this type of democracy and wealth distribution policy fair for a low-wealth-skewed community? Of course, one concern might be that in one time period the rich person's personal spending was driven below that of the two low-wealth people and not readjusted. The type
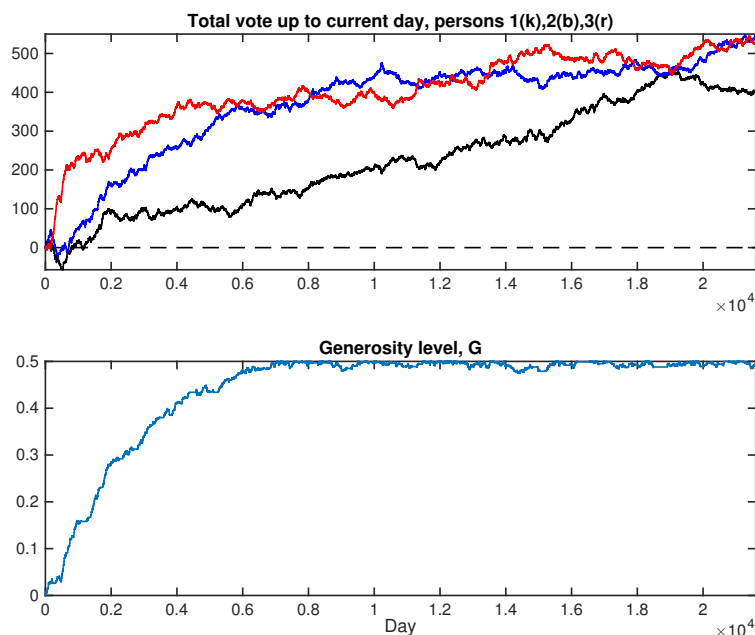
Figure 2.16: Voting on a wealth distribution strategy in a low-wealth community of equals: sum all votes up to current day vs. day for persons 1 (black), 2 (blue), and 3 (red).

of compromise achieved clearly depends on the criteria people use to cast their votes and the dynamic interaction between voting and wealth redistribution as both affect each other due to a feedback loop from signals from the community (e.g., donation amounts and spending) to the majority-chosen values of $G(k)$ that then affects the voters' criteria captured in $J^i$.

Finally, note that some feel that the value of money changes depending on how much money you have. For instance, if you are making $1 per day and you get a raise to $2 per day, that is quite significant; however, if you are making $65,000 per year, getting a raise of $365 per year is not normally viewed as being as important. Such an effect could be added to the model via a simple nonlinear function of wealth that decreases as wealth increases, and then redistributions could be completed based on each person's view of the value of wealth.

In a rich-skewed community, the low-wealth people can still fair well assuming there is a democracy adjusting a wealth distribution policy.

### Rich-Skewed Unequal Community

Suppose that persons 1 and 2 each make an average of $1.25 per day ($0.25 constant guaranteed income, and a random amount uniformly distributed on $[0, 2]$) and that persons 1 and 2 try to have stored wealth of, after ramping it up, $30 each. Suppose that person 3 makes an average of $1 per day and
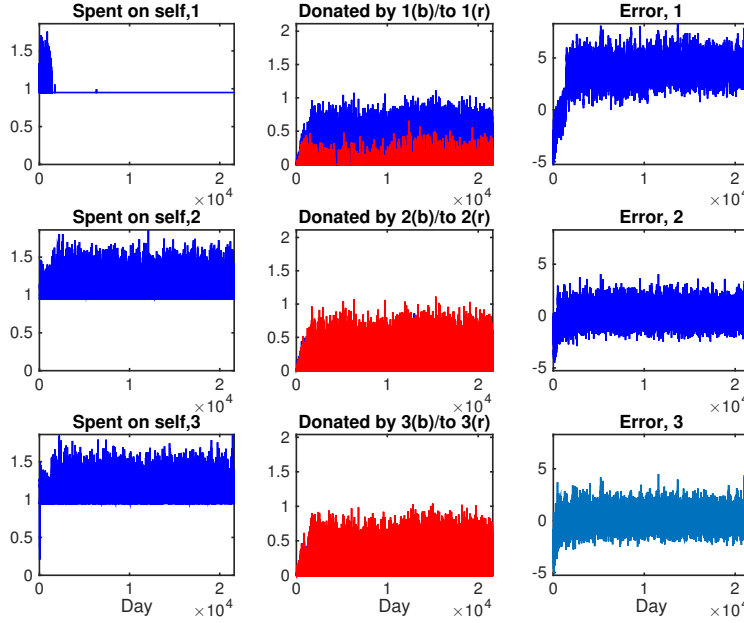
Figure 2.17: Voting on a wealth distribution strategy in a low-wealth-skewed community: spending, donations, and desired wealth minus actual wealth per day.

tries to have stored wealth of, after ramping it up, $25. This community is "rich-skewed" since there are more rich people than low-wealth people.

Figure 2.19 shows that spending, donations, and wealth error are basically the same for the two rich people. However, both rich persons donate more than receiving (except in a short initial period), and both generally maintain a slightly higher wealth than the low-wealth person though they do not reach their wealth objectives. The low-wealth person spends *more* than the two rich persons because they get donations from them and since they do not have as high of wealth objective. Figure 2.20 shows a predicable voting pattern, with the two rich voters requesting decreases in generosity, but the low-wealth person is more insistent on increases so there is still a compromise that keeps generosity nonzero as shown in the bottom plot, which has $G(k)$ values generally lower than in the low-wealth-skewed community shown in Figure 2.18 as the majority is rich.

**Impact of Inequality on an Average Community**

To study the impact of inequality on an average community, a parameter $I$, $I \in [0, 1]$, is used to adjust the inequality amount, with $I = 0$ representing the
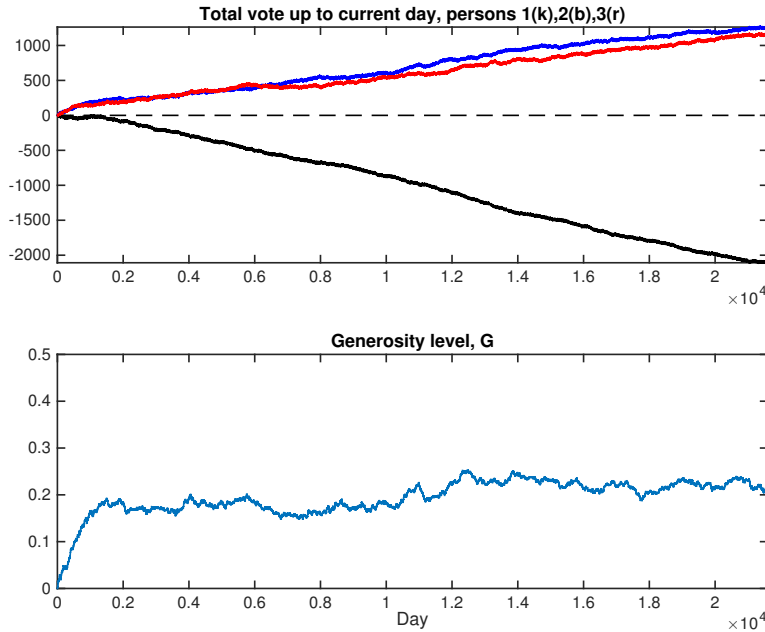
Figure 2.18: Voting on a wealth distribution strategy in a low-wealth-skewed community: sum all votes up to current day vs. day for persons 1 (black), 2 (blue), and 3 (red).

equal community:

- *Persons 1, 2, and 3 (equal):* Earn \$1.125 per day on average and try to ultimately have a savings of \$25 per day

The case where $I = 1$ represents the most unequal community considered:

- *Person 1 (rich):* Earns average of \$1.25 per day and tries to have \$30 in savings.

- *Person 2 (middle):* Earns \$1.125 per day on average and tries to ultimately have a savings of \$25 per day (that is, their parameters do not change; they stay constant in the middle between the rich and low-wealth person).

- *Person 3 (low-wealth):* Earns average of \$1 per day and tries to have \$25 in savings.

The rich and low-wealth person's parameters change linearly in terms of $I$ to change the equal community into the unequal one. Ten values of $I$ are considered, linearly spaced in $[0, 1]$, and 100 communities for each of the ten unequal
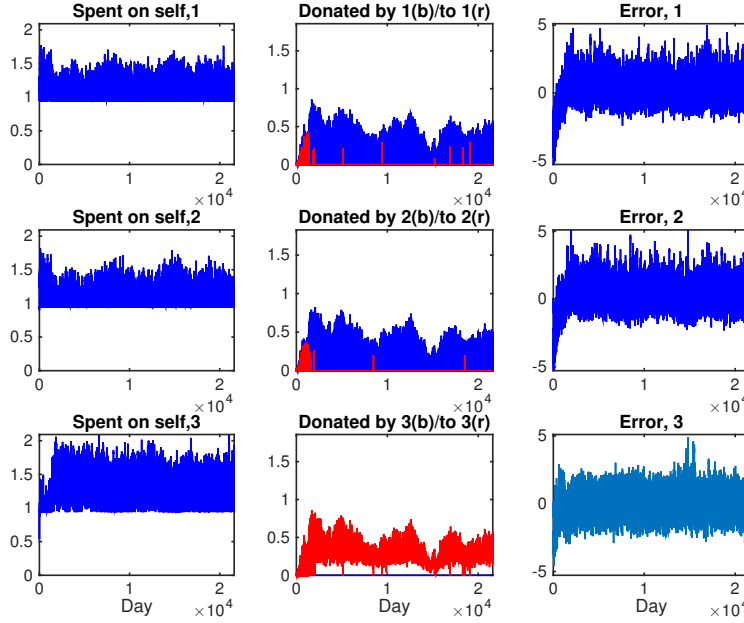
Figure 2.19: Voting on a wealth distribution strategy in a rich-skewed community: spending, donations, and desired wealth minus actual wealth per day.

community cases and statistics (means and standard deviations) are gathered for each of the ten parameter values.

To understand what happens as inequality increases in the community consider both Figure 2.21 and Figure 2.23 simultaneously. Figure 2.22 is, however, mostly inconsequential as it simply shows that for all levels of inequality everyone fairs almost the same via these metrics except the low-wealth person for around the highest levels of inequality as his well-being degrades some even with a wealth distribution strategy agreed upon that has a non-zero level of generosity on the average. For $I = 0$ everyone does the same by the metrics in Figure 2.21, and this is due to the fact that for the equality case, on average, a relatively high average level of generosity is achieved. To maintain this, note that in Figure 2.23 for $I = 0$ everyone is on average voting often enough for increasing generosity (see top plot, how the red, blue, and black curves all start *above* zero). Next, as inequality $I$ increases, the rich person spends less because s/he donates more, the low-wealth person spends more because s/he receives more, and the middle person spends, donates, and receives about the same independent of inequality. Next, comes the interesting part. As inequality increases, further average generosity *goes down* so that the rich person does
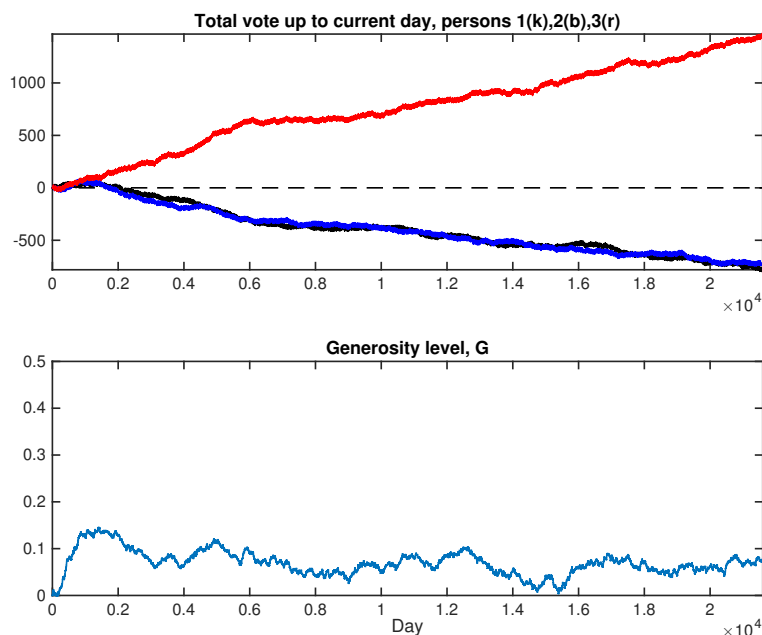
Figure 2.20: Voting on a wealth distribution strategy in a rich-skewed community: sum all votes up to current day vs. day for persons 1 (black), 2 (blue), and 3 (red).

not spend so little and then this drives the rich person's donations to others down (and all others' donations). This is similar to the dynamical situation we saw above. As inequality increases further, and as $I$ approaches one, the most unequal case, the rich person's donations and spending increase, and the low-wealth persons spending goes down but their received donations goes up; hence in the highly unequal case the donations to/from others of the rich and low-wealth person are mirror images of each other. So, at higher levels of inequality, spending is *equalized to some extent*, but not entirely as you see that the low-wealth person is still spending on average a more than the two who are richer.

Finally, note that the far right column of plots in Figure 2.21 shows that wealth is not completely equalized, and to see this more clearly consider Figure 2.24. This shows that as inequality $I$ increases, there is a rise in inequality of mean wealth of the three individuals due to the issues discussed above, but that as inequality $I$ increases more, the inequality in mean wealths stays about the same, but while the mean wealths are relatively close to each other they are never the same; this is due to the maintenance of a compromise to keep generosity elevated above zero. Notice that the mean of the mean wealths is always
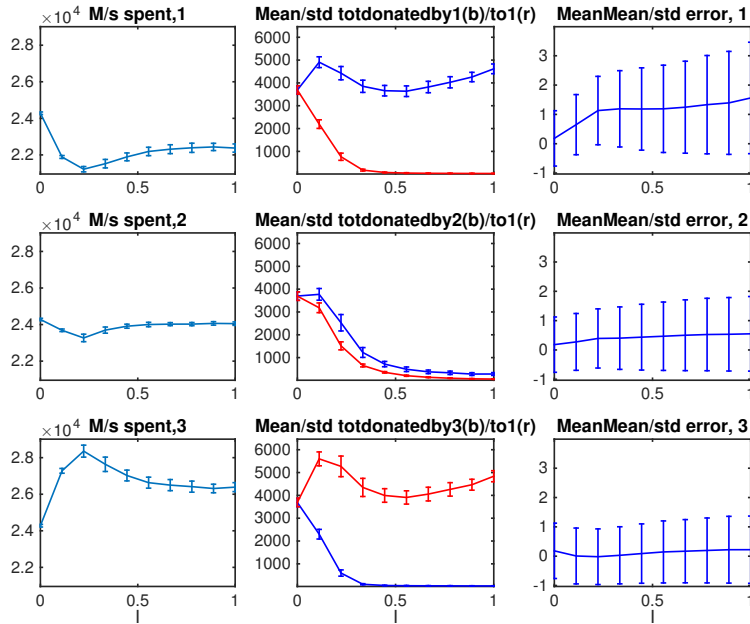
Figure 2.21: Impact of inequality in a low-wealth community with a democracy choosing their wealth distribution policy: Horizontal axes represent equal people on the left and increasing inequality as $I$ moves to the maximum inequality at $I = 1$. Vertical axes for the three plots on the far left, top to bottom, correspond to persons 1, 2, and 3, with values shown the means and standard deviations of the total amount these individuals spend on themselves. Vertical axes for the three plots in the middle, top to bottom, correspond to persons 1, 2, and 3, with values shown the means and standard deviations of the total amount these individuals donate (to any individual) and have donated to them (by any other individual). Vertical axes for the three plots on the far right, top to bottom, correspond to persons 1, 2, and 3, with values shown the mean (over all simulation runs) of the mean error in a life time, and the mean (over all simulation runs) of the standard deviation, of the difference between the individual's desired wealth and actual wealth.

ordered such that the richest person has highest mean of mean error, the middle person next, and the lowest-wealth person with lowest mean of mean error (and lowest variances). This means that the lowest-wealth person is best at achieving her/his target wealth, but that target wealth is lower than the others.
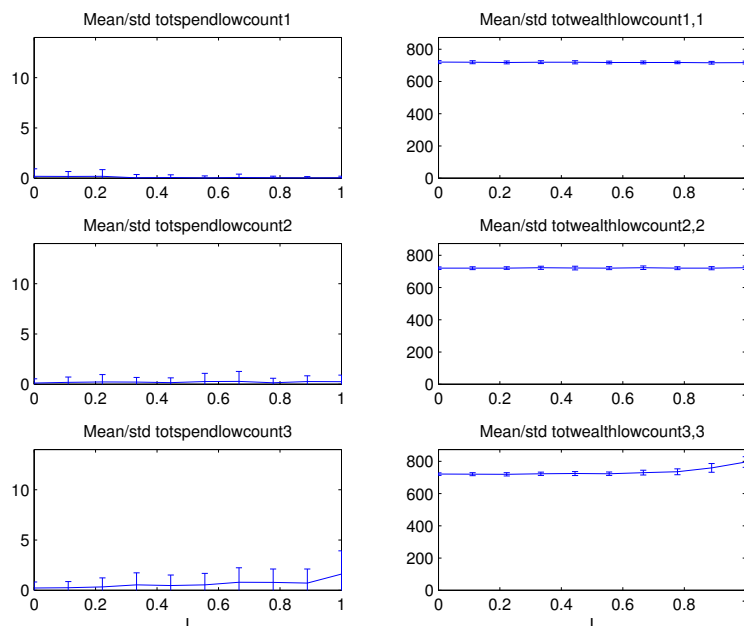
Figure 2.22: Impact of inequality in a low-wealth community with a democracy choosing their wealth distribution policy: Horizontal axes represent equal people on the left and increasing inequality as $I$ moves to the maximum inequality at $I = 1$. Vertical axes for the three plots on the left, top to bottom, correspond to persons 1, 2, and 3, with values shown the means and standard deviations of the total number of times the individual spent less than \$0.5 per day. Vertical axes for the three plots on the right, top to bottom, correspond to persons 1, 2, and 3, with values shown the means and standard deviations of the total number of times the individual's wealth fell below \$15.

**Challenges in Analysis of Integrated Democracy and Distributive Justice**

Consider the following questions and ideas:

1. Could an electronic app or device assist with not only personal finance management via the PID spending strategy and the wealth distribution policy implementation, but also in helping collecting data for the metrics used for voting by computing the $J^i$ for $i = 1, 2, 3$, and recommending a vote on whether to increase or decrease generosity? What if the person does not like the recommendation periodically and votes the other way?
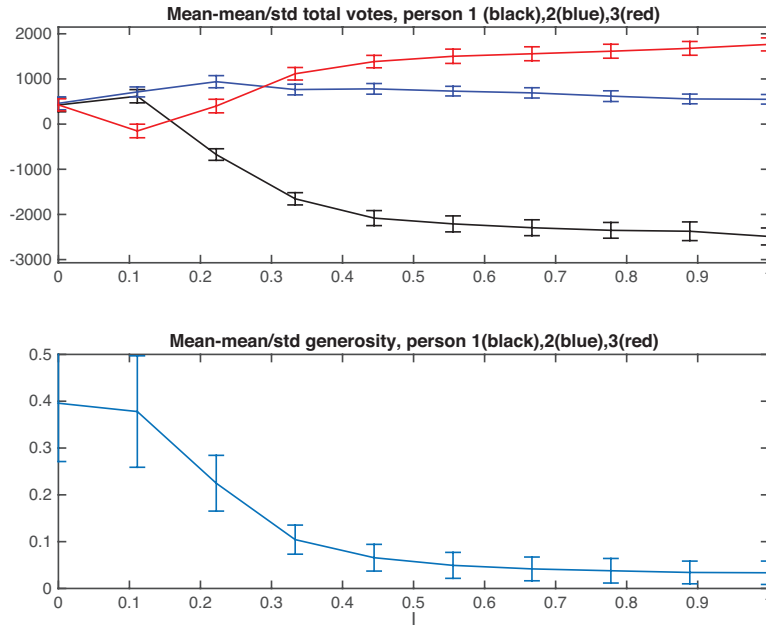
Figure 2.23: Impact of inequality in a low-wealth community with a democracy choosing their wealth distribution policy: Horizontal axes represent equal people on the left and increasing inequality as $I$ moves to the maximum inequality at $I = 1$. Vertical axes for the plot on the top shown the mean and standard deviation of the total number of votes for each voter (rich person, black; middle person, blue; and low-wealth person, red) and for the plot on the bottom the mean (over 100 communities) of the mean (over a life time) and mean (over 100 communities) of the standard deviation (over a life time) of the generosity parameter.

2. What will happen with many more humans? A topology that is not fully interconnected? The addition of a grand re-distributor like a government? Are the above results sensitive to changes in the criteria that make up the $J^i$? The gains used there? Whether or not everyone chooses a basically different $J^i$? Such issues can be analyzed by standard methods for "sensitivity analysis" in systems theory where pieces of the system are perturbed and you study how this perturbs outcomes (e.g., see Section 3.6.2). What happens in the presence of corruption where wealth transfers are stolen, or increasing wealth gives each voter more "power" in the sense that they get amplified influence? What happens when there is oppression such that if your wealth is low, you do not vote for one reason or another (you are
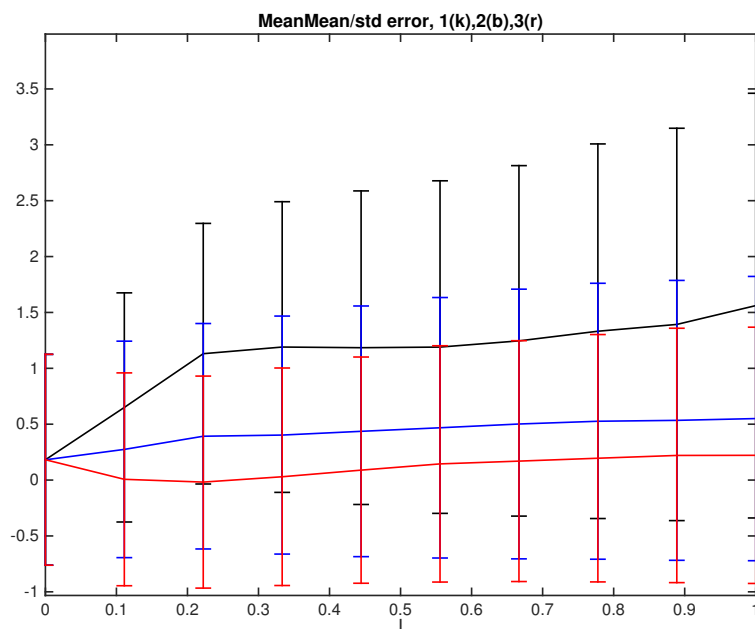
Figure 2.24: Impact of inequality in a low-wealth community with a democracy choosing their wealth distribution policy: Horizontal axes represent equal people on the left and increasing inequality as $I$ moves to the maximum inequality at $I = 1$. Vertical axes for the three plots on the far right, top to bottom, correspond to persons 1 (rich, black), 2 (middle, blue), and 3 (low-wealth, red), with values shown the mean (over all simulation runs) of the mean error in a life time, and the mean (over all simulation runs) of the standard deviation, of the difference between the individual's desired wealth and actual wealth.

"marginalized"), or at least somehow your vote counts for less? Generally, we want a "robust" system so that a wide range of variations can be coped with (even ones like corruption) and the system basically operates the same.

3. What would the religious doctrines say about this democracy integrated into distributive justice? Could the religious, and philosophers, have predicted the types of dynamics that are seen in all cases, that indeed do matter to people in their every day lives? What about John Rawls? Would he view a three person community of the type studied as large enough, having "reasonable pluralism," a fair system of social cooperation, and a political conception of justice via democracy (his assumption) that in-

deed results in something like the difference principle since the average $G$ value, even for larger inequalities, is non-zero? Does this show that Amartya Sen was wrong to doubt that Rawls was correct about the difference principle? Was Rawls right about his idea of stability? Are these questions even appropriate when considering wealth equalization rather than income equalization or spending equalization?

### 2.4.5  Environmental Justice and the Commons

In Section 1.6.7 we studied the dynamics of how utilization of resources in the commons can lead to a tragedy in the sense that the commons are destroyed. Recall that the "commons" include many aspects of the environment, including oceans and lakes, forests, the climate, etc. Equation (1.6), which is repeated here for convenience,

$$R(k+1) = R(k)\left(e^{r\left(1-\frac{R(k)}{K}\right)} - U(k)\right)$$

characterizes a single resource $R(k)$, at step $k$, in the commons and its dynamics in the presence of the total utilization by all $N$ users, $U(k)$, $k \geq 0$. Recall that we consider the commons to be destroyed (i.e., a tragedy) if $R(k) < R_d$ at any step $k$.

Individual users, $i = 1, ..., N$, have resource utilizations of $u_i(k)$, $k \geq 0$, and $0 \leq U(k) = \sum_{i=1}^{N} u_i(k) \leq 1$. It is assumed that user $i$'s utilization is

$$u_i(k+1) = u_i(k)e^{r_{u_i}\left(1-\frac{u_i(k)}{K_{u_i}}\right)} \tag{2.3}$$

where $r_{u_i}$, $r_{u_i} > 0$, is the rate of growth of utilization and $K_{u_i}$, $K_{u_i} > 0$, is the maximum amount the user's utilization will increase to. With this model,

- If $u_i(0)$, the initial utilization, is $u_i(0) < K_{u_i}$, then $u_i(k)$ will *increase* to the ultimate value $K_{u_i}$.

- If $u_i(0)$, the initial utilization, is $u_i(0) > K_{u_i}$, then $u_i(k)$ will *decrease* to the ultimate value $K_{u_i}$.

- If $u_i(0)$, the initial utilization, is $u_i(0) = K_{u_i}$, then $u_i(k)$ will stay at $K_{u_i}$ for all $k \geq 0$.

- The *rate* at which convergence to $K_{u_i}$ occurs is dictated by $r_{u_i}$, with low $r_{u_i}$ values leading to slow convergence and high $r_{u_i}$ values leading to fast convergence.

Environmental justice is concerned with, among other things, specifying what is fair in terms of resource use for a shared resource.

**Environmental Justice Policy**

The value $u_i(k)R(k)$ is the "benefit" to user $i$, and since $R(k)$ is the same for all users, user $i$'s benefit is proportional to $u_i(k)$. Should user benefits from the commons be equalized? There is a basic difference between equalizing income (as in the previous section) and reducing inequalities in user utilizations. You can pass money from one person to another. Can users transfer quanta of utilization? Someone with a high utilization could voluntarily reduce their own utilization, and "pass" the right to that amount of utilization to someone else. But, the person they transfer it to may not need or want it, or even have the capacity to use it. Exchanges in utilization can be fundamentally different from money. However, it may still be possible to reduce inequalities in utilization, basically by assuming (i) reductions for over-utilizers, either voluntarily or imposed by law; or (ii) increases in utilization by under-utilizers being allowed so long as they are not too much. The combination of these two ideas allows for some level of equalization of utilizations.

Goals of environmental justice could be:

1. *Equality:* Seek equality of utilizations, that is $u_i(k) = u_j(k)$, for all $i, j = 1, ..., N$.

2. *Approximate equality:* Seek equality within a range, that is $|u_i(k) - u_j(k)| \leq \epsilon$, for all $i, j = 1, ..., N$, for some $\epsilon > 0$.

3. *Upper limit:* Combined with objectives like these two, there is most certainly going to need to be an upper limit on individual utilizations. Why? Without some type of upper limit on utilization there will *always* be the possibility of a tragedy of the commons if utilizations can increase arbitrarily. An upper limit makes sure that a single user, or a group of users, do not take an unfair proportion of the resource, destroying the commons, or making it so that others' resource utilizations cannot increase hardly at all, or the commons will be destroyed. Setting an appropriate utilization upper limit involves consideration of the utilization patterns by all users, and how these will affect resource dynamics, and in particular resource depletion.

Goals of environmental justice can be sought via a policy.

Here, to *try* to meet goals like these we introduce a specific environmental justice policy (EJP). First, set an upper limit $u_c(k)$ on *ultimate* utilization, $k \geq 0$. Next, consider the policy:

1. *Under-utilization:* For individuals below $u_c(k)$, let them increase their utilization, but no more than to the level of $u_c(k)$. In particular, for user $i$, if $u_i(k) < u_c(k)$,

$$u_i(k+1) = \min\left\{u_i(k)e^{r_{u_i}\left(1 - \frac{u_i(k)}{K_{u_i}}\right)}, u_c(k)\right\}$$

2. *Over-utilization:* For individuals above $u_c(k)$, require them to decrease their utilization by some percentage of the difference between their current

utilization and $u_c(k)$. In particular, for user $i$, if $u_i(k) > u_c(k)$,

$$u_i(k+1) = \alpha(u_i(k) - u_c(k)) + u_c(k)$$

where $\alpha \in (0,1)$, and $(1-\alpha)100$ is the percent reduction of $(u_i(k) - u_c(k))$.

3. *Utilization at the limit:* If $u_i(k) = u_c(k)$ then let $u_i(k+1) = u_i(k)$.

Notice that the policy *restricts* utilization, but in a flexible way. Users with $u_i(k) > u_c(k)$ are required to slowly reduce their utilization down to the $u_c(k)$ level. Users with $u_i(k) < u_c(k)$ are allowed to increase their utilization, for example, users who become wealthier, or gain a better ability to gather resources, may increase utilization; however, such users cannot increase their utilization above $u_c(k)$.

Does this policy *always* result in achievement of the utilization equality goal above as $k \to \infty$? It will if for all users, $K_{u_i} > u_c(k)$. However, if for some $i$, $K_{u_i} < u_c(k)$, then user $i$ will never have utilization grow to even reach the $u_c(k)$ limit. Hence, in general, only the "approximate equality" and "upper limit" goals above will be met with this EJP.

### Effects of Policy on Utilizations and Resources

Assume there are $N = 200$ users. Let $K_{u_i}$ be randomly drawn from a uniform distribution on $[0, 0.0045]$ so that $K_{u_i}$ are random numbers such that $0 \le K_{u_i} \le 0.0045$. Let $r_{u_i}$ be randomly drawn from a uniform distribution on $[0, 0.8]$ so that $r_{u_i}$ are random numbers such that $0 \le r_{u_i} \le 0.8$. Let $u_i(0)$ be randomly drawn from a uniform distribution on $[0, K_{u_i}]$ so that $u_i(0)$ are random numbers such that $0 \le u_i(0) \le K_{u_i}$. This means that for all $i$, $i = 1, ..., N$, $u_i(k)$ will be increasing in $k$ if there is no environmental justice policy implemented.

Figure 2.25, in the top-left plot, shows the user utilizations $u_i(k)$ for all $i$, $i = 1, ..., N$, vs. $k \ge 0$. Notice that in all cases, the user utilizations are increasing at different rates, and achieve different ultimate values by the time step $k = 60$. Some ultimate utilizations are very low, and others are high. In this section, and the next, we will assume that $u_c(k)$ is constant for all $k \ge 0$. For the EJP of the last section, pick

> If a policy reduces utilization, resource levels will degrade less, and a tragedy may be avoided.

$$u_c(k) = 0.001, k \ge 0$$

and

$$\alpha = 0.6$$

Figure 2.25, in the top-right plot, shows the user utilizations $u_i(k)$ for all $i$, $i = 1, ..., N$, vs. $k \ge 0$ and the green horizontal line represents $u_c(k) = 0.001$. Notice that for $i$ such that $u_i(k) > u_c(k)$, the $u_i(k)$ decreases such that $u_i(k) \to u_c(k)$. This represents the use of the EJP as a law to get users who are over-utilizing the resource to decrease their utilization. It does not demand an immediate reduction, but a gradual one. Next, notice that for $i$ such that $u_i(k) < u_c(k)$, the $u_i(k)$ increases such that $u_i(k) \to u_c(k)$, or $u_i(k)$ increases such that $u_i(k) \to$

Figure 2.25: Number of users $N = 200$. User utilizations with no policy (top-left), user utilizations with environmental justice policy (top-right), total utilization of all users for the no policy and policy cases (bottom-left), and resource dynamics with and without the environmental justice policy.

$K_{u_i}$ if $K_{u_i} < u_c(k)$. Hence, the EJP demands heavy users to reduce usage and at the same time allows light users to increase usage.

The total utilization (sum of individual utilizations) $U(k)$, $k \geq 0$, for the case where the EJP is, and is not, used are shown in the bottom-left plot of Figure 2.25. Notice that in the case where there is no policy (red), $U(k)$ only increases. When the EJP is used, total resource use $U(k)$ is decreased, then held at a constant value. Plots of the resource values $R(k)$, $k \geq 0$, for a number of initial conditions $R(0)$, are shown in the bottom-right plot for the no-policy case (red) and when the EJP is used (blue). Here, the black horizontal line is $R_d = 20$ which is consider the threshold for destroying the commons. Hence, it is clear that without the policy, before $k = 20$ the red lines cross the black line, representing that $R(k) < R_d$ and the commons are destroyed. However, in the case where the EJP is used, the blue lines never cross the $R_d = 20$ line so due to the reductions in utilization from the EJP (top-right plot, bottom-left plot), the tragedy of the commons is avoided.

**Impact of Population Growth**

Suppose all the parameters from the last section are used, except the number of users is increased from $N = 200$ to $N = 400$. Figure 2.26 shows the results for this increase in the number of users. Compare to Figure 2.25. Qualitatively, the two cases are similar for all subplots except the bottom-right plot that shows a faster occurrence of the tragedy of the commons (red), but that even with the EJP the (blue) steady state value of $R(k)$ (at $k = 60$) is slightly *below* $R_d$ so a tragedy of the commons also occurs in this case. The problem is simply that $u_c(k)$ is set too high to cope with a doubling in the number of users. Setting a lower value of $u_c(k)$ will result in an avoidance of the tragedy; however, what is really needed is a way to make $u_c(k)$ a function of $N$, or at least dynamically adjust $u_c(k)$ so that if there are increases in the number of users (population) there will be no tragedy. This is the focus in Section 3.6.6.

Population size increases increase utilization and can result in a tragedy of the commons.
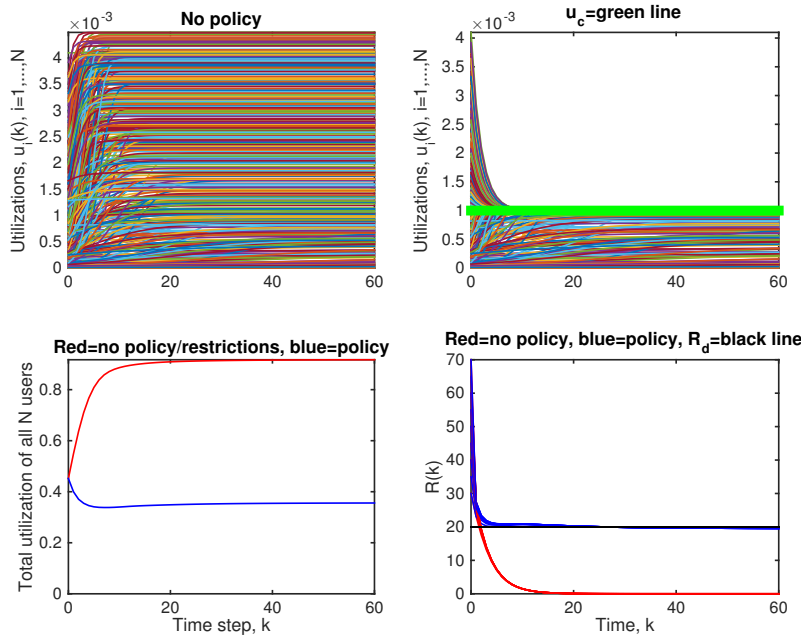


Figure 2.26: Number of users $N = 400$. User utilizations with no policy (top-left), user utilizations with environmental justice policy (top-right), total utilization of all users for the no policy and policy cases (bottom-left), and resource dynamics with and without the environmental justice policy.

Above, the chosen parameters do not represent an actual physical situation; hence, the above results only show qualitatively the behavior of the utilization dynamics, EJP, and resource dynamics. Adjusting parameters, and the model,

to fit an actual physical situation in nature is challenging and important as then simulations like above would suggest actual environmental policy.

## 2.4.6 Distributed Control: Principles and Approaches

The above wealth distribution policy and democracy are "distributed controllers" in the sense that they use process output information (e.g., individual wealths and donation amounts), but for *local decision-making* for what wealth to transfer to neighbors and what vote to cast (however, what they vote on, $G(k)$, is known by all). Distributed feedback control goes under a number of names in the literature including decentralized control, control of large-scale systems, and sometimes control of complex systems.

### Stability and Robustness

The connection between the ideas above and "stability analysis" in dynamical systems theory provides many ideas on how to study distributive justice and the integration of democracy as studied in this chapter (see bibliography below), among other social justice concepts. For instance, analysis of "asymptotic stability" would be the study of dynamical models of wealth distribution, where the objective would be to define a wealth distribution policy such that if there is wealth equality across a population, then there is a perturbation off such an equilibrium, then the wealth distribution would dynamically return to the equilibrium. Or, likely, true equality of wealth across a population will not be the objective. It is likely that a bounded variation of wealth would be allowed. Then, what class of wealth distribution policies will result in a wealth distribution that is "uniformly ultimately bounded" (that is, so that if the distribution starts within a neighborhood of equality, then eventually it will enter a neighborhood of equality, hopefully one where the size of the variations in wealth are known to be within a fixed acceptable level).

Design of robust systems (e.g., for "stability robustness"), as discussed in Section 1.6.8, is a central area of study, and common theme, in centralized and distributed feedback control systems and can be found in many textbooks today, especially for the centralized case; however, modeling, analysis, and design of robust systems for very high dimensional and distributed cases like we consider here, with the possibly low information flow, nonlinearities, and noise, is generally very challenging. Robustness is, however, central to the very idea of social justice, even though it does not seem to be discussed in a number of religious or secular perspectives. What does it mean in a social justice context? For instance, the mandates of social justice must be developed considering all eventualities (i.e., uncertainty) and for all societies. They have to be robust in the sense of general applicability. All the ideas in Section 1.6.8 apply to the challenge of modeling and analysis of robustness of distributed controllers for social justice. Here, we used a computational approach to such analysis.

**Distributed Feedback Control Via Optimization**

Optimization theory and algorithms (Bertsekas, 1999) are very well-developed fields of study with many applications (e.g., to development investment allocation in Section 3.6.3), including the distributed case (Bertsekas and Tsitsiklis, 1989). In a number of contexts, distributed control is realized via on-line real-time distributed optimization (e.g., in some distributed adaptive control approaches where errors are minimized by adjusting parameters) or game-theoretic approaches (Passino, 2005).

In Section 2.4.4, democracy is modeled as a type of distributed optimization process. Each individual tries to maximize the benefits to her/himself using only local information (and the globally known generosity parameter) and votes accordingly by choosing to increase or decrease the generosity parameter for the community. Then, via a majority vote, the "best" generosity parameter for the community is implemented. This distributed optimization process tries to make everyone happy by allowing each individual to be greedy and try to maximize its own benefit (by maximizing $J^i$), and, as we saw, this results in an "interpolation" between the individual desires in the community, that is, a compromise. Optimization approaches have also been used for distributed and cooperative processing of tasks (e.g., see (Pavlic and Passino, 2014)).

Finally, it should be noted that all the functionalities of centralized controllers discussed in Section 1.6.8, including adaptive/learning, planning, etc. can be used in a distributed context by incorporating such features in individual local controllers, or at a higher level, for example, for low-level controller supervision. The democracy strategy in Section 2.4.4 can be viewed as an adaptive strategy for the wealth distribution policy in the sense that a parameter $(G(k))$ is adjusted to achieve a compromise in a democratic fashion (in a control-theoretic view, the wealth distribution policy is a distributed set of controllers and the democracy adjusts the parameters of those controllers).

## 2.5 Conclusions

The broad conclusions for each section of this chapter are:

1. To understand the struggle for human rights you need a close-up view where you talk to people. The UN Universal Declaration on Human Rights provides a list of rights that has been ratified by all member nations. Engineers are rich in technological capacity and are encouraged to help those who are not.

2. The religious perspectives on social justice, here Buddhist, Catholic, Confucian, Hindu, Islam, and Jewish, share some perspectives, but differ on others.

3. The secular perspectives on social justice, here Rawls's and Sen's, and engineering ethics, have commonalities with some of the ideas in the religious perspectives, but also provide engineering-friendly ideas (e.g., the

capability perspective of Sen, or the ideas in engineering ethics as they apply in the developing world). Almost all these perspectives have a common goal that special attention is deserved by the lowest-income and least developed.

4. In the analytical approaches, a wealth distribution policy, and a form of democracy to vote on it, are simulated and used to explain their advantages and disadvantages. Environmental justice can be connected to sustainability, development, and population increases via a computational model, and then used to study the impact of policy on the environment.

## 2.6   Homework Problems

**Problem 2.1 (Human Rights):** View the (9:51) YouTube video

<div align="center">

Brief History of Human Rights

</div>

which was uploaded Feb. 10, 2012. What are the key human rights issues today? Is the world slowly making progress on achieving human rights of all people? Can we expect a major set back in the future like the world wars were in the past?

**Problem 2.2 (UN Universal Declaration on Human Rights (UDHR)):** Read the UN UDHR and then:

(a) Identify three cases where your native country has not followed the declaration for some right in the list. Explain.

(b) Identify for three rights who (or whom) has the duty to fulfill that right (e.g., which individuals, institutions, or government).

**Problem 2.3 (Dr. Martin Luther King, Jr., I Have a Dream Speech):** View the YouTube video on Aug. 28, 1963, and answer the following questions:

(a) List his main points and issues identified.

(b) Has anything he was concerned about changed in the greater than 50 years since his speech?

**Problem 2.4 (Technological Capacity Inequality and Traps: Engineers' Responsibility to Fix?):** Read Section 2.1.2.

(a) Explain what "inequality of technological capacity" is. Does social justice say that engineers are the key persons responsible to reduce this inequality (analogous to the case where you define inequality in terms of wealth and demand that rich people are the ones primarily responsible to reduce

the gap)? Give your answer from at least one religious and one secular viewpoint in this chapter (e.g., the Catholic "preferential option for the poor," Rawls's difference principle, etc.).

(b) Define what a "technology capacity trap" means. Does the existence of such a trap imply that technology capacity be given for free to some people or groups (by engineers or, for instance, aid agencies paying engineers to provide technologies and technology/engineering education) to help people break out of the trap so that they can increase their own technological capacity? You may provide a personal perspective on this, or use of of the systems of social justice in the chapter.

**Problem 2.5 (Buddhist Perspective on Social Justice):** Read Section 2.2.1. Summarize and critique Buddhism's perspective on social justice from the religious and secular social justice perspectives in this book. What is unique about the Buddhist perspective relative to the others?

**Problem 2.6 (Catholic Social Doctrine):** Read Section 2.2.2.

(a) Define human dignity and human fulfillment.

(b) State the 7 principles of social justice and give a 2-3 sentence definition of each.

(c) Identify the main issues in application of the principles to family, work, economics, politics, environment, and peace. In each case, use 2-3 sentences to describe the main points.

**Problem 2.7 (Catholic Relief Services):** View the YouTube (11:09) video

Catholic Relief Services–General Awareness Video

that was uploaded Dec. 21, 2010. Summarize the main points of the video and explain the connections to Catholic social doctrine.

**Problem 2.8 (Methodist Perspective on Social Justice):** Summarize and critique the (Christian) United Methodist Church perspective on social principles. Compare and contrast to the Catholic perspective covered in this book.

**Problem 2.9 (Mormon Perspective on Social Justice):** Summarize and critique the (Christian) Mormon perspective on social justice. Compare and contrast to the Catholic perspective covered in this book. What is different in these two Christian perspectives? Read (Ferguson, 1992). From the perspective of their social justice stance, is the claim in (McKenzie, 2013) that Mormonism is the "most capitalist religion in the world" supported by the Mormon view of social justice?

**Problem 2.10 (Confucian Perspective on Social Justice):** Read Section 2.2.3. Summarize and critique Confucianism's perspective on social justice from the religious and secular social justice perspectives in this book. What is unique about the Confucian perspective relative to the others?

**Problem 2.11 (Hindu Perspective on Social Justice):** Read Section 2.2.4.

(a) Summarize and critique Hinduism's perspective on social justice from the religious and secular social justice perspectives in this book. What is unique about the Hindu perspective relative to the others?

(b) How would a person following the Catholic perspective view the caste system?

(c) How do you view the lowest castes, and in particular the issue of the untouchables?

**Problem 2.12 (Islamic Ethics):** Read Section 2.2.5.

(a) View the (4:09) YouTube video of Myriam Francois Cerrah

<div align="center">Inspired by Muhammed–Social Justice</div>

that was published Nov. 2, 2013.

(b) Summarize the main points of the systems of ethics for the Islamic case.

(d) Investigate, and form an opinion on, the issue of women's rights from an Islamic perspective.

**Problem 2.13 (Islamic Ethics and Jewish Social Justice):** Read Section 2.2.6.

(a) View the (5:14) YouTube video,

<div align="center">A Jewish Conversation on Social Justice</div>

that was uploaded on Sept. 15, 20111.

(b) Summarize the main points of Jewish social justice.

(c) Summarize and briefly critique the universalistic and particularistic perspectives.

**Problem 2.14 (Secular Humanism Perspective on Social Justice):** Identify, summarize, and critique the secular humanism perspective on social justice using the religious and secular perspectives on social justice covered in this book. To do this, use the statement on secular humanism by the

<div align="center">Council for Secular Humanism</div>

Consider their "Affirmations" and "Declaration," and, for instance, identify their positions on poverty, religious freedom, and the environment.

**Problem 2.15 (Rawlsian Justice):** Read Section 2.3.1.

(a) Identify the main points of Rawls's theory of justice.

(b) Consider his two "principles." Do you agree with his ordering of the two principles? Do you agree with the "difference principle?" How does it related to the Catholic preferential option for the poor? To charity in the Islamic and Jewish perspectives?

(c) Explain, in a brief paragraph, the concept of "stability" that Rawls uses.

**Problem 2.16 (Amartya Sen's Capabilities and Justice Perspectives):** Read Section 2.3.2.

(a) Define public reasoning and explain why it is important to justice. What is "freedom?" Define capabilities and functioning.

(b) List what you feel are the "essential capabilities" and compare and contrast your list with the Nussbaum/Glover list given in the chapter.

(c) Explain why Sen says that "capability deprivation" is the proper way to measure poverty.

(d) What is a perfect and imperfect obligation? Give your answer in terms of observing a person who is extremely low-income.

(e) Does Sen support paying special attention to the most capability-deprived humans? Explain. Do you think he supports Rawls's difference principle?

(f) Explain the relationships between capability, freedom, and liberty.

(g) What Sen feel is good and bad about the free market?

**Problem 2.17 (Libertarian Perspective on Social Justice):** Summarize and critique the US Libertarian Party Platform from the religious and secular social justice perspectives in this book. Identify how the Libertarian view is consistent or inconsistent with religious and secular social justice perspectives (e.g., their view of ownership, charity, income redistribution via taxation, support for public education, economic systems, defense, and foreign policy).

**Problem 2.18 (US Political Party Platforms and Social Justice):** Summarize the Democratic, Republican, and Green Party platforms for the United States (you can find those on the web). Which religious or secular perspectives on social justice seem to have influenced each party platform? If social justice were your only concern, which party would you join (if you would like, you could consider the Libertarian perspective too, via Problem 2.17)?

**Problem 2.19 (Effects of Economic Inequality on Society):** View the (16:55) TED talk by Richard Wilkinson,

<div align="center">How Economic Inequality Harms Societies</div>

from July 2011.

(a) Summarize each way inequality affects society.

(b) Why does inequality matter as compared to absolute poverty?

**Problem 2.20 (How Equal Do We Want the World to Be: You'd Be Surprised):** View the (8:53) TED talk by Dan Ariely

<div align="center">How Equal Do We Want the World to Be: You'd Be Surprised</div>

from March 2015.

(a) What questions did he ask with respect to inequality? How does this compare with the data? What is the knowledge gap? What is the desirability gap?

(b) What does he say about what we want? Why is Rawls's veil of ignorance relevant here? Did anyone want full equality? Do these ideas hold up for other groups? Does he say that people do not like inequality in wealth, but for other things (health or education) people like inequality even more. Why?

**Problem 2.21 (Violence, Law Enforcement, and Poverty):** View the (22:06) TED talk by Gary Haugen

<div align="center">The Hidden Reason for Poverty the World Needs to Address Now</div>

from March 2015. What was the reason for the Rwandan genocide? What most deeply moved him about poverty, what person and what happened with that person? He views the fight against poverty as a movement of compassion. Are we making progress in the fight against poverty? He says compassion has the power to succeed. But, he qualifies the statement. How? What caused the

destitution of Venus? Who is Griselda? What was her problem? How does the violence he talk about compare, in impact, compared to malaria? What is the slavery problem he is talking about? What is the "locust effect? What does he say about law enforcement and the protection of law? Do low-income people live outside the rule of law? What is the role of private security in the developing world? Who gets it? Can low-income people get it? What is the path forward? What is a failure of compassion? What does he say about the grandchildren? See also (Risman and Miguel, 2008).

**Problem 2.22 (Engineering Ethics Case Studies: Developed and Developing World):** Read Section 2.3.3. Go to the National Society of Professional Engineers

<div align="center">

Board of Ethical Review cases

</div>

Pick three cases of interest to you.

(a) Write a one-paragraph long analysis of the case along with your conclusion. In your discussion use the principles of engineering ethics identified in the chapter. Assume for your analysis that the "public" includes only people from the developed world.

(b) Repeat your analysis for the cases in (a) but suppose that the public includes only persons from the developing world who are of significantly low socio-economic status.

(c) Compare and contrast the analysis for the two different publics for (a) and (b) for each of the three cases.

**Problem 2.23 (Engineering Professionalism and Service):** Read Section 2.3.3. Consider the following statement: "Every engineer must perform voluntary service for their community." Do you agree? Disagree? Explain. If you want, you can use the ideas from (Passino, 2009).

**Problem 2.24 (Social Justice in an Engineering Code of Ethics):**

(a) Read the National Society of Professional Engineers (NSPE) code of ethics that can be found in (Martin and Schinzinger, 2005) or at

<div align="center">

NSPE Code of Ethics for Engineers

</div>

(b) Summarize the main points of the code of ethics having to do with social justice.

(c) Do you find the NSPE views on social justice to be similar to some religious views? Which ones? Are there cultural influences on the construction of this code? How?

**Problem 2.25 (Changing Engineering Codes of Ethics?):** Read Section 2.3.3, and if you would like, see (Passino, 2009).

(a) Consider the following three statements: (i) "hold paramount the safety, health, and welfare of the public," (ii) "hold paramount the safety, health, and welfare of the public, and give special attention to these for the least advantaged," and (iii) "hold paramount the safety, health, and welfare of the public, and encourage engineers to pay special attention to least advantaged." Which statement do you think is best? Explain why.

(b) Should some type of statement be put in engineering codes of ethics on reduction of "inequality of technological capacity"?

**Problem 2.26 (Humanitarian Engineering as Social Experimentation):** Read Section 2.3.3. What is especially problematic about the social experimentation aspect of engineering when it comes to humanitarian technology?

**Problem 2.27 (Safety, Laws, and Global Engineering):** Read Section 2.3.3. Suppose your country has very stringent laws about worker safety and polluting the environment. Suppose you are doing engineering work in a country that has very lax laws (or no followed laws) on these two issues. Which framework of laws do you use in your engineering practice in the country with lax laws? Justify your answer. Take into account consideration of what a competing engineering firm may be doing.

**Problem 2.28 (Women, Minorities, and Humanitarian Engineering):** Why do you think women participate in humanitarian engineering at higher rates than men (Colledge, 2012; Bixler et al., 2014)? Do you think minorities have/will participate in humanitarian engineering at higher rates than non-minorities? Why or why not?

**Problem 2.29 (Social Justice in Social Work):**

(a) Read

National Association of Social Workers Code of Ethics

and summarize the main points of the code of ethics having to do with social justice. For more on social justice issues in social work see (Segal, 2013; Gilbert and Terrell, 2013).

(b) Do you agree with all their positions in the code of ethics? If not, explain why not.

(c) Do you find their views on social justice to be similar to some religious views? Which ones? Are there cultural influences on the construction of this code? Identify them.

**Problem 2.30 (Culture of Disengagement in Engineering Education?):** Read (Cech, 2013). Summarize the main points of the paper. What do you think are the main reasons for disengagement? Do you think that humanitarian engineering education or practice can enhance engagement and social responsibility perspectives?

**Problem 2.31 (Expand Influence Diagram Model of Catholic Social Justice):**

(a) Add to the influence diagram in Figure 2.1 the Catholic social doctrine on the environment. Include node(s) and arc(s) as needed. Explain your representation in terms of the Catholic social doctrine.

(b) Add a healthcare system to the model that follows Catholic social doctrine. Include node(s) and arc(s) as needed. Explain your representation.

**Problem 2.32 (Influence Diagram Model of Rawlsian Justice):** Read Section 2.3.1. Draw an influence diagram model of Rawlsian justice. Include in the model the system of fair cooperation, overlapping consensus, principles of justice, and basic structure. A key challenge is what a node represents, whether there needs to be more than one type of node, and whether nodes are only humans or whether they can be concepts (e.g., laws or policies). Another challenge is picking appropriate meanings for arcs, and possibly arc strengths. Overall, you do not need to develop a very detailed diagram: use the approach in the chapter and only develop one that fits in less than one page.

**Problem 2.33 (Influence Diagram Model of Distributive Justice With Multiple Human Features):** Read Section 2.4.2, and in particular, Section 2.4.2. Draw an influence diagram model of distributive justice when the humans' features are all the same, and are income, health, and education. Draw the influence diagram for the interaction of the features inside the humans. Consider three super-nodes representing a business employing the individuals, a group of health care experts, and a group of educators. Identify at least one feature for each group. Connect the group of people and super-nodes by drawing arcs between features of both. Discuss interactions between individuals, individuals to super-nodes, and between the super-nodes. Discuss any insights you can gain into setting policy for transfers (wealth, healthcare, and education) and the ultimate distribution that will result.

**Problem 2.34 (Wealth Distribution in a Small Low-Wealth Community: Increased Willingness to Suffer):** Read Section 2.4.3. Use the code at the web site: (i) `CooperatingPoorPeople.slx`, the Simulink model of the community; and (ii) `CooperatingPoorPeoplePlotter.m` the Matlab code that allows you to set parameters, calls the simulation, and plots data from it. Set the incomes to be identical (zero "raises" for everyone), and the desired wealth trajectories the same, with ultimate values of $25 per day as was the case for the first set of simulations above. Next, go into

<div align="center">

`CooperatingPoorPeople.slx`

</div>

and adjust the lower-limit of the PID spending strategy, for each of the three people, to two other values: 0.5, and 0.75 (lower than the results in the chapter for 0.95). To do this you open up each of the three subsystems representing the people, and inside there open the "PID" block, then click on "PID Advanced" and enter in the block beneath "Lower saturation limit" one of the two above values for the following cases. Case 1: Equal community, but more suffering allowed: Do two simulations for $G = 0$, one for the 0.5 case lower limit and one for the 0.75 case, and compare the resulting plots to the one shown in the chapter (equal community case) for 0.95. Repeat, but for $G = 0.5$. Compare all the cases and discuss. Is generosity useful in this community? Case 2: Unequal community: Suppose that person 1 is willing to suffer such that s/he picks a value of 0.5 for their lower recommended spending limit, but that persons 2 and 3 pick the higher value of 0.95 for their lower spending limit. Do simulations for both $G = 0$ and $G = 0.5$ and compare the plots for all cases, including the cases of equality.

**Problem 2.35 (Wealth Distribution in a Low-Wealth Community: Effects of Size and Interconnectedness):** Read Section 2.4.3. Consider the effects of two $G$ values ($G = 0.05$ and $G = 0.5$) for the following two cases: (i) Expand the simulation by increasing its size to $N = 10$ people and assume a fully connected community so that everyone can sense everyone else's wealth, send donations to whomever they want, and receive donations from everyone. Repeat the analysis in the chapter for the equal community case. What is the effect of increasing $N$ from three to ten? Does it help or hurt everyone? (ii) Repeat (i) but for the case where the community is less well connected in the sense that their topology is a "line" so that each person in the middle can give to a neighbor on their left and right, but a person on the far left can only give to one person, the person on their right, and the person on the far right can only give to the person on their left. Compare and contrast results from (i) and (ii) for both $G$ values. Discuss implications for the community.

**Problem 2.36 (Democracy in Unequal Low-Wealth Communities):** Read Section 2.4.3. In this problem you will study the effects of various types of distributions in differences between individuals in a community. Use

PoorPeopleDemocracy.slx

and

PoorPeopleDemocracyPlotter.m

to: (i) Suppose the ultimate desired wealth for all three individuals is $25. Suppose $P = 0.001$. Let person 1 have a constant raise of $0.5, person 2 have a constant raise of $0.25, but person 3 have no raise. Run the simulation, provide the plots, and explain the relations between the variables and answer the basic question: "Is this an economically fair community?"; (ii) Repeat (i) but for two more cases, one where $P = 0.002$ (increase) and the other where $P = 0.0001$ (decrease). Compare the three cases for the $P$ values and explain the relationships between all the plots to provide an explanation about what the effect of $P$ is on the outcomes; and (iii) Suppose $P = 0.001$. Consider a "wealth-skewed community" where person 1 makes an average of $1.25 per day (i.e., give the person a raise of 0.25) and tries to ultimately save $30, person 2 makes an average of $1.125 per day (i.e., give the person a raise of 0.125) and tries to ultimately save $27.5, and person 3 makes an average of $1 per day and tries to ultimately save $25. Run the simulation, provide the plots, and explain what happens by explaining relationships between the plots. Be sure to explain why the generosity parameter changes in terms of all the key variables.

**Problem 2.37 (Democracy in a Low-Wealth Community: Effects of Size and Interconnectedness):** Read Section 2.4.3. Consider the following two cases: (i) Expand the simulation by increasing its size to $N = 10$ people and assume a fully connected community so that everyone can sense everyone else's wealth, send donations to whomever they want, receive donations from everyone, and voting occurs as in the chapter. Repeat the analysis in the chapter for the equal community case. What is the effect of increasing $N$ from three to ten? Does it help or hurt everyone? (ii) Repeat (i) but for the case where the community is less well connected in the sense that their topology is a "line" so that each person in the middle can give to a neighbor on their left and right, but a person on the far left can only give to one person, the person on their right, and the person on the far right can only give to the person on their left. Assume that there is a centralized place to gather votes and accordingly adjust $G$. Compare and contrast results from (i) and (ii). Discuss implications for the community.

**Problem 2.38 (Analysis of Environmental Justice):** For Section 2.4.5, and the program EnvironmentalJusticeTOC.m:

(a) Change $u_c(k) = 0.001$ that produced Figure 2.25 to $u_c(k) = 0.0015$ and generate the same type of figure as in Figure 2.25. What are the differences for the new $u_c(k) = 0.0015$ case compared to the previous $u_c(k) = 0.001$ in terms of utilization and resource dynamics?

(b) Let $u_c(k) = 0.001$. Change $\alpha$ to $\alpha = 0.8$ and run the simulation to produce a plot like in Figure 2.25. Explain the differences between the plot you obtain for $\alpha = 0.8$ and the one in Figure 2.25 that was for $\alpha = 0.6$ in terms of utilization and resource dynamics.

(b) For all the values of parameters in Section 2.4.5 use, instead of $N = 200$, a value $N = 300$. Explain the impact on utilization, resource dynamics, and the tragedy of the commons, comparing to the $N = 200$ and $N = 400$ cases in Section 2.4.5.

**Problem 2.39 (Modeling and Analysis of the Common Good):**

(a) Explain the relationship between cooperative control to avoid the tragedy of the commons in Problem 1.35 and "the common good," as it is discussed in Section 2.2.2, and as it is applied to safeguarding the environment as discussed in Section 2.2.2. For the more general case where the principle of the common good applies to any social condition (see Section 2.2.2), for an assumed set of $N$ individuals, highlight the differences between resource renewal and use vs. social condition establishment, improvement, and maintenance. Include in your "social conditions" schools, healthcare facilities, infrastructure (e.g., for water, sanitation, and energy), etc.

(b) Create a mathematical/computational model of the process of building social conditions by a group of people, that is, how people contribute to, and draw from, the common good. One aspect you will need to represent is how and why people will contribute to the common good, and how they benefit from it (e.g., by full community development they may obtain more profitable interactions with community members so their donations to the common good are essentially investments). Keep the model as simple as possible, but representative of the dynamics involved in achieving the common good. Simulate your model and analyze the results.

## 2.7   Annotated Bibliography

**Social Justice and Engineering:**   Work on connecting engineering to social justice is in (Catalano, 2006; Baillie, 2006; Riley, 2008; Baillie and Catalano, 2009; Baillie et al., 2012; Lucena, 2013). Also relevant is the paper (Leydens and Lucena, 2006). There is a significant-sized intersection between social justice and engineering in engineering ethics, with references given below in "Secular Views on Social Justice," and an on-line course that integrates the two here (ECE 3080/7080).

**Religious Views on Social Justice:** A broadly inclusive reference on religious and faith tradition views of social justice is in (Palmer and Burgess, 2012). See also, (Fuchs et al., 1992). The Buddhist perspective covered here is based on (Fen, 2012; Emmanuel, 2012). The treatment of Catholic social justice follows the development in (Compendium, 2005); for a free on-line version, see the Vatican web site and see related issues discussed here. Another comprehensive reference for Catholic social teaching is in (Himes, 2004) and an easy-to-read and relatively brief treatment of Catholic social teaching is in (Himes, 2001). The Confucian case is based on (Chan, 2012; Angle, 2012), and the Hindu case on (Dwivedi, 2012; Singh, 2012). The sources for the section on Islamic social justice and ethics are in (Timani, 2012; Stiles, 2012) and other sources include (Ramadan, 2009; Hallaq, 2013). The sources for the section on Jewish social justice are in (Hellinger, 2012; Segal, 2012) and other sources include (Jacobs, 2009; Schwarz and Messinger, 2011; Yanklowitz, 2012).

**Secular Views on Social Justice:** The section on Rawls's view of justice is based on (Rawls, 2001); this book is based on, and is an integration and revision of, Rawls's other work (see preface of (Rawls, 2001) for an explanation and references) and especially the book (Rawls, 1971). The section on Sen's perspective on justice and development is based on (Sen, 2011, 2000). The list of capabilities in the section on Sen's approach is from (Nussbaum and Glover, 1995). See also, (Sandel, 2007). Some ideas related to social justice, from the perspective of development and technology, are on p. 167 of (Toyama, 2015). The sources for the section on engineering ethics and social justice are (Martin and Schinzinger, 2005; Harris et al., 2014; Passino, 2009). Engineers may be attracted to the "common morality" view in (Gert, 2004). See also the on-line course that integrates engineering ethics and social justice, here (ECE 3080/7080). The coverage of the impact of cultural differences on engineering ethics is based on my personal experiences, (Harris et al., 2014), and (Luegenbiehl, 2004) (click here). The issue of the higher rates of participation of women in humanitarian engineering is discussed in (Colledge, 2012; Bixler et al., 2014).

**Modeling and Analysis of Social Justice:** The ideas about modeling, sensing, transfer, policies, and distributions for the economic distributive justice case (wealth only) when influence diagrams are considered are based on (Passino and Burgess, 1998; Bertsekas and Tsitsiklis, 1989) by drawing an analogy between "load balancing" in computer networks and redistribution of wealth in a group of humans (wealth is load, peoples' savings are queues of tasks in computers, and human interactions are represented by arcs that characterize sensing and transfers over the network). The connection between stability, boundedness, and distributive justice can be seen by using this analogy and studying (Passino and Burgess, 1998). For more discussion on robustness and fragility, and the relation between the two, see, for instance, (Passino, 2005). For an excellent book on parallel and distributed computing algorithms, and in particular distributed optimization, see (Bertsekas and Tsitsiklis, 1989). For more analytical

studies of the influence of politics on economics, including a model and analysis of democracy, see (Acemoglu, 2009). For ideas on management of the commons, see (Hardin and Baden, 1977).

# Chapter 3

# Development Strategies

## Chapter Contents

*The poor you will always have with you.*

*Jesus, Matthew (26:11)*

*Life's most persistent and urgent question is, 'What are you doing for others?'*

*Martin Luther King, Jr.*

*In a country well governed, poverty is something to be ashamed of. In a country badly governed, wealth is something to be ashamed of.*

*Confucius*

*In poverty and other misfortunes of life, true friends are a sure refuge.*

*Aristotle*

*Poverty entails fear and stress and sometimes depression. It meets a thousand petty humiliations and hardships. Climbing out of poverty by your own efforts, that is something on which to pride yourself but poverty itself is romanticized by fools.*

*J.K. Rowling*

*Let no one be discouraged by the belief there is nothing one man or one woman can do against the enormous array of the world's ills–against misery and ignorance, injustice and violence. Few will have the greatness to bend history itself: but each of us can work to change a small portion of events, and in the total of all those acts will be written the history of this generation. It is from the numberless diverse acts of courage and belief that human history is shaped. Each time a man stands up for an ideal, or acts to improve the lot of others, or strikes out against injustice, he sends a tiny ripple of hope, and crossing each other from a million different centers of energy and daring, those ripples build a current which can sweep down the mightiest walls of oppression and resistance.*

*Robert Kennedy*
*(as quoted in (Sachs, 2006))*

*Human progress is neither automatic nor inevitable... Every step toward the goal of justice requires sacrifice, suffering, and struggle; the tireless exertions and passionate concern of dedicated individuals.*

*Martin Luther King, Jr.*

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Historically, what has been the role of technology in human development? If a "development strategy" is an approach to promote human development, what are the most effective ones? How, exactly, can a strategy address the challenges of poverty and underdevelopment to meet social justice goals?

What insights do the broad perspectives of development economists offer on how to address the interconnected challenges in development? What do the health, education, or business perspectives offer over what the development economists have to say?

Using analytical approaches, what do the dynamics of economic growth and poverty traps offer to our understanding of development? What do the principles

of dynamic technology diffusion teach us? What are the proper ways to adjust an environmental justice policy when faced with development and population increases?

This chapter, which has the theme of "strategies," will answer all these questions.

## 3.1 Society, Technological Change, and Development

In this section, an overview of the relationships between society, technology, and development are briefly discussed. The objective is to provide a broad historical and society-level perspective on technology to orient the engineer in their approach to creating technological solutions for development.

### 3.1.1 Technological Change and Society

Good and bad things come from technology. Good things include the reduction of human toil, the ability to cure diseases, to feed many people, to filter water, and many others. Bad things from technology include pollution and the threat of nuclear annihilation. Often, however, people have a positive view of technology, in general (Volti, 2006). In (Volti, 2006), the author says "Technologies are developed and applied so that we can do things not otherwise possible, or so that we can do them cheaper, faster, and easier" and this drives the positive views we have of technology.

Volti goes on to say that "the development, production, and employment of particular technologies requires a group effort" and hence requires organization. He says that "when technology is seen as a combination of devices, skills, and organizational structures, it becomes natural to think of it as a system." Then, he defines technology as "a system that uses knowledge and organization to produce objects and techniques for the attainment of specific goals" (Volti, 2006). Sometimes, a key issue in humanitarian engineering is whether the "organization" is present in a developing country to support a technology (e.g., a supply chain, or for operation and maintenance). If the proper organization is not present, then a society generally cannot reap the benefits of technology.

Technology both responds to needs ("pull," due to demand) and creates needs ("push"). Corresponding to these two cases, are the statements "necessity is the mother of invention" and the less-often made statement "invention is the mother of necessity." Sometimes, however, technologies are created for fun or intellectual pursuit. The process of technology creation is dynamical and *cumulative* as technologies build on one another. Technological progress is often linked to human progress, and "technological advance has been the greatest single source of economic growth" (Volti, 2006). Indeed, technology plays a prominent role in the study of economic growth (Acemoglu, 2009). A central assumption in humanitarian engineering is often that by helping provide basic

crucial technologies (e.g., ones impacting health and education), there will also be subsequent economic growth.

Diffusion of technologies (Rogers, 2003) drives technological advance via an "infusion of ideas, tools, and materials from other places, coupled with an ability to use them" (Volti, 2006). The end of that sentence is important. Transfer of technology can be useless if people on the receiving end do not know how to operate and maintain the technology (this will be an issue that arises several times in Chapter 4). Often, for technology transfer, technologies have to be adapted to the local situation and this is also a central theme of Chapter 4 (e.g., in the emphasis on understanding context and in the study of appropriate technology in Section 4.6.3).

Technological change often alters social arrangements, in the sense that is a "subversive process" that leads to "the modification or destruction of established social roles, relationships, and values" (Volti, 2006). Some view this as one of the costs of technological change, others would view it as a benefit. Technological change leads to altered "power relations, redistribution of wealth and income, and an alteration of human relationships" (Volti, 2006). For example, consider the movie, "The Water of Ayolé" in Section 4.7.1 and the effect of the pump technology on the role of women in the community. Or, consider the effects of information and communication technology on access of information about market prices (or skipping over the "middleman"), information about the operation of a government, or the opening of the information on the internet to school children. Sometimes, the effects of technology on people, communities, and society is good and sometimes it is tragic. Besides the examples given above, sometimes technologies can eliminate jobs (e.g., due to automation) and be a major contributor to unemployment, thereby causing significant adverse and immediate impacts on people's livelihoods. There have been movements against technological change, such as by the Luddites ("machine-smashers") and more recent related activities (Volti, 2006). Social issues may impact technological change, but technology is also used to try to improve certain types of social problems (e.g., overcome bad driver behavior), and while the technology may not get at the root cause, it may provide some mitigation of symptoms.

"Technology is a human creation, and because humans are social creatures, technological change is necessarily a social process" (p. 35, (Volti, 2006)). The sole inventor, acting completely alone, is rare. Technological change typically occurs by many people making small changes, often to past technologies. The many small changes accumulate into large gains, for example, for productivity (see pp. 172-173 of (Rivoli, 2009) for one case). Research, for instance in engineering, can be viewed as the basis of technological change, as fundamental to technological progress, but much research does not immediately result in usable products. Typically, progress is built over time from research advances that identify new principles on how technology can work. Sometimes, research is slow to get translated into technologies due to "belated demand" (e.g., taking time for people to figure out how the research ideas are useful and wanted by people). Competition among people creating technologies, which improves technologies, is promoted by ensuring private returns to innovators (see below).

"Whereas science is directed at the discovery of knowledge for its own sake, technology develops and employs knowledge in order to get something done" (p. 57, (Volti, 2006)). In relating science to technology, history has shown that a great deal of technological advance does not rely on substantial inputs from science (p. 55, (Volti, 2006)). Also, on p. 58, of (Volti, 2006):

> The ultimate question asked of scientific knowledge is "Is it true?"
> For technological knowledge, the key issue is "Will it work?"

Science is often used to try to later explain why technologies work. Of course, sometimes new scientific knowledge is needed (and used) to develop new technologies. Technologies often drive scientific advance (e.g., sensing technologies crucial for experimental measurements, like the microscope). Some would argue that science is only valuable insofar as it produces technology, while others would strongly reject this notion, and value the science done solely based on the pursuit of knowledge and truth. Broadly, science and technology share many features such as values, a rational thought process, the use of mathematics, a sense of optimism with respect to progress, and characteristics in that they are both based on gathering knowledge/information and progressing via incremental and cumulative advancements. As stated in (Volti, 2006), Isaac Newton said he could see further because he stood on the shoulders of giants. Also, on p. 64 of (Volti, 2006):

> Above all, science is predicated on the belief that the world is knowable, while technology is animated by a conviction that it will always be possible to do something better.

"A great deal of scientific information finds its way into technological practice through the education of engineers" (Volti, 2006), and building on the quote by Amartya Sen (Sen, 1975) in Section 1.5.1, it is engineers who use science to create technologies to promote development. It is the responsibility of the professional humanitarian engineer to know the relevant science, when needed, and use it to solve practical development problems. However, humanitarian engineering as a field has as strong need for advanced research that seeks to address extremely challenging problems that could have significant impact after some number of years.

### 3.1.2   Impact of Technology on Development

In the past, and even today, the development paradigm has involved the transfer of technological innovations from aid agencies to their clients (Rogers, 2003). Examples of this abound in the literature, in aid agency programs, and humanitarian engineering projects. Sometimes, experts, aid agencies, and governments are excited about the latest technologies (e.g., information technology), but individuals in a targeted community might not even have the most basic needs met (Easterly, 2014) and hence other technologies could be much more appropriate (e.g., water filtration technology or pump technology). Consider Easterly's statement (p. 276, (Easterly, 2014)):

> The top down leaders and experts in technology do not have enough knowledge or incentives to get it right for the reality of what is happening at the bottom.

Moreover, Toyama says (p. xv, (Toyama, 2015)):

> Even in a world of abundant technology, there is no social change without change in people.

Both Easterly's and Toyama's concerns are addressed via the participatory approach to development that is provided in Chapter 4.

Easterly raises the issue of whether development with technology occurs via "conscious direction versus spontaneous solutions" (p. 277, (Easterly, 2014)). People are innovators who try to solve their problems via trial and error. Innovations are not like typical goods; they are ideas, in the case of technology "how to do it" (a recipe or set of instructions), and can spread, perhaps without costs in transactions. If there are more people trying to innovate, the probability of success goes up, and it can also be more likely that the idea will spread across the group faster (e.g., due to closer living quarters). Easterly says that "The prediction of this simple story is that the more-populous parts of the world will at any moment have better technology than less-populous parts. The more populous parts will also have more technological innovation than less-populous parts" (p. 280, (Easterly, 2014)); here, he is not talking about nation-states, but regions or continents. Essentially, with a sizable population of innovators, innovation is more likely, spreading progresses, then innovation occurs on past innovations, creating a "technological virtuous circle" (pp. 280-285, (Easterly, 2014)). In this connection, Easterly says (p. 285, (Easterly, 2014)) in relation to 1500 AD:

> We confirmed that technology in 1500 predicts technology (and thus per capita income) today. In fact, 78 percent of the income difference today between Europe and sub-Saharan Africa can be explained by technology that was already in place by 1500.

Easterly also highlights that Western ideas of the individual promoted innovation, in particular, the idea of challenging authority and getting private returns on innovations, and this is also discussed in (Acemoglu, 2009). In a conformist society, too many people try the same things to solve problems, whereas in an individualistic society people try things on their own; this raises the chances of creating a new innovation as then more different things are tried. Societal freedoms positively impact technological innovation. Easterly uses this idea to explain why the West pulled ahead of the East after the Enlightenment (Easterly, 2014). Being allowed to keep the rewards for an innovation encourages people to try to innovate and this also differentiated the West from the East. Easterly says "Since ideas are nonrival (i.e., they will be used by everyone else), the social return (return to everyone else) to your coming up with a productive idea is a lot higher than your private return to yourself. This means that incentives for innovation are inadequate" (pp. 287-288, (Easterly, 2014)).

One way to address this is via patents for technology and intellectual property rights. Easterly also cites work by Paul Romer in (Romer, 1990) that says that so long as the returns to the inventor are generous but not excessive, innovation will occur and grow (p. 289, (Easterly, 2014)).

There is also the relevant idea of "creative destruction" by Schumpeter. For this, the inventor is said to have a jump on everyone else in technology commercialization and may be able to maintain the lead via secrecy for some time period if this is allowed (this is also discussed in (Acemoglu, 2009)). Of course, "destruction" of the inventor's lead can result from: (i) "reverse engineering" of existing products, (ii) by modifying the inventor's idea (to avoid patent infringement), or (iii) perhaps even improving the idea or finding a new market.

Indeed, in (Acemoglu and Robinson, 2012) there is a lengthy discussion on the role of general forms of creative destruction throughout history and how allowing different forms of creative destruction is important for economic growth. On p. 183, (Acemoglu and Robinson, 2012) the authors say:

> Technological innovation makes human societies prosperous, but also involves the replacement of the old with the new, and the destruction of the economic privileges and political power of certain people. For sustained economic growth we need new technologies, new ways of doing things, and more often than not they will come from newcomers...

An institution (e.g., monarchy or dictator) may stop creative destruction if they will be a loser due to a new technology or way of doing things. Economic development naturally flows from allowing new technologies to be created and to replace old ones, and likewise is generally hindered when creative destruction is not allowed (Acemoglu and Robinson, 2012). Creative destruction for one class of technologies, those for apparel manufacture, is discussed, starting on p. 185, in (Rivoli, 2009).

Technology spreads in many ways (Rogers, 2003), such as via trade, setting up manufacturing sites at international locations, and copying technologies (such "imitation" is easier for a population if it has a richer technological history); however, a key cause of technology spread recognizes that moving people move technology (Volti, 2006). The history of people is what matters (i.e., ancestry). In particular, Easterly says that a "people-based measure of technological heritage from 1500 drastically outperforms the place-based measure in predicting today's technology and income" (p. 291, (Easterly, 2014)). Moreover, the manner in which technologies spread matters to development (Acemoglu, 2009). The diffusion of technological innovations "often widens the socioeconomic gap between the higher- and lower-socioeconomic status segments" (p. 130, (Rogers, 2003)) as power, wealth, and information is in the hands of the wealthy who can then gain the benefits of technological innovation. This is one version of what Toyama calls the "law of amplification" of technology, which, as he points out, is not a new idea (see p. 37, (Toyama, 2015)), but he emphasizes its many implications in the attempt to use technology to promote social change, especially for the case of digital and information technology. This law

is a direct consequence of the common definition of technology in the Preface: "a tool that extends human capability." If those in the top of the socioeconomic class are given technology, they can do more with it than those at the bottom and the result is the widening of the socioeconomic gap. Put another way, if people do not have basic capabilities (using Sen's definition of capabilities as in Section 2.3.2 and (Sen, 2000, 2011)), or opportunities, they cannot do much with technology. Yet, if people have some capabilities, technology can amplify these (e.g., for digital learning). Toyama says that "Technology amplifies preexisting differences in wealth and achievement" (p. 117 in (Toyama, 2015)). This places Toyama's focus directly and primarily on people, and he emphasizes people's fundamental role in social change, even if technology is involved.

There is also the issue of the rate of technological advance related to "cultural lag" where "habits, thoughts, values, and social arrangements often fail to change at the same speed as technological innovation" (p. 273, (Volti, 2006)). Sometimes, technology diffusion is slowed by attitudes of non-acceptance of an imported technology, even if it can be adapted to local conditions (e.g., if there is the "not-invented here," NIH, syndrome/attitude) (Volti, 2006). See also (Acemoglu, 2009) where political and other barriers (e.g., control by elites) has hindered technology spread. Yet, there is the "convergence theory" that says that "Although the world's nations have different histories and cultural orientations, convergence theory argues that they are becoming more similar to one another (that is, they are converging) as they make use of the same technologies" (p. 274, (Volti, 2006)).

### 3.1.3   Lessons for the Engineer

The following are important ideas for the humanitarian engineer from the previous subsections:

1. While development and deployment of a crucial technology is the central focus of humanitarian engineering, proper attention must be paid to organizational issues. For instance, such organizational issues involve the process by which the community can effectively operate and maintain the technology.

2. Toyama says to focus directly and primarily on people, and he emphasizes people's fundamental role in social change, even if technology is involved (Toyama, 2015). He says that technology amplifies capability; if there are not basic capabilities, then technology's amplification will fail.

3. A central assumption in humanitarian engineering is often that by helping provide basic or crucial technologies (e.g., ones impacting health and education), there will also be subsequent economic growth. To verify success of a humanitarian engineering project it may be important to verify that such economic growth indeed occurred.

4. It is the responsibility of the professional humanitarian engineer to know the relevant science, when needed, and use it to solve practical devel-

opment problems. However, humanitarian engineering as a field has as strong need for advanced research that seeks to address extremely challenging problems that could have impact, perhaps not immediately, but after some number of years.

5. The humanitarian engineer must be cautioned by Easterly's points about top-down imposition of technologies versus bottom-up demand for technologies. The engineer must understand what is happening on the ground, as is repeatedly emphasized in Chapter 4 where a bottom-up participatory development strategy is discussed, especially with respect to assessing needs, resources, capacity, and aspirations of a community.

6. History and culture explain the level of technological advancement at the location you visit, to some extent.

7. It is important that the humanitarian engineer seek fair and equitable distribution and use of technology resources, and not technologies that simply help the elite. Clearly, a goal is not to widen the gap between socioeconomic classes.

Technology issues arise in each of the development perspectives to follow, from those of development economists, to health, education, and business perspectives. The previous two sections provide the engineer with a broad perspective on how they fit into the overall world-level technological advancement process, the overall process of humanitarian engineering, and for each of the following sections, how they fit into each development strategy/thrust.

## 3.2 Development Economists' Perspectives

Five development economists' perspectives on development are provided here via books by the following authors: Jeffrey Sachs (whose perspectives were also considered in Section 1.3, and whose more recent views are in (Sachs, 2014)), William Easterly (his more recent book is in (Easterly, 2014)), Paul Collier, Abhijit Banerjee, and Esther Duflo. Their viewpoints are not consistent, and sometimes are in conflict. Seeing such conflict, illustrates that persons focused on development do not agree, even on some of the most basic principles.

### 3.2.1 Jeffrey Sachs: The End of Poverty

Jeffrey Sachs is a professor of economics at Columbia University (and past professor at Harvard University), Director of Columbia's Earth Institute, and past Director of the UN Millennium Project work on the Millennium Development Goals (for which he served as an advisor). This section is based on (Sachs, 2006), except the last part where the "lessons for the engineer" are identified and discussed. Parts of his newer book, "The Age of Sustainable Development" (Sachs, 2014), are covered in Section 1.3, Problem 1.22, and Problem 1.23. The following topics from (Sachs, 2006) are not covered here: (i) his examples of

how specific low-income people and communities lead their lives; (ii) the history of economic development over the last 200 years that tries to explain at a high level why some countries today are rich while others are low-income; (iii) the impressive work he has done to help specific countries (e.g., help Bolivia with hyperinflation, help Poland transition from a command economy under communism to a market-economy, etc.); and (iv) data justifying the rationale and outcomes of his approaches. Besides, his history of advising other countries is somewhat autobiographical. The interested reader will have to see (Sachs, 2006) to fully appreciate the rationale behind his arguments; quotes in this section are from that book.

Sachs believes that rich countries do not contribute enough to the development of low-income countries in the way of direct aid or debt relief (e.g., he sites the size of the US military budget and that only one thirtieth of that amount is spend by the US on foreign aid). He feels that with the preconditions of infrastructure, including roads, power, and ports, along with health and education, markets can take over and be powerful forces for development. Without preconditions, markets ignore low-income people and leave them to suffer. He feels that governments need to provide infrastructure, perhaps with foreign aid when needed, and better international "rules of the game" (e.g., trade policies). Sachs breaks poverty into three types: extreme (or absolute) poverty (e.g., less than \$1/day PPP, around 1 billion people) where survival is in question, moderate poverty (e.g., between \$1-\$2/day PPP, around 1.6 billion people) where basic needs are barely met, and relative poverty (people with incomes less than some percentage of their nation's average income) where lack of educational and healthcare opportunities hurt their social mobility. Sachs says that the hardest part of development is "getting a first foothold on the ladder" (the ladder of economic development, with the top of the ladder representing economic well-being). He says that the extremely low-income people are stuck as they cannot get up to even the first rung of the ladder (i.e., they are in a "poverty trap"–for a discussion on other traps see the section on Banerjee and Duflo's work below and the Annotated Bibliography at the end of the chapter per (Collier, 2008); also see Section 3.6 for analytical studies of poverty traps). He feels that it is our generation's responsibility to help them get on the first rung. To him, "the end of poverty" means getting the extremely low income people onto the ladder to end extreme poverty by 2025, and getting the moderately low-income people climbing up the ladder. In this connection he sites the UN Millennium Development Goals that were set to be met in 2015. His basic stance is that extreme poverty has not been ended since required large investments have not been made to break the trap; past low levels of aid, at best, have only helped reduce suffering.

Sachs feels his formal training was not up to the task, and hence says that the field of economics needs to reevaluate how it educates economists so that they are more effective at development work. In particular, he argues that development economics needs to be more like clinical medicine. He feels that development problems should be approached as a medical doctor approaches the human body. First, clinicians recognize the deep complexity of the prob-

lem, the value of splitting the system into pieces (respiratory, circulatory), the many interactions between subsystems, that there can be cascading failures, and relationships between failures. Second, the complexity demands a "differential diagnosis" (a systematic procedure to identify something when there are many alternatives present–it is a process of elimination, or at least reducing the probability of candidate conditions to a low level–it can be considered a "hypothetico-deductive method"). Third, "all medicine is family medicine" so not only must the individual be understood, but also their social setting (e.g., family); to the development economist this means that you must understand context (e.g., village, city, and country). Fourth, "monitoring and evaluation are essential" to treatment. To the development economist, this means that if you implement a solution, then you have to monitor whether it is succeeding (perhaps requiring more tests, re-diagnosis, and different treatment), and assess its success. You start with your best hypothesis, then stay flexible as new information is gathered. Outcomes need to be measured and used to change approaches. Fifth, "the development community lacks the requisite ethical and professional standards;" he is not saying that development practitioners are corrupt, but he is saying the do not take on work with the "sense of responsibility" that is required (not like the medical clinician).

Next, Sachs (on p. 84 of (Sachs, 2006)) provides a "checklist" of issues to consider in developing a differential diagnosis for development that includes the following issues: (i) poverty trap, (ii) economic policy framework, (iii) fiscal framework and fiscal trap (public spending on health, education, and infrastructure), (iv) physical geography, (v) governance patterns and failures, (vi) cultural barriers, and (vii) geopolitics. He lists many attributes of each of these seven points, all of which need to be evaluated. The clinical economist must carefully consider each of these issues before arriving at a differential diagnosis.

**Economic Advancement and Decline**

Sachs says there are four main ways to achieve economic growth (often occurring simultaneously) as measured by gross domestic product (GDP): "saving and capital accumulation, increasing specialization and trade, technological advance (and a resulting rise in output for a given amount of inputs), and greater natural resources per person (and a resulting increase in the level of output per person)." Correspondingly, he says that there are several ways economic decline can occur: lack of saving (due to nothing being left over after meeting needs to survive), absence of trade (even if a low-income person can trade it may be blocked due to a lack of roads, violence, monetary chaos, and price controls and this then leads to a tendency of low-income people not to "specialize" in what they are good at and profitably trade based on that), technological reversal (e.g., due to a death of the oldest child due to AIDS, the younger children have to take over farming, but without the technical know-how to get good yield), natural resource decline (e.g., due to soil depletion, without affordable fertilizer, farm yields go down), adverse productivity shock (e.g., due to natural disasters or disease that may eliminate household income for a year), and population growth (e.g., when via

inheritance sons split a farm size in half but then have much more difficulty surviving on such a small farm).

Traditionally, the reason given why countries are low-income is corrupt governments and "retrograde cultures" that impede economic development. Sachs says, however, that it is much more complicated than that and highlights eight factors causing economic stagnation or decline for a country:

1. *The poverty trap:* Extreme poverty can make it impossible to get out of poverty, hence causing a trap. For example, low-income rural villages lack "trucks, paved roads, generators, and irrigation channels. They also lack "human capital" due to hunger, disease, and illiteracy. Natural capital has been depleted since trees have been cut down and soil nutrients depleted. Savings are needed to overcome these problems, but extremely low-income people do not have extra income to save. The point about being trapped can be especially acute in some countries in Africa. In this connection, Sachs discusses relations between malaria, HIV/AIDS, and poverty. He explains how local conditions and poverty promote the spread of these diseases (e.g., climate, species of mosquitoes, lack of access to prevention methods and treatments, and lack of access to education), and how these diseases cause poverty (creation of orphans, impact on work, absenteeism in education, etc.). How can extremely low-income people break out of such a cycle without outside assistance?

2. *Physical geography:* But, why are some countries trapped and others are not? Natural resources in a country have a big influence (e.g., fertile farmland, ample rainfall, navigable rivers, coastline and natural ports for trade). The lowest-income countries today have high transport costs due to being landlocked, being in the mountains, having no navigable rivers or good coastlines, or natural harbors. Or, they have a poor climate in that they are arid and have prolonged droughts. In the tropics there are much more favorable conditions for diseases like malaria, dengue fever, and many others. Malaria seems to be a major factor contributing to lack of economic development in Africa. Sachs says, however, that all these problems can be overcome and hence we should avoid the notion of "geographic determinism."

3. *Governmental fiscal trap:* The government of a low-income country may lack the resources to pay for the infrastructure that economic growth is based on. They cannot afford public goods and services like healthcare, roads, power grids, ports, etc. Why? They have an impoverished population so they cannot raise enough taxes, they may be "inept, corrupt, or incapacitated" and hence unable to collect taxes, or the government may already be carrying a large debt load that they need to "service" (this is called "debt overhang").

4. *Governance failures:* To achieve economic growth, the government must be oriented toward development. It must invest in the right projects, set

the right environment for private investments, not demand bribes and side payments, must maintain peace and safety, and protect private property. When they cannot do these things, "state failure" can occur (e.g., via wars, revolution, coups, and anarchy).

5. *Cultural barriers:* Cultural or religious norms may obstruct women and hence try to develop without the full help of half its population. Denying women education creates many problems, including their lack of economic productivity for their family, increased family size and child-rearing responsibilities. Similar barriers are sometimes set up for religious or ethnic minorities (e.g., cultural divisions in Latin America between indigenous, mestizos, and those of direct Spanish descent).

6. *Geopolitics:* There are trade barriers erected (by rich and powerful countries) that impede a low-income country's development. Sometimes economic sanctions are used against low-income countries, ones supposedly aimed at an authoritarian leader, but which mainly adversely affect the population.

7. *Lack of technological innovation:* Inventors in a low-income country may develop innovative approaches for local needs, but how do they recover their investment in research and development (their government is not likely to support them)? Sales in the local market are likely to be low. This leads to a large difference between the abilities of rich and low-income countries to innovate. In a rich country, innovation increases the size of the market, which in turn encourages more innovation. Sachs says that "the top twenty countries in patenting, all high-income countries, account for 98% of all patents." Sachs does, however, see opportunities for innovation for low-income countries: (i) via diffusion of technology via importation of technology (e.g., cell phones and computers) but there are problems with this since technologies are often designed for the environmental conditions in rich countries and cannot be reliably used in tropical, arid, or mountainous regions where the low-income people live; and (ii) foreign investors often bring technology and methods with them that then are used in the low-income country and "spill over" into their way of doing things.

8. *Demographic trap:* Half the world is at a fertility rate of "replacement" and as the GDP of a country increases it is well known that total fertility rate decreases. Low-income countries typically have a fertility rate of five or more, so that their population will double each generation. Sachs says that with large family size, less is invested in each child's nutrition, health, and education (e.g., they may only be able to send one son to school). This results in many impoverished children who grow up to be impoverished adults, who in turn have many children. This creates stresses on farm size, and environmental resources, that further promote poverty. Moreover, family size is driven by the need to have enough boys that will survive so that they can support the parents in old age.

But, despite the poverty traps of various sorts, some low-income countries have achieved economic growth. Sachs says the most important determinate of their success was food productivity that allowed them to break out of their problems. Overall, Sachs says that be biggest problem is how to overcome the poverty trap, that is, to get "their foot on the ladder of development," and he says that rich countries should help them get a foot on the ladder, after which "the tremendous dynamism of self-sustaining economic growth can occur."

Sachs identifies five key interventions to end poverty: agricultural, health, education, energy, communications, water, and sanitation.

**Solutions for Ending Poverty**

Based on his own work around the world, and in particular in Africa (e.g., Kenya), along with the UN Millennium Project, Sachs identifies what he calls "the big five development interventions:"

1. *Agricultural:* Fertilizers, fallows, green manures and cover crops, small-scale irrigation, and better seeds would increase yields and end chronic hunger. Storage facilities would help farmers get better market prices.

2. *Basic health:* A staffed village clinic (e.g., for every five thousand people) that would also provide bed nets, medicines, HIV/AIDS medicines (e.g., low-cost Bactrim to treat AIDS-induced infections and antiretroviral therapy for late stage AIDS), and reproductive health services.

3. *Education:* Meals for children at school, vocational training (e.g., for farming), computer literacy, infrastructure maintenance (e.g., electrical wiring, generator use, water harvesting, and borewells), carpentry, etc. Training in hygiene, HIV/AIDS, malaria control, computer and mobile phone use, and others are important.

4. *Power, transport, and communications:* Electricity via a power line to the grid, or via off-grid methods (diesel generators, bicycles, solar, etc.), are needed to power lights (to work or study after dark), perhaps a computer for a village school, water pumps, power for milling grain, refrigeration, construction, charging of batteries, etc. A village truck would be useful for delivering goods to the village, taking goods to market, or in case of emergency to deliver people to a distant hospital. Having at least one cell phone nearby (if it can get a signal) is useful for emergencies, market information (so they can sell their goods at the best price), and to connect them with the outside world.

5. *Water and sanitation:* Sufficient supply of clean water affects health and significantly reduces the toil for women and children to find and carry water. Springs, borewells, and rainwater harvesting can all be useful, as could a pipe to a nearby large-scale storage tank. Proper sanitation is important so that at least the immediate environment is not polluted so that health problems arise (of course, concerns for the larger surrounding environment are important too).

After identifying these solutions, Sachs does a cost analysis and determines that $70/person is the cost of applying all these strategies. He feels that extremely low-income communities cannot raise such capital; hence, he calls for a global network of rich countries, donors, and low-income communities to work together to solve the problem of extreme poverty. Sachs says low-income people are ready to act individually and collectively, are hard-working, prepared to struggle to get ahead, have a realistic idea about their conditions and how to improve them, they do not accept fate, and are ready to govern themselves so that help is not pocketed by an individual but used for the whole community. The rich world is concerned about whether money will really reach low-income people and really end poverty rather than being part of an endless provision for basic needs. Sachs calls for financing simultaneous with accountability. He does an analysis to show that the only way to break out of a poverty trap is via investments based on donors to increase the capital of low-income people to enable them to break the trap.

**Technological Capacity and Scaling Up Solutions**

Use of new technologies like the cell phone, computer, seeds, or bed nets require training and technical competence in order to exploit their benefits. Training beyond primary levels has come to be quite important, as is the availability of a university to train groups of technical experts (teachers, medical experts, agricultural experts, and engineers) to harness technologies for local needs of the country. Sachs says that for rapid economic growth, technical capacity must "suffuse the entire society, from the bottom up." He asks, however, how this can be done when there may even be widespread illiteracy? He feels we should start in the village training local experts for the main tasks presented to their community. For example, someone in the village could be trained in basics of health care delivery or agricultural issues. Or, a "community-based engineer" could be trained in the operation and maintenance of a diesel generator, "electrical wiring, hand pumps, road grading, and the village truck." The use of electronic methods to disseminate and educate the village on issues should be considered.

Sachs highlights the importance of local technological capacity for development.

Sachs also feels that there needs to be efforts along these lines at the government level, to promote scientific research (rather than just leaving that to the rich countries). India created its famous Indian Institutes of Technology long before people really thought it made sense for such a low-income country; however, they trained people in the technical knowledge that drove the well-known "information technology" (IT) boom in India. Indeed, Sachs says that both China and India are converting from "technology importers to technology producers" on a large scale and this has a big impact on their development. Similar efforts are needed in other developing countries, even in the presence of "brain drain" that is driven by individual's desires for good labs, colleagues, and grant support. Sachs says: "The infrastructure for science–well financed universities, laboratories, and a critical mass of research funding and collegial support–will have to be built, and just like other infrastructure, this one will require the backing of rich-country donors. They will have to understand the

critical importance of investment in higher education alongside primary education."

Sachs says that the main challenge is not to show that some approach works in a single village or area (that provide a valuable initial proof of concept), but to "scale-up" solutions to the country or world. He then sites 10 programs that were successfully scaled up: the "green revolution" in Asia (via development of high-yield varieties of crops by the Rockefeller Foundation), the eradication of smallpox, the campaign for child survival, the global alliance for vaccines and immunization, the campaign against malaria, the control of African river blindness, the eradication of polio, the spread of family planning, export processing zones in East Asia, and the mobile phone revolution in Bangladesh. He feels that, backed by appropriate and widely available technology, organizational leadership, and appropriate financing, similar good ideas can also be scaled up.

### Global Compact to End Poverty

Sachs says that to end global poverty by 2025 requires a "global compact" between rich and low-income countries with responsibilities on both sides:

1. Low-income countries must be serious about ending poverty and devote more of their resources to this objective than to war, corruption, and political infighting. Low-income countries often go through the motions of reform but actually do little. Low-income countries do not "have a guaranteed right" to receive development assistance from rich countries; "they only have that right if they themselves carry through on their commitments to good governance." Governments of low-income countries that do not want to, or are not able to, make a commitment (with a plan of action and a demonstrated will to carry it out in a "transparent and honest manner") "need not apply" for aid from rich countries as their responsibilities are then limited.

2. Rich countries must end their frequent moral but empty statements about ending poverty and really follow through on promises to help more. Aid agencies often focus on projects at a symbolic rather than national level in order to capture headlines. Sachs says that the main problem is not that poorly governed countries get too much help, but that well-governed countries get far too little help.

Sachs overviews the Millennium Development Goals-Based Poverty Reduction Strategy (involving differential diagnosis, investment planning, financial planning, donor planning, and public management planning), and then outlines four global policy issues for poverty reduction. First, per the "debt crisis" he feels that debts for highly-indebted low-income countries should be cancelled. Second, low-income countries need to trade with rich countries to spur economic growth; however, trade barriers implemented by rich countries hinder exports from low-income countries. He highlights, however that in the fight over "trade not aid" issue, what low-income countries really need is "aid plus

> Sachs says that a global compact between rich an low-income countries is needed to end poverty.

trade" since trade alone will not allow them to break out of their poverty trap. Gains in poverty reduction from trade (i.e., the market) have mainly benefited rich and middle-income countries, not the lowest-income countries or regions (e.g., remote low-income villages in Africa). Trade liberalization in agriculture is, however, will not clearly provide benefits to low-income people; it may help farmers in low-income countries, but could drive up food prices for the larger consumer population. Sachs feels it is most likely to mainly help the large food exporters like the US, Canada, Argentina, Brazil, and Australia.

### Science for Development

Many key breakthroughs impacting long-term economic development have come from technology. Usually, the technological breakthroughs have come in rich-country markets, or were sponsored for low-income countries via donor-led approaches. It is rare that the private sector develops technologies to meet challenges in low-income countries; market incentives are simply not sufficient for private sector research and development. The scientific community then often ignores low-income countries; hence, Sachs feels it is important to identify priority needs for low-income people and then to mobilize the donor community to support research and development. Some especially high priority scientific needs for low-income people are (quoted exactly):

*Sachs highlights the importance of science for development for diseases, agriculture, energy, climate, water, and ecosystem management.*

1. Diseases of the poor: new preventative, diagnostic, and therapeutic measures for diseases specific to low-income countries, especially tropical diseases.

2. Tropical agriculture: new seed varieties, water management techniques, and soil management techniques.

3. Energy systems in remote and rural areas: special technologies for off-grid power, including renewable energy sources (for example, photovoltaic cells), power generators, improved batteries, and low-watt illumination.

4. Climate forecasting and adjustment: improved measurement of seasonal, interannual, and long-term climate changes, with a view toward prediction as well as adjustment to climate changes.

5. Water management: improved technologies for water harvesting, desalination, small-scale irrigation, and improved management of aquifers being depleted by overuse. Water will rise in importance as population densities and climate change interact to produce more regions in acute water stress.

6. Sustainable management of ecosystems: fragile ecosystems around the world (coral reefs, mangrove swamps, fisheries, rainforests, to name a few) are succumbing to anthropogenic forces, often with dire consequences. In many cases, poor communities do not have the technical capacity to monitor changes or to respond in an effective and sustainable manner.

### Can the Rich Afford to Provide Help to People of Low Income?

Sachs feels this is the wrong question. He feels the right question is whether the rich countries can afford not to help low-income people. The developed world, including the US, has repeatedly promised to commit 0.7% of their gross national product (0.7 cents of every $10 income) to low-income countries. The US has not meet its promise in this respect (it is currently only at a level of 0.15% of GNP, relatively low compared to other donor countries), and Sachs explains that a large increase in contributions is needed from the US as it is the richest country in the world. He does an economic analysis to show justification for this, and sites other authoritative groups who also reach similar conclusions. So, all the debate about support is only concerned with less than 1% of rich-world income. He explains that the relative level of financial supported needed by low-income people is so low today since the percentage of extremely low-income people in the world population has already gone down so much, and since his focus is on extremely low-income people. The money is needed to overcome poverty traps, where it is really needed. He says that today it will be much easier to end extreme poverty since we now have a whole host of proven low-cost interventions (e.g., technologies) to help.

Sachs is quite concerned, however, that contributions from rich countries will "go right down the drain" based on what we have learned from history. There is a sort of rationale used to justify not contributing (based on low-income-country corruption, values, and morality), but he rejects this. He points out that while many in the US, even officials and politicians, think we are spending huge amounts on helping, for instance, Africa, but making no progress. Sachs says that actually we have achieved little only because we are contributing very little (not because of the other problems). Some argue that the market will solve all problems without any aid. As an economist, he rejects this as markets are not designed to work for health, education, social security, water, energy transmission, roads, and rail. The prevalence of AIDS in Africa has led many to be concerned that the problem arises from culture and morality (e.g., sexual promiscuity and irresponsibility). The prevalence of AIDS in Africa is not currently well understood; however, studies have shown that in several countries in Africa men and women have fewer sexual partners that those from several other non-African countries. The explanation from the epidemic must be found elsewhere (i.e., it is not a promiscuity/irresponsibility issue). Others have asked "if we save the children of Africa, won't they just grow up to be hungry adults?" First, ending extreme poverty will reduce, not increase, population sizes. This is since they will not need to have enough children to economically depend on their children (e.g., by making sure they will have one or more surviving sons who will support them during and later in life). Higher child mortality rates increase fertility rates so that areas with high child mortality rates have higher population growth. Also, as people move away from farming to commercial enterprises (e.g., in an urban setting) they need fewer children, unlike the help they needed on the farm. As they get piped-in water, they do not need children to fetch it. When the mother is freed of so many responsibilities of child rearing,

Sachs argues that the rich can indeed afford to help low-income people.

she can work to seek economic gain for the family. Sachs says that availability of contraceptives assists in the process. Then, he says that as family size decreases, parents can invest more in each child.

Some argue that globalization will "raise all boats" and hence solve the problem of extreme poverty; hence, there is no need for aid. They say "if your boat is not raising it is your own fault." While market forces are powerful, due to geographic reasons (consider the many remote villages and areas in extreme poverty), the market is ignoring these areas. Then, when the market does not take root, there can be economic decline (see above) rather than economic advancement. Next, note that there is also, among some individuals, the "social Darwinism" notion that warns against soft-hearted liberalism and which says that real life is competition and struggle. Economic progress is about competition and survival of the fittest. Some people dominate, others fall behind. The state of affairs today is simply the outcome of that process (the author must insert the point here that this view represents a significant misunderstanding of Darwinian evolution, for instance, considering the evolutionary theory for social/cooperative animals/humans such as "multi-level selection"). Free-market economic theory supports these views. Yet there is a long history in economic theory, dating back to Adam Smith (the father of modern economics) that "competition and struggle are but one side of economic life, and that trust, cooperation, and collective action in the provision of public goods are the obverse side." Sachs said that just like the communist attempt to eliminate competition from the economic sphere "failed miserably," so would trying to manage a modern economy using only market forces. Successful economies are based on a mix, with private and public sectors contributing to economic development. The same idea holds at the international-global level. Indeed, there is broad consensus that public goods need to be provided at the national level, but there are debates about where to draw the line between private vs. public activities. Even hard-line conservatives generally support public financing of education, medical research, and a number of kinds of healthcare. In the US, public spending is around 30% of the GDP, and Sachs does not think this will decrease. But, when it comes to spending the promised 0.7% of GDP to help end extreme poverty around the world, it looks burdensome and is highly controversial.

Is it rich countries' responsibility or simply low-income countries' problem? Don't rich countries have enough problems of their own? Will helping low-income countries really help with our security, or should we simply rely on our military? Surveys show that Americans think they are spending significant amounts on foreign aid (e.g., at times estimating it as 20% of the federal budget). Second, many believe that the US military can provide security in the presence of an unstable world. Evidence shows that there are  strong links between extreme poverty abroad and threats to US national security. Acts of altruism in the past have worked, with Sachs giving the examples of the US Marshall Plan, ending slavery, supporting countries seeking independence, extending assistance for development, or providing humanitarian relief after natural disasters. Sachs claims that the problem is not lack of support for foreign aid from the American public, but a lack of political support to explain why it is important and asking

Sachs provides reasons why it is the best interest of rich countries to help low-income ones.

the public for greater efforts. Americans have shown an amazing willingness to help those in need, but they think the US is already doing a lot.

If a country is in a poverty trap, this often leads to State failure (e.g., revolution, ethnic war, genocide, politicide, or adverse or disruptive regime change). Failed States create problems for the rest of the world, including violence, terrorism, international criminality, mass migration, refugee movements, drug trafficking, and disease. The developed world spends a lot on these problems and needs to invest in solving the root problems causing State failures. Americans cannot assume that they can live on a island of prosperity and stability surrounded by global poverty and economic failure. History is full of examples of the spread of problems from one country to another and resulting military entanglements. Sachs is emphatic that even though it is difficult, that the politics of aid can be overcome and sites three examples of success: the Marshall Plan (after WWII), Jubilee 2000 (campaign to drop debt), and the Emergency Plan for AIDS. Sachs views ending extreme poverty as the challenge, and "breathtaking" opportunity of our generation.

### Is Globalization Good?

Sachs likes aspects of the antiglobalization movement, including their efforts at exposing hypocrisies, shortcomings of global governance, and helping to end years of "self-congratulation by the rich and powerful." However, Sachs opposes some positions the antiglobalization movement has taken. For instance, he opposes the general anti-corporate views and proposals for protectionism (supposedly to protect low-income countries from rich ones). Antiglobalization people also tend to ignore the fact that globalization led to 500 million total people being lifted out of extreme poverty in India and China. This was not the result of exploitation by multinational corporations. Foreign direct investment has a profound impact on a developing country. Historically, open economies have outperformed closed economies. But, many companies have clearly behaved badly (see below), but he feels the movement is too pessimistic about "capitalism with a human face." He is pro-globalization, if it is done properly (what he calls "enlightened globalization").

Sachs is pro-globalization, but via capitalism with a human face.

Protests in the developed world about sweatshops have helped improve the safety and working conditions in sweatshops. However, such protesters should support the increased number of such jobs (under safe working conditions) by protesting against trade protectionism that restricts the import of products from the developing world. The jobs at sweatshops give low-income people a "step up the ladder" from extreme poverty. Even though there are long hours, lack of labor rights, and harassment, women working in sweatshops find that a sweatshop provides them the greatest opportunity they could ever have imagined, and that it has changed their lives for the better (they were hungry, illiterate, lived in domineering conditions, etc.). Some protesters argue that a fair wage should be provided or the sweatshops should be closed; but this would result in great misery for the employees. Sachs says that historically many countries have gone through such a phase of development.

**Lessons for the Engineer**

Sachs has an approach that is friendly to the engineer, even though he (like many others) has some basic misunderstandings of the differences between science, engineering, and technology (but he does, surprisingly, use the word "engineer" in the book). Scientists sometimes do engineering (e.g., in physical electronics or to invent a technology to measure some scientific phenomenon), engineers sometimes do science (consider materials science and engineering), and technology is a product of both fields, but it is mainly the task of the engineer to create and redesign/improve technology. Engineering is generally not a well-understood profession, but some claim that this is the fault of engineers themselves. You will see this problem arise in other readings on development. However, recognizing when an engineer has a role in solving a problem is not generally a problem for an engineer. When an economist, philosopher, development expert, businessperson, etc. starts talking about science and technology, and problem-solving methods, the engineer immediately sees his or her role. As an example of when Sachs demonstrates he does not understand the role of engineering, consider his call to "science" to solve development problems. Several of what he lists are not science problems, but engineering problems (e.g., essentially all the topics he lists under "energy systems"). For many of the problems he lists the science is very well understood, and in most cases the science is certainly understood well enough for an engineer to use it to develop an effective solution for development. Effective use of power generators or low-watt illumination does not require new science (of course, as is always the case, new science could help with improving current engineer's use of such methods). Now, that is not to say that the engineer may not do new science in inventing a new method; all I am saying is that much can be done via a competent engineer using existing scientific knowledge.

Sachs call for "clinical economics" is intriguing. It raises a number of questions. How many economists are involved in development? Are they just involved at the "high level" (level of markets, economic policy, and political systems)? Or, at the individual and village levels? Who has the proper education to really tackle the problems on the ground (learning by trial-and-error is clearly not satisfactory)? It seems impossible to me that any one person can understand all the issues and solutions. How effective are the major development practitioners at forming teams with the right people on board? More to the point, how often are engineers involved, at least when it comes to creating and using technologies in solving development problems? Next, in a more basic sense, Sachs is questioning the problem-solving methodology of the field of economics for development. I think that Sachs did not go far enough with his analogy to the medical clinician. It is a whole medical establishment that enables the clinician. For instance, the science supporting medicine involves many areas (genetics, cell biology, anatomy, physiology, etc.) and these areas contribute significant understanding that is a fundamental enabler of the field of medicine. Next, medical researchers study not only science, but create solutions, technologies, or treatments for problems based on the relevant science. Some methods are found to

*Engineering is a misunderstood profession.*

be ineffective, while others go to trials. After much careful experimentation, and maturation of the approach, the treatment methods are handed to the typical medical clinician (of course, this ignores fast-track treatments for severe problems related to terminal illness). Many types of engineering disciplines, in addition to biomedical engineering, get involved in this process, especially when it comes to creating technologies (e.g., EKG, laser surgery, ultrasound, pacemakers, neuromodulation, etc.). Sachs ignores the whole creative component to the medical establishment, and thereby largely ignores both the role of creation of new poverty solutions and the specific role of engineering in development. Moreover, he does not raise the issue of whether "engineering problem solving" has a role in development. Engineers approach to problem-solving has some broad similarities to the clinician's approach, but many differences.

Sachs identifies the importance of technological innovation and highlights the need to redesign existing technologies to survive in harsh environments (e.g., the tropics), a standard challenge for an engineer. Moreover, his "solutions for ending poverty" identify many opportunities for engineering to use existing technologies, modify technologies, or create new technologies to solve important problems. Sachs explains the broader issue of "technological capacity" of a community (or country) and has specific recommendations on this matter (e.g., training in basic technologies and the importance of universities–though he does not explicitly say we need improvements in engineering education at the university level it is obvious that this is what he is calling for). It is also interesting, and a significant challenge, that he points out that there are really very many existing good solutions, including technologies, that have been tested at a local level and found to be effective; he highlights, moreover, the importance of "scaling up" the solutions to wider regions, countries, and the world (which, an engineer well knows often involves redesigning a technology or realizing that a different new technology needs to be developed). Finally, the engineer should pay attention to his opinions on sweatshops–manufacturing sites in the developing world. Engineers play a central role in setting up and operating such sites. For more on sweatshops and engineering, see Section 4.6.6 and Problem 4.51.

> Sachs identifies important technological challenges for engineers and highlights the importance of technological capacity.

### 3.2.2 William Easterly: The White Man's Burden

William Easterly is a professor of economics at New York University where he is also Co-Director of NYU's Development Research Institute. He is a Senior Fellow at the Brookings Institution and spent 16 years at the World Bank doing research on development. Here, the key points from (Easterly, 2007) are summarized, except at the end of the section "lessons for the engineer" are provided. Also, his detailed discussion on aid institution bureaucracy is not covered (much of it has to do with feedback and accountability); nor is his analysis of the successes and failures of aid institutions and how to fix their problems; his discussions on health (e.g., the trade-offs in AIDS treatment vs. AIDS prevention); colonialism, de-colonialization, and postmodern imperialism (with its exploitation objectives, but sometimes humanitarian ones, but always failures), "invading the poor" via military action (e.g., during the Cold War) and how

it always fails; and "homegrown" successes (in Japan, East Asia, China, India, Turkey, Botswana, Chile). Some section headings from his book are used directly. We discussed some of Easterly's later work from (Easterly, 2014) in Section 3.1.

**Planners vs. Searchers**

Easterly first points out the large volume of Western aid, $2.3 trillion over the last 50 years, such well-intentioned compassion, has often not reached needy people in the "Rest." He laments that we are very effective at providing, on a massive scale, products to the rich very fast. Yet, we are not nearly as effective at delivery of products to low-income people (even getting them 12-cent medicines). Easterly says that the heart of the problem, considering the history, is the traditional "Big Western Plans." He feels that "the right plan is to have no plan." He does not want to abandon low-income due to past ineffectiveness, but try to improve the process.

    He calls advocates for the traditional approach "Planners" and introduces an alternative set of advocates he calls "Searchers." He says that the short answer as to why low-income people do not get their 12-cent medicine is that Planners try to provide it, while the rich get their new product since "Searchers" provide it. He does not mean to imply, however, that everything should be turned over to the free market since low-income people do not have the money to motivate market-based Searchers to help them. It is the mentality of the Searchers in markets that he seeks to capture in the aid approach. Consider the following list of characteristics of Planners and Searchers doing foreign aid, quoting Easterly for the cell entries in Table 3.1.

    Easterly sites successes of Searchers, but says that foreign aid has been dominated by Planners so this has hurt the effectiveness of Searchers. He uses aspects of what Sachs does as an example of Planners at work, with grand "utopian" promises, and a "Big Push" that Easterly says has not worked in the past. Using history as a guide, he says "Big Plans will always fail to reach the beautiful goal." Easterly does say, however, that while aid will not end poverty, it can solve "desperate needs of the poor and give them new opportunities." He advocates looking for specific ways to help, not infeasible objectives.

    Easterly says that feedback and accountability are key parts of being a Searcher. Feedback comes from low-income people or community. Feedback exists in markets (via consumer's willingness to purchase a product at a set price), and in democracies (protests, voting, etc.). He feels that a critical flaw with current aid is lack of feedback. Accountability is present in markets as businesses' performance is evaluated via profits and market share. Politicians have accountability to the public to make sure they get reelected. He calls for aid agencies and practitioners to have accountability. Low-income people generally do not have money or political power to make their needs known so they cannot hold anyone accountable to meet their needs. Typically, it is the rich (providing the aid) that aid agencies are accountable to and big promises help to satisfy them. People in rich countries generally do not understand the

*Easterly feels that the overall approach to aid is fundamentally flawed due to how people and programs approach development.*

Table 3.1: Easterly's planners vs. searchers.

| Planners | Searchers |
|---|---|
| Announce good intentions but don't motivate anyone to carry them out. | Searchers find things that work and get some reward (incentive). |
| Planners raise expectations but take no responsibility for meeting them. | Searchers accept responsibility for their actions. |
| Planners determine what to supply. | Searchers find out what is in demand. |
| Planners apply global blueprints. | Searchers adapt to local conditions. |
| Planners at the top lack knowledge of the bottom. | Searchers find out what the reality is at the bottom. |
| Planners never hear whether the plan got what it needed. They do not use feedback, and do not have accountability. | Searchers find out if the customer was satisfied. They use feedback and have accountability. |
| Planners think they already know the answers and think of poverty as a technical engineering problem that the Planner's answers will solve. | Searchers admit they don't know the answers in advance and believe that poverty is a complicated tangle of political, social, historical, institutional, and technological factors. |
| Planners think outsiders know enough to impose solutions. | Searchers hope to find answers to individual problems only by trial and error experimentation and believes only insiders have enough knowledge to find solutions, and that most solutions must be home-grown. |
| Planners keep pouring resources into a fixed objective, despite previous failures, and a track record showing the objective is infeasible or the plan does not work. They may even escalate the intervention if a previous intervention fails. | Searchers find concrete proven solutions to help low-income people (by trial-and-error) in specific cases. |

effectiveness of foreign aid and hence do not complain about it.

The divide between Planners and Searchers is not the same as the divide between the Left (liberals) and the Right (conservatives). Big Plans find support from he left as they like big government programs to help, and from the right since they like the idea of benevolent imperialism to spread capitalism and reduce opposition to the West. Critique of the Big Plan comes from both the Left and the Right. The Right says solutions will come via homegrown markets and democracy, the Left does not like Western imperialism trying to make the Rest like the West. Searchers in the middle feel that neither Left nor Right Big Plans can end poverty in the Rest, and simply want to find specific ways to help. Easterly claims that "poor people have already accomplished far more for themselves than the Planners have accomplished for them" (this will be revisited below).

### The Legend of the Big Push

The idea of the Big Push comes from the 1950's and is based on the belief that low-income countries are in a poverty trap that they cannot get out of unless there is a Big Push that has investments and actions to address all aspects of development, and that this will lead to a "takeoff" into sustained growth when aid will no longer be needed. Easterly gives evidence that does not support the legend of the Big Push by providing evidence against the features of the legend: (i) "the poorest countries are stuck in a poverty trap from which they cannot emerge without an aid-financed Big Push" (e.g., "countries with below-average aid had the same growth rate as countries with above-average foreign aid," but he says that there are many types of traps and so argues only about the lack of existence of a trap for the lowest-income countries); (ii) "whenever poor countries have lousy growth, it is because of a poverty trap rather than bad government" (e.g., he sites evidence that bad governments lead to slow growth more than poverty does); and (iii) "foreign aid gives a Big Push to countries to achieve a takeoff into self-sustained growth" (e.g., he sites evidence that aid did not accelerate growth). Besides, he points out, there have not been efforts at assessing the impact of a Big Push to show that it has worked.

### Perspectives on Issues in Development

**Controlled Experiments:**  If goals and interventions are more modest, it is possible to assess success of approaches. He highlights the importance of the "controlled experiment." For this, you randomly create a treatment group (that gets the intervention) and a control group (that does not get the treatment) by randomly selecting members of each group. Then you conduct the "experiment" where intervention occurs (for members of the treatment group) and outcomes are measured for both the treatment and control groups. Then, do statistical analysis comparing the outcomes for the two groups to find the differential impact of using the treatment vs. not using it. This provides a quantitative assessment of the effectiveness of the intervention (see Section 4.9.4). Such an

approach is used for drug testing in the medical community. Statistical analysis of aggregate data can also be useful (perhaps not via a small controlled experiment). Such experimental methods have been used at times in the development community at the family, firm, and country levels.

**You Can't Plan a Market:** Sometimes aid has been conditioned on the Rest rapidly transitioning to markets. Easterly argues that free markets work, but free-market reforms often do not. He says that a free market depends on "bottom-up emergence of complex institutions and social norms" that are difficult to understand and change, so they are difficult to put into place so they are socially beneficial. Top-down imposition of markets has not worked. Economic freedom to produce, buy, and sell leads to individual "specializing" in what they do best (rather than generalizing and doing everything for themselves) and thereby profit in the market via trade for what they need. Financial markets for loans, savings, and investing are important also. But, he argues that it is too difficult to put into place markets from the outside.

Moreover, markets are even difficult to establish if they are homegrown and in this connection Easterly highlights the following problems: (i) cheating when the customer cannot immediately observe the quality of the product being sold, (ii) payment at the time of service may not be possible so payment may not follow, and (iii) different societies have different levels of trust (of strangers) so that people may or may not follow rules without coercion (and evidence shows that there is less trust in low-income countries than rich countries). In some low-income countries, people trust their family and friends, but feel it is acceptable to cheat strangers. All these things affect business significantly, for instance, in trust of employees. There is a tendency to have family enterprises in low-income countries. Courts to enforce rules are unreliable in low-income countries and may be corrupt, and it is much too expensive to prosecute cheating on small transactions. Often, trade relationships in low-income countries are built after time so people can trust each other, and often they are among members of the same ethnic group. This also leads to "ethnic specialization" (e.g., Jews in diamond trade in New York) that shuts out outsiders, especially common in low-income countries. These ethnic markets reduce the amounts of potential gains (e.g., by promoting based on ethnicity rather than merit), and can cause opposition to formation of free markets as they can reduce profits in the ethnic market.

**Security:** Property and individuals must be protected in a society, otherwise there can be dangerous games of threat and self-protection. Self-protection, if you have to pay for it yourself rather than relying on the State, costs a lot of money, money that is not then used for productive activities like investment. Once you get armed, others feel they need to arm themselves and before you know it there is a perpetual "showdown." Property rights impact whether a market will work. Do you own the pieces that make up your business? If I do own it, I will invest in it. Property rights provide the incentive to accumulate

assets over time, even over generations. But, property rights are only as strong as those around us allow. It is best to let law with respect to these issues evolve bottom-up, rather than try to impose it top-down. Easterly then discusses the successes of common law based on cases (a bottom-up approach) vs. the civil law approach that seeks a plan for all eventualities. He argues that civil law is a top-down inflexible approach and that common law has succeeded better historically speaking.

**Politics:** Good governments could fix policies to help promote the market, but low-income countries have bad governments. One approach is to get tough with bad governments and force them to change in order to get aid. Another approach is to take the view that governments in low-income countries are not so bad and to let them produce their own development strategies. Easterly considers the possibility that both of these positions are true. A central theme in his approach is that democracies work, but cannot be imposed from outside. Planners try to impose good government and it does not work.

Easterly explains that democracies include feedback (from the press) and accountability (from the voters at election time). It is difficult to make a democracy emerge, even from the bottom up, more difficult than making a free market emerge. There is the problem in democracy of the "tyranny of the majority." Hence, a complete definition of a democracy involves also protection of rights and freedoms (e.g., of dissent). There is the problem of corruption. Besides, low-income countries generally do not have democracies, they have authoritarian governments that are corrupt. Having lots of oil has been shown to lead to bad governance (the natural resources curse), but there is also evidence that aid leads to bad governance, even worse that oil does (the aid curse). But, he says that there are counter-examples where governments with aid are not always failures. Easterly feels that since experience has repeatedly shown that many governments are so bad that aid does not get to people with low incomes, that the obsession of working with governments should be dropped. He says that if working with a government is not working, something else should be tried. He is opposed to intervening in other governments, or overthrowing them.

### The Future of Western Assistance

First, for aid institutions he has several recommendations. Drop the utopian goals that lead to trying to change whole political systems (i.e., be more humble). Focus on getting the lowest income people "such obvious goods as the vaccines, the antibiotics, the food supplements, the improved seeds, the fertilizer, the roads, the boreholes, the water pipes, the textbooks, and the nurses." This does not promote dependence; it helps low-income people raise the payoff of their own efforts. Easterly calls for accountability for aid institutions to reach goals, and for the promotion of aid institutions specializing in specific problems. Second, Easterly calls for quantitative analysis of what works and what does not, along the lines of the work in (Banerjee and Duflo, 2012) (and Section 4.9.4). But, he

says that is not enough. He also calls for people to understand problems and learn (be creative) about how to come up with solutions (i.e., to be a Searcher).

Third, Easterly highlights the ideas of Whittle and Kuraishi to establish a marketplace of foreign aid with three actors (quoting): (i) social entrepreneurs close to low-income people who propose projects to meet their needs; (ii) individuals and institutions with technical and practical knowledge; and (iii) donors who have funds they want to give away. Such a decentralized market will result in good matches, "projects would compete for funds, technical specialists would compete to be hired, and donors would compete to get results." Whittle and Kuraishi put together a web platform for this called "globalgiving.org". This approach helps solve coordination problems, avoids institutional bureaucracy, avoids corrupt governments, and political manipulation by donor governments. How well does it work? I recommend that you study the web site and judge for yourself.

Fourth, he proposes that "development vouchers" are given to extremely low-income people that they can redeem at any NGO or aid agency for any development good they wanted. Institutions would set aside a pot of funds to support these vouchers. Aid groups would compete for voucher funds, with winners being ones that provided the best services. Agencies not delivering good services would see its budget go down since it turned money over to the voucher fund but none of the voucher funds came back. This would put low-income people in control, and give them a way to say what they want (feedback). Such individual vouchers would not work for community projects (like building a road, health clinics, or education); instead, vouchers could be given to communities. Easterly feels that both the marketplace and voucher ideas need to be tested to see if they work. Fifth, Easterly feels that direct cash assistance to low-income people should be tried. It would allow, like a voucher system, choices to be made by low-income people who best understand how to help themselves.

Sixth, Glennerster (of the Poverty Action Lab) and Kremer suggest creating a fund that would "make an advance-purchase commitment to whoever succeeded in developing a vaccine against malaria." This would provide incentives for rich countries to do malaria research. But, this idea could be expanded to other areas of aid. There could be world-wide or regional competitions for effective aid projects with large awards given to the best results (judged by independent panels).

Easterly feels that low-income people should be surveyed to see if they are getting good aid. He wonders if there are ways to give low-income communities a vote on what services and projects they want and if local "watchers" should be put in place to make sure that aid is delivered.

### Lessons for the Engineer

Easterly proposes that aid should be about lots of well-informed local projects that are evaluated for success (e.g., via controlled trials), rather than one Big Push with utopian goals. His perspective is friendly to an engineer's role in development as engineers generally are not good at changing political or economic

systems, but are good at problem solving at the local level (with solutions perhaps scaled up if they are successful). It is interesting that, analogous to Sachs's call for clinical economics, he calls for a new approach to problem solving in development by introducing the notions of Planners and Searchers, and advocating the Searcher approach. Keep in mind that there is a well-known engineering methodology. All aspects of what Easterly calls the Planner are elements of bad engineering practice (each and every one, please review the table). Now, Easterly does, however, commit a significant error in his statement that Planners "think of poverty as a technical engineering problem." He, like many others (e.g., see discussion on Sachs), misunderstand engineering and the very nature of the process of creating practical technologies. When I have talked to people with this kind of understanding it always seems to stem from them taking courses in algebra and perhaps calculus, thinking of problems as having only one solution that is systematically found with no creativity or considerations of robustness, and then using that one solution. They assume that what the engineers do in their calculus class, is all that they do that for the rest of their lives. They know nothing about the fundamental fact that engineers are inventors of technology, and sometimes businesspeople taking technologies to market. They do not understand how practical engineers are, the role of constraints and trade-offs in design, the concept of design optimization, or how many engineers are motivated to go into the field because they are "tinkerers" (in the past, like with me, tinkering with lawnmower engines, like the magneto-spark system, or like now how they tinker with apps on their smart phone), who have the characteristics of exploration and creation based on good scientific, mathematical, and technical knowledge.

Now, Easterly and you may ask if are engineers Searchers? The answer is a definite yes in call cases (again, review the table) as the features he lists are those of *well-known* good engineering practice, but a comment is necessary on two issues: (i) engineers may be assisted in evaluating demand, and evaluating success, with the help of others like social workers and business people (e.g., via needs assessments, consumer research, and market competition assessment), yet there are times when relatively little is done to evaluate demand (e.g., in the case of a lone software designer inventing a new web/app service that s/he "guesses" will be of use (perhaps simply because it would be useful to them), introduce it to the market, and simply see if it succeeds for fails as there is a low cost for doing that–something that may not be the case for a poverty solution); Easterly should not ignore this possibility in the context of poverty solutions (sometimes some solutions create their own market–remember the old saying "necessity is the mother of invention" but others often say that also "invention is the mother of necessity"); and (ii) engineers use a number of approaches that Easterly does not list as being characteristics of Searchers, even though I think they are, at least for the technological solution case (e.g., acceptance of imperfect initial/partial solutions, the notion of iteration for improvement of design (e.g., by using "engineering as social experimentation"), the importance of "robustification" of a method so that it is successful in a wide range of situations, and others–see the discussion on engineering design methodology for

participatory technology development in Section 4.7).

I am left with the same questions raised after analyzing Sachs's approach: Are engineers on the teams at the highest levels of aid institutions? I am not saying engineers should be in charge and that they would fix everything. I just wonder if there is a diversity of expertise being used; after all, engineers are known to be problem solvers, not just for simple technology like your blender, but for creation of robust, successful, and complex technologies like the internet, avionic systems, etc. Engineering can cope with complexity in many cases, but it certainly appears that the poverty reduction problem is far more complex than existing technologies; hence, the role of the engineer is primarily, in my opinion, at the lower level of aid (engineers do not generally have good knowledge of economic and political systems). But, interestingly, Easterly is calling for work at the lower-level, closer to low-income people.

I find all his discussion on the future of aid to be useful from an engineering perspective. It is interesting that the internet/web is being used to implement the marketplace. Engineers and computer scientists design such web sites and such roles in assisting the community can be great humanitarian work in itself, even though it is not direct assistance. I wonder if a digital tracking system for development vouchers would be useful in assessing the success of such a program. There are other examples of "digital humanitarianism" (Meier, 2015) that provide great opportunities for the humanitarian engineer (e.g., mapping where aid projects are occurring or gathering and correlating inputs of many cell phones during a disaster to improve response). Moreover, with respect to the marketplace stakeholders he identifies, clearly engineers have an important role due to their generally excellent engineering knowledge for technologies.

> Accountability for success in development is crucial.

Finally, Easterly's views on assessment (needs and solution quality), feedback, and accountability resonate with engineers as mentioned above. Per the accountability portion, though, there are points to be made with respect to university-based humanitarian engineering involving students, and these are in Section 4.11.4.

### 3.2.3   Paul Collier: The Bottom Billion

Paul Collier is a professor of economics and public policy and the University of Oxford, England, and Director of the Centre of the Study of African Economies. For five years, he was the Director of development research at the World Bank.

Paul Collier's book (Collier, 2008), not covered here in detail, first covers four (somewhat interrelated) "traps" that keep countries low-income. There is the "conflict trap" where such factors as low income and slow growth lead to internal violence (e.g., civil war or coups) and even if that violence ends it leaves the country low-income so future violence is likely, creating a cycle. There is the "natural resources trap" where an abundance of natural resources (e.g., oil or diamonds) often keeps a country locked in poverty. What happens is that the "resource curse" results in export of those natural resources that causes the country's currency to rise in value relative to other currencies, making the county's other exports (manufacturing and service) uncompetitive (this

is called the "Dutch disease"). Without other exports the country stays locked in poverty. There is the trap of "being landlocked with bad neighbors" that results in high transport costs, making products uncompetitive, and with bad neighbors it is difficult to improve transport access (e.g., to a port) and trade with neighbors (he provides a number of strategies to try to solve this problem). There is the trap of "bad governance in a small country" where policies (e.g., economic policy) and corruption keep a country low-income, and make it difficult to escape since quality of governance is usually associated with wealth. In the past, some of these traps have been broken and then the country has started to catch up, but it has been increasingly difficult in the last 10 years for them to succeed because of a hostile global market. In fact, while globalization has helped China and India, it is not helping the "late-comers." Opportunities for global trade could help, but often there are trade barriers erected by rich countries (e.g., in agriculture) and trade unhelpful trade restrictions in low-income countries. Other problems are the one of "capital flight" out of low-income countries (where their rich, for instance, invest in a foreign stock exchange) and emigration of educated people ("brain drain"). Collier says that "we cannot rescue them" from these traps, they have to do it themselves from within, perhaps via us helping their "heroes" solve the country's problems.

Next, Collier discusses the interconnected "instruments" useful for breaking the four traps: aid, military intervention (e.g., peace-keeping after a civil war or to stop a genocide), laws and charters (e.g., for democracy or transparency to discourage corruption), and trade policy to reverse marginalization. With respect to these issues, Collier says that "it is important to us that these people win their struggle, but the odds are stacked against them." He says that to help with conflict traps we should focus on post-conflict issues (to help them avoid slipping back into conflict) and prevention. He says that post-conflict aid is usually "too little too soon" to be effective, that post-conflict military assistance must be long-term to avoid the reoccurrence of violence, and that breaking the conflict trap is "really about breaking all the other traps." With respect to the land-locked he feels that substantial aid is needed as long-term poverty is likely, and there is in the mean time a need to simply help people live decently. He also feels that a temporary "big push" for aid is needed for some countries to improve export infrastructure (roads, ports, etc.) to globally competitive levels.

Overall, Collier's perspective is balanced and based on high-level statistical analysis of the problems of the bottom billion, and in some cases on effectiveness of past strategies. There are no derived "Lessons for the Engineer" for this section beyond those already stated in the last two sections.

### 3.2.4 Abhijit Banerjee and Esther Duflo: Poor Economics

Abhijit Banerjee and Esther Duflo are both professors of economics at MIT. This section is based on (Banerjee and Duflo, 2012), except the last part where "lessons for the engineer" are provided. Their book is based on the authors' 15 years of work with people living on less than $0.99/day PPP, of which there are

865 million people, 13% of the world's population (based on 2005 data). Their overall approach is based on extensive efforts to understand "the economic lives of the poor," and the conduct of social experiments and quantitative analysis is used to understand low-income people, and to assess and select the best methods to help low-income people. The book contains many anecdotes where the authors have talked to specific low-income people in a range of developing countries to understand their lives, predicaments, and decision-making; indeed, this is one very interesting aspect of the book. In this section, only the conclusions of their randomized controlled trials and the conclusions of their discussions with low-income people are covered (i.e., the insights the authors have gained); for the actual descriptions of the lives of low-income people, and data to justify their conclusions consult (Banerjee and Duflo, 2012). All quotes of this section are from (Banerjee and Duflo, 2012), and some section headings from there are used.

Banerjee and Duflo reject the approach often used by development experts who try to answer the big questions like whether aid helps solve the problem, or whether it creates more harm than good (think of Sachs and Easterly). They feel that real evidence is needed to be able to decide what to do, and not of the type that has been typically used to try to answer big questions. They argue that specific anecdotes (e.g., about what, in one case, helped low-income people) are not useful, as ones can be found to support any position. They do not seek answers to big questions, only answers to whether or not, for instance, aid is useful in a specific situation, or whether more democracy in a local region would be helpful. Besides, they point out that the role of aid in development is relatively small (e.g., India receives almost no aid). Banerjee and Duflo do not want to talk about the deep problems of the world (which can be quite depressing) without talking about practical on-the-ground solutions.

### Principles

**Randomized Controlled Trials To Assess Solution Effectiveness:** As an example, with respect to the use of bed nets to fight malaria, they might ask whether low-income people should pay full price for the bed net (will they buy them or go without?), get a subsidy (will they use it?), or get it free (via aid), and the subsequent question of how this will effect their willingness to purchase, perhaps with subsidy, a bed net in the future? To evaluate these options, they want to consider these options for comparable groups of people. But, people who pay for vs. get the bed nets for free are generally not comparable (e.g., their level of income, wealth, knowledge, and social connections). To solve this problem, Banerjee and Duflo suggest using the idea of the "randomized controlled trial" (RCT) that has been used in other fields, particularly in medicine. In such an approach for bed nets you randomly select individuals to receive different levels of subsidy (zero to free) to purchase a bed net. This eliminates the problem of having comparable groups of people; the randomness assures that for each payment case there are many different types of people and then conclusions are made for "the average person" in each group (i.e., the randomization and av-

*RCTs are way to quantitatively evaluate success of a development solution.*

eraging makes the groups comparable). Next, you see what everyone does and what happens to them, that is, the outcomes (e.g., assess outcomes in terms of frequency of bed net purchases, use patterns, willingness to purchase bed nets later, effectiveness in reducing incidence of malaria, or all of these). Then, you group the individuals per the subsidy level they obtained (e.g., no subsidy, partial subsidy, free) and compare the results to determine which payment strategy (subsidy level) is best as judged the outcomes quantified by data (e.g., the average and standard deviation of metrics measuring each outcome characteristic). This answers the question of how much aid is effective, if any, for the particular case of bed nets in a certain region. Also, it provides insights into the lives of low-income people: for instance, you may learn that low-income people do not know enough about the benefits of bed nets, or that they are not worried about the future possibility of contracting malaria considering everything else they have to worry about. Conducting an RCT when there is only one approach to alleviating problems, and only one measurable outcome, is clearly easier and does enjoy the benefit that selecting random individuals for the group have (e.g., one may be able to say that for randomly chosen individuals this approach as a certain mean level of effectiveness). Conducting RCTs is not, in general, easy though Banerjee and Duflo have shown that it is both a practical and useful approach to eliminate guess-work (and ideologies and ignorance) in establishing strategies for development. Elements of RCT include: (i) a good experiment design to make sure you are asking the right questions and considering the right outcomes; (ii) you need to establish practical ways to measure outcomes so you can gather data; and (iii) you need to have enough individuals in the study ("large enough $N$") to be able to obtain conclusive findings (e.g., if you have three options for solving a poverty problem you clearly need far more than three individuals, one for each option, in order to make any kind of general conclusion; you need many randomly chosen individuals for each option). For more information on RCTs, see Section 4.9.4.

**Is There a Poverty Trap?** A "poverty trap" means that poverty itself, and other extreme deprivations, make it impossible to escape poverty. Is there a poverty trap for countries? Sachs feels there is and wants to use aid to break through the trap, but Easterly does not. Is there a poverty trap for individuals? What does that mean? Sachs discussed that in his book, and this discussion was covered in the above section. Here, however, we discuss the issue again, but from Banerjee and Duflo's perspective. First, note that your income today affects your future income. For instance, your ability today to get nutrition, healthcare, and education all determine how well you will do in the future. When you are in a poverty trap, your future income is less than your current income, and then when you get to the future (say a month or year away), your current income is not sufficient to raise your future income, and so on. Your income gets lower and lower (or stays the same). On the other hand, if you have enough income to get a higher future income, you are not in a poverty trap (or your escaped it), and you can get more and more income over time

Banerjee and Duflo find evidence of several types of poverty traps for individuals.

(which is consistent with how many people think in developed countries, and is how some people then assume it is for low-income people). In my view, this is a quantification of the old statement: "the rich get richer and the poor get poorer." Your view of, or belief in the validity of, poverty traps has a big influence on whether you are willing to provide aid. If you believe that everyone is on the path of increasing their income you are going to be much less willing to help them move up; you may feel that it is best to leave them alone and let them create their own success. If, on the other hand, you believe the poverty trap is real, then your strategy might be to use aid to give them a boost to get them out of the poverty trap so that they can help themselves. Hence, this issue is at the heart of a number of debates (e.g., between Sachs and Easterly) on the need for aid. Banerjee and Duflo give several specific examples of low-income people who are in a real poverty trap, though the issues surrounding why they are in the trap differ between individual cases.

**Ideology, Ignorance, and Inertia:**  Their work, however, goes well beyond poverty traps, and repeatedly raises the issue of now "ideology, ignorance, and inertia–the three I's on the part of the expert, the aid worker, or the local policy maker, often explain why policies fail and why aid does not have the effect it should." "Ideology" is a system of ideas and ideals (or manner of thinking), and often is very general (religious and secular viewpoints both lead to ideology, as does the degree to which someone is conservative or liberal). Sticking to an ideology, perhaps in spite of real evidence on the ground that contradicts the ideology, can clearly make someone ineffective in solving specific problems. "Ignorance" here means  having a lack of deep understanding of the problem at hand, including interconnections between aspects of a problem, or external influences on the problem. Banerjee and Duflo advocate gaining a deep understanding of low-income people before trying to help them, or at least in the process of helping them. "Inertia" is the problem of getting things moving in the right direction quickly. For example, this may mean getting the team doing RCTs to get trials done in a reasonable amount of time. Or, getting aid or government workers to work effectively and quickly at solving problems.

Ideology, ignorance, and inertia all hinder good development practice.

### Hunger, Health, Education, and Family

Humans need enough nutrition just to survive, let alone conduct activities (e.g., work) in order to get enough food to survive. Lack of nutrition may cause a poverty trap if malnourishment is so bad that someone cannot earn extra income. It is natural to assume then that if low-income people have a chance to eat more so that they can start doing work and get out of the poverty trap, they would. Banerjee and Duflo say, however, that this is not the case: low-income people living on less than $0.99/day do not seem to act like they are starving (e.g., by spending every penny on food). When they get a little extra money, the proportion spent on food does not correspondingly increase. Also, you would think low-income people would concentrate their resources on high-calorie and micro-nutrient rich food (which they might not understand), but

they do not. If low-income people get a chance to spend a little more on food they purchase better-tasting and more expensive calories (e.g., they may buy rice or wheat rather than millet, a fast-growing cereal plant whose seeds are edible). Indeed, in India rich or low-income people are eating less and less, the share of their budget dedicated to food has decreased over the years, and more of the budget is spent on more expensive food (of course low-income people eat less than the rich). So, low-income people are not eating more when they can, but it seems less. Why? You have to assume that low-income people know what they are doing. So, perhaps eating more really does not make you more productive so that there is not a nutrition-based poverty trap. Perhaps most low-income people have enough to eat. Today, we have enough available food to feed every person in the world, but starvation occurs due to how the food is shared. Most people, even of very low-income, generally have enough money to buy food since it is relatively inexpensive (except in an extreme situation, like during some famines). Banerjee and Duflo say that in 2004 only 2% of people in the world felt that they did not have enough food. So, are people just not as hungry these days? Some evidence has been found that the decline in calorie consumption is due to the (modest) decrease in the number of people engaged in physically demanding work for most of the day. There is also evidence that very low-income people do benefit more from eating more calories per day than slightly higher income people; this is evidence against a nutrition-based poverty trap. Yet, the authors say that while historically  nutrition-based poverty traps probably existed, today they may only exist in certain circumstances. They conclude that today hunger is not a "big part of the story of the persistence of poverty."

*Banerjee and Duflo say that hunger is not a big part of the persistence of poverty.*

But, are low-income people really eating well? There are statistics showing wide-spread malnourishment in underdeveloped countries (e.g., about one in five children under the age of three has severe malnourishment). Malnourishment results in stunted growth and low weight, including for babies born of mothers malnourished during pregnancy. Malnourishment also results in deficits in cognitive functioning (e.g., low IQ), and it has been shown that smarter people earn more money. But, what about the issue of eating enough? First, some evidence shows that better nourishment that translates into higher productivity may or may not result in higher earnings. An employer may not pay an employee more if they are more productive. On the other hand, evidence shows that the well-nourished self-employed worker does obtain higher earnings. So, if you work for an employer, why eat more? Other evidence shows that if someone works for an employer based on piece-rate (i.e., based on what they produce), then their productivity results in higher earnings, but when working at a flat rate it does not.

But, is there really a nutrition-based poverty trap? Banerjee and Duflo feel that most adults, including very low-income people, are not in a nutrition-based poverty trap since they can eat enough to be productive. But, that does not mean that malnourishment is not a problem for people with low incomes. The issue is not quantity, but quality (e.g., shortage of micronutrients). Proper nourishment can greatly affect life-long earning potential. It is for this rea-

son that Banerjee and Duflo see great social returns from direct investment in nourishment of children and pregnant mothers.

Another important issue at hand is what is important to people with low incomes, food or other issues? Low-income people in the developing world spend large amounts on weddings, dowries, and christenings (likely to save face). Entertainment also matters to low-income people (they provide an example of man who bought a television because he said it was more important than food). What seems to be at play here is that the lives of low-income people can be quite boring (this seems to be why they may buy more tasty food when they have the money). There is a strong basic need for a pleasant life. Low-income people do not take decisions along these lines lightly; they clearly think hard about what they are doing. Banerjee and Duflo also say:

> We are often inclined to see the world of low-income people as a land of missed opportunities and to wonder why they don't put these purchases on hold and invest in what would really make their lives better. Low-income people, on the other hand, may well be more skeptical about supposed opportunities and the possibility of any radical change in their lives. They often behave as if they think that any change that is significant enough to be worth sacrificing for will simply take too long. This could explain why they focus on the here and now, on living their lives as pleasantly as possible, celebrating when occasion demands it.

It seems that low-income people learn not to have hope for the future, and this significantly affects their behavior in the present.

There are clear cases where there are health-based poverty traps (including ones that Sachs identifies). Health affects your ability to work, to get a good income, to get an education, and a pregnant woman's ability to give birth to a healthy baby. Eradicating, for instance malaria in some developing countries would have a significant long-term impact on the reduction of poverty. It is viewed as having a high return on investment. Other good investments are for clean water and sanitation. Still other opportunities include chlorine (for purifying water), ORS (an inexpensive rehydration solution based on key ingredients of salt and sugar, that is used to treat diarrhea), "getting children immunized, deworming drugs, exclusive breast-feeding until six months, and some routine antenatal procedures such as a tetanus shot for the expectant mother," "Vitamin B against night-blindness, iron pills, and iron-fortified flour against anemia." Sachs feels that with so many good solutions, there are many ways to help people out of health-based poverty traps, and part of that should be done with aid.

Evidence shows, however, that demand for chlorine and bed nets is not high among low-income people, even if these are subsidized, and even though the low-income people's return on investment is significant. Demand does not significantly increase if a low-income person has more income. So, do low-income people care about health? Evidence suggests they do: when low-income people are asked if in the last month they have been "worried, tense, or anxious"

*Low-income people often do not have hope for change.*

*Health plays a fundamental role in development.*

about one quarter say yes (much higher than is found in the US), and identify their most frequent source of such stress as their own health or that of close relatives. Moreover, low-income people spend a significant amount of money on healthcare. But, the problem is that low-income people spend their money on expensive cures (e.g., from private doctors rather than free ones provided by the government), rather than inexpensive prevention. The problem is that there is a lack of availability of well-trained doctors (e.g., some only have a high school education) and their assistants (who may have no training) who see patients. Some of these poorly-trained health providers know their limitations, and send cases elsewhere if they cannot deal with them; however, this is not universal. Doctors in the developing world tend to "underdiagnose and overmedicate" (e.g., few questions are asked of patients, and they may rely only on the patient's self-diagnosis, and then treat that). Why don't preventive approaches work? They tend to be ineffectively administered by governments, and there are high absenteeism problems with health providers (so that low-income people cannot even rely on a public clinic being open). Is it possible that since prevention is free or very inexpensive that it is viewed as worthless? First, even given the evidence about the value of prevention, many people in the developed world do not follow advice about prevention. How can we expect low-income people to understand the value of prevention and use it when they may underestimate its value? Second, prevention is often put off in favor of doing things that help you right now (i.e., procrastination). It seems that sometimes low-income people just do little things to help their health, since they cannot afford to confront big problems (e.g., tests, hospitalization, and surgery). Sometimes, preventative measures do not fit into belief systems, for instance, immunization is not the approach to avoid health problems; such problems are cause by "the evil eye" that is caught by appearing in public early in life. Giving away immunization is problematic (should people be bribed to do what they should do?, does it degrade what is given and the person it is given to?); hence, the approach should be to try to convince low-income people of immunization benefits (e.g., via education). Should prevention approaches be mandated, or should financial incentives or fines be used? Or, can "nudges" work? For instance, in the bed net case, it has been found that if a low-income person gets a subsidized or free bed net, they see its benefits, and hence are more likely to get a second bed net, and friends and neighbors of those getting free bed nets were more likely to buy a bed net (information travels, the community educates each other).

Next, contrast these issues with the lives of people in the developed world who are not low-income who:

1. Live in a house with piped-in clean water (no need to remember to purify water every day), and sewage that goes away without a thought and does not pollute the immediate environment, including the water supply.

2. Do not worry about where their next meal is coming from.

3. Have access to well-trained doctors, other healthcare providers, and a public health system all of which can most often be trusted.

It is important to compare your life to the lives of low-income people and consider how taxing the lives of low-income people can be.

4. Have required immunization (e.g., by public schools) and if you fail to get it you are likely going to be alright since most other people have gotten it.

5. Have health insurers that reward us for joining the gym or for eating nutritious food.

People in the developed world do not need to draw on their "limited endowment of self-control and decisiveness, while low-income people are constantly being required to do so." People in the developed world get "invisible nudges" towards good health. In developing countries we need to make it as easy as possible for low-income people to get preventive care, and need to regulate the quality of treatment. Banerjee and Duflo feel we need to provide preventive services for free (or along with rewards), and make getting them the natural default. This is paternalism; however, people in the developed world are constant beneficiaries of embedded (and somewhat invisible) paternalism.

In much of the developing world, schools are available and free, at least at the primary level, and most children are enrolled; however, surveys show that absentee rates vary between 14% and 50%. This absenteeism is not being driven by a need to have the children at home, but student health issues do have an impact, along with whether parents are willing and able to make children go. These issues enter into the "supply vs. demand debate" on education (with a similar dividing line as in the debate on aid). Many policy makers, who the authors call "supply wallahs" (Indian term for "purveyor of") feel that the approach should be to find a way to get children in school and taught by a well-trained teacher and all will go well. There is significant evidence that such an approach works, at least measured by attendance rates (which does not include what is actually learned, where there are significant concerns). "Demand wallahs" see no value in providing education if there is not a clear demand for it and feel that it can result in a waste of money. They feel that the quality of education is low since parents do not care about it, and they do not since they know the actual benefits are low. They feel that when benefits become high enough, enrollment will go up, parents will demand high quality education, all without the state pushing it; hence, they feel that there should be no education policy. Banerjee and Duflo feel that the role of demand is important as, for example, evidence shows that enrollment depends on benefits to education. They feel that the supply-demand debate misses the point: they feel that both supply and demand are important.

Private schools generally perform better than public ones. Expectations by parents of what will be obtained as a result of an education are often unrealistic (e.g., assuming if they finish high school that they will definitely get a job). Often, parents focus their resources on what appears to be their most promising child, and other children lose out. There are many examples of teachers "teaching to a test" needed for advancement, teachers having very low expectations, or teachers "teaching over the heads" of the students rather than trying to make sure all students have basic knowledge. If both parents and teachers to not believe a student can succeed in school, why should the student? Many

schools' curriculum and teaching are designed for the elite, not regular children who attend school. Children of the rich go to schools where more is taught, it is taught better, and the students are treated with compassion and helped to reach their potential. Schools of low-income people make it clear the students are not wanted unless they show some exceptional gift, and generally students are expected to suffer in silence till they drop out.

Yet, the authors hold out hope since evidence strongly suggests that making sure that every child learns the basics is easy. There is a need for a focus on basic skills and a commitment that every child learn these, something that relatively little teacher training takes. They feel that schools should be reorganized for self-paced learning, and helping children who fall behind.

Countries with higher fertility rates are lower-income; however, this does not mean that they are lower-income due to high fertility. Does family size create poverty for a family, for instance, since they cannot invest as much in nutrition, education, and healthcare for each of the children? Banerjee and Duflo's evidence shows that in some countries (not all) children in large families tend to have less education; however, is this due to being in a large family? It could be that low-income families with many children simply do not value education. There is, in fact, no evidence that children born into small families get more education, and other evidence showing that family size has no adverse impacts on children's education. There is even one case (China) where when family size was allowed to go from one to two children, if the first child was a girl she got more education than if she had not gotten a sibling. But, this seems counter-intuitive. If children do not suffer from larger family size, is the mother suffering? There are health problems due to pregnancy, especially for young mothers. Also, pregnancy and marriage make it likely that a mother will drop out of school.

Banerjee and Duflo ask if low-income people lack access to modern contraception? Will they use it? There is another supply-demand debate on this issue. They ask if the focus should be on simply supplying contraception? Demand wallahs reply that if people really want contraception they can find their way to it without any outside help. One study showed that access to contraception via clinics had no impact on fertility. But, it has been shown that better access to contraceptives leads teenagers to postpone pregnancy. What is the impact of education? One program, based on teaching "abstain, be faithful, use a condom, or you die" (ABCD), showed no impact on sexual behavior or even risky sexual behavior (e.g., risking getting AIDS). In another approach, girls were simply told that older men tend to be infected with HIV than younger men. This approach resulted in a significant decrease in girls having sex with older men, but an increase in sex with boys their own age (yet an overall slight decrease in pregnancy rate). In a third program, girls were simply given school uniforms to make it easier for them to stay in school (which gives them a reason not to get pregnant); this resulted in a small decrease in pregnancy rates.

While decisions about whether to have a baby are made by a couple, the woman pays most of the physical costs of bearing the children. Surveys show that men report a desire for a larger family size than women. The mother-in-

law may influence the decision to have a baby. Community norms also influence family size since they define what is acceptable or good from the viewpoint of the community the couple lives in. Also driving the family size decision is the issue of whether children are a sound economic investment. Children are often viewed as an insurance policy (to take care of parents in their old age), a savings product (to later garner their income), and lottery tickets (not being sure who will succeed well enough to help). Having a large family can help ensure that at least one child will "pay off." Of course, having a large family risks that something will go wrong with one child (e.g., they may have health problems). Sons are often viewed as the ones that will help parents later in life, so having sons may be particularly important (in some cultures, daughters cost you a dowry and they leave the house to live with their husband and then have no future financial liability to their parents). But, parents who have fewer children, may find themselves of lower income during their lifetime. Parents in rich countries have the luxury to think differently about family size since they have life insurance, mutual funds, social security, health insurance, retirement plans, and so on. Evidence shows that since children are a way to save for the distant future, when fertility drops, savings go up. This helps to explain why when family size decreases, there is not a corresponding increase in healthier and better-educated children (e.g., for instance, parental investment in these areas). Parents may place higher economic value on boys than girls; this has a number of implications including sex-selective decisions (e.g., abortion or infanticide) and how a girl will be treated as a child. Indeed, parents may continue to have children until they have "enough boys" so that girls tend to grow up in larger families, ones where they really wanted boys. After a girl is born, in some countries she is not breast-fed as long as a boy (with corresponding resulting health problems for the girl) to avoid the contraceptive effect of breast-feeding so that the mother can conceive faster to try to get a boy. Banerjee and Duflo say all these issues degrade our trust in parents to look out for the best interests of their children, especially girls. Moreover, there is reason to be concerned about whether the mother of the family is treated fairly. For instance, there is evidence that women's initiatives at earning are given less support than men's. This results in households being less productive than they could be.

*Family size choice is driven by economic considerations.*

### Risks, Loans, Savings, and Jobs

Risk is a key part of the lives of people who have a low income. Bad luck often hurts low-income people more (drops of income cut into essentials). Risk causes worry, stress, and depression (more prevalent among people of low income) and these make it harder to focus, impair cognition, impair decision-making ability, and make low-income people less productive. Many low-income people run small businesses or farms, often to create employment for themselves since they cannot get steady employment within, for instance, a company or government institution. For the farmers, who often do not have irrigation, their success depends heavily on the weather. Many low-income people are involved in "casual labor" where they get day-jobs in for instance, construction or farming. But,

*Risk figures large in the lives of low-income people.*

such jobs are of indeterminate length (one day, a week, or a month?).

How do the low-income people cope with risk? If income drops, they might try to work more, but often many may be trying to work more (e.g., during a famine) so that their wages drop. Another approach is for low-income people to develop a "diversified portfolio" of activities. For instance, low-income people often have many occupations (e.g., farming and multiple small business like selling fruit and vegetables or washing windshields in the street). Or, as mentioned above, they may diversify their portfolio by having more children who may be able to contribute. Moreover, low-income people may be very conservative in how they operate (e.g., they may not invest in a new seed or fertilizer). They may also decide to become someone's share-tenant so that the landlord pays part of the cost of farming, but gets some of the return. Another effective strategy is to rely on their extensive network of social connections to elicit cooperation of other low-income people in their community (i.e., everybody helps everybody else out). Such cooperation has its limits in some cases (e.g., if you help someone, will they really help you later?), for instance, in helping with wide-spread health problems.

Standard forms of insurance in the developed world (e.g., against crop failure, health insurance, or against death of livestock) are essentially absent in the developing world. Is there an opportunity here for insurance companies, something like how the micro-credit industry? Even a very small profit per client could result in large profits for the company since there are so many low-income people. But, there seems to be a low demand by low-income people for insurance. Over-provision of help by governments and others may to be blamed (if someone always shows up to help when there is a disaster, why invest in insurance against the disaster?). Or, it could be that low-income people do not understand insurance (you pay, but hope you never get the benefit of payment). There is also the problem of trust–low-income people must place great trust in an insurance company since they pay without any initial return (like in most of their typical transactions). Banerjee and Duflo think, however, that the central problem is that "the type of insurance the market can offer only covers people against catastrophic scenarios." They feel that governments should subsidize insurance premiums of low-income people and cite evidence of beneficial cases where low-income people had insurance and it helped.

Loans to low-income people are often of very high interest (e.g., by the money-lenders); this created an opportunity for companies to offer "micro-loans" to low-income people. Microfinance is not based on wanting to make money off low-income people, but can charge enough money to low-income people in interest to make a business financially sustainable, with perhaps a modest profit. Sometimes, micro-loans can help lift someone out of poverty. But, low-income people generally pay higher interest than the rich for loans (20-40% per year). Are low-income people more likely to default? Evidence does not support this. Besides, raising interest rates encourages people to try to find ways not to pay back, so that the borrower needs more monitoring/screening which adds to the cost of giving a loan and may drive interest up (a vicious cycle). Also, some microfinance institutions have significantly raised interest rates and

hence drawn criticism that they are the "new usurers," which is considered by many to be morally wrong (especially in cases where loan officers use extreme coercive loan recovery methods). Microfinance is now a relatively wide-spread anti-poverty approach. Is it effective? Often, the loans are made to women, and the idea is that putting economic power into the hands of women should result in helping with primary education of children, lower child mortality, and maternal health, all issues that men do not care as much about. There is some evidence that microfinance is effective in helping low-income people. For instance, it was found that if micro-loans were available to a community, more people started businesses (but not a dramatic impact on this) and purchased durable goods. But, there were not signs of radical transformation. They could find no measurable impact on women's empowerment (e.g., in gaining control over how their household spends money), spending on education or health, or the likelihood that children would be enrolled in a private school. Banerjee and Duflo were, however, pleased that even though it was not a miracle, microfinance seemed to be working; they conclude that it has a rightful place as one approach to fight poverty (but feel that more study is needed on its effectiveness). It seems that microfinance is not as successful as it could be because low-income people are not willing or able to start a business even if they can get a loan. Also, some of the policies and approaches in microfinance are not entirely effective. There are also problems with the typical "zero-default" policy by microfinance groups. They find a "clear tension between the spirit of microcredit and true entrepreneurship, which is usually associated with taking risks and, no doubt, occasionally failing." Could microfinance groups back off on their insistence on zero-default? Could microfinance be extended to help give larger loans (ones banks will not be likely to give) in cases where they are needed (e.g., for medium-sized enterprises)? In the developed world such loans are typically relatively easy to obtain, given proper justification.

> Microfinance loans are largely directed at women who have better pay-back rates than men.

One common strategy to save is to slowly build a house. Each time a low-income person has extra money they may buy and add more bricks. Without credit and insurance, shouldn't low-income people save as much as they can to avoid risk (e.g., a bad farming year or health problems)? But, how do you save when you do not have much in the first place? Even saving a little still makes sense. Banerjee and Duflo feel that the recognition of "the nascent capitalist inside every poor man and woman" moves us away from the view of low-income people as carefree and incompetent. Generally, low-income people show significant ingenuity in managing their finances. Few have savings accounts in banks, but they save nonetheless. They form "savings clubs" with other savers and each member tries to make sure the others meet their savings goals. In another group-approach, members contribute at each meeting to a pot, and they take turns getting the whole pot. Others deposit money with local moneylenders. Sometimes, they hide money in their house for emergencies. In some cases, cell phone technologies are used to facilitate deposits (so low-income people do not have to travel far to make a deposit). There are international efforts to promote microsaving. Patience and self-control affect savings patterns, and low-income people make myopic and irresponsible decisions in their current purchases (e.g.,

> Low-income people have ingenious ways to save.

on foods with poor nutritional value) but plan on spending in more responsible ways in the future. Sometimes, the low-income people's savings behavior shows that they are not trying to protect their saved assets from others, but from themselves (so they will not spend them on all the problems that arise and need financial attention). Paradoxically, some low-income people use microfinance loans in order to save (even though the interest rate on the loan is far higher than the interest gained from saving). They need to save for important things in the future, and did not want to spend that savings as things keep popping up. The reason for this loan-saving strategy is that microfinance companies strictly enforce repayment and this imposes a discipline that borrowers may not be able to achieve on their own. Essentially, the discipline for repayment forces discipline in savings (if you spend your savings you will not be able to repay). An approach to achieve self-control in savings is not to save at all since you know you will not be able to achieve self-control. But, this makes it so they cannot purchase larger items. Saving may be less attractive to low-income people since the goals are far away and temptations along the way are great, yet if they do not save they continue to have low income. Stress of low-income people results in them making more impulsive decisions. Saving patterns are significantly affected by what a low-income person expects to happen in the future (e.g., if they are hopeful or if everything seems impossibly far away). If a low-income person foresees that there will be opportunities, this may improve their saving and help them get out of poverty. Desperation leads to more immediate spending. Hope, optimism, and having long-term goals can improve saving and have many positive effects.

Are low-income people natural-born entrepreneurs? There are many amazing stories of their creativity, initiatives, and resilience in entrepreneurship and a goal of the microfinance enterprise and other private groups is to try to help them along these lines. Low-income people have fresh ideas and "the bottom of the pyramid" has been largely ignored as a business opportunity. But, Banerjee and Duflo say there are two problems: the businesses that low-income people operate are very small and they make very little money. Hence, giving them a loan to start a new business may not lead to a significant impact on their welfare. Yet, there is evidence that businesses of low-income people have high "marginal return," that is if they grow a little it could be worthwhile. Low-income people manage to make a lot from a little, but they are focusing on very small businesses (e.g., selling fruit in the street) that are basically the same as those run by many other low-income people around them. Moreover, the low-income people are not making enough money on their small businesses to be able to invest in growing their businesses large enough to make some real money (and loans are not available to make that happen either, as discussed above). Associated with some microfinance programs, there have been training programs for entrepreneurs; however, these have been ineffective. Banerjee and Duflo conclude that while there are some effective entrepreneurs among low-income people, that a blanket statement that low-income people are "natural entrepreneurs" is not true. The small businesses of low-income people are more often a way for them to "buy a job" (when no such regular employment is avail-

Entrepreneurship often arises due to lack of regular jobs.

able) than a representation of their entrepreneurial spirit or ability. The small businesses of low-income people represent a failure of the country's economic system to provide jobs.

Many low-income parents in the developing world hope that their children will grow up and get a government job, partly since that is viewed as stable employment. Indeed, stability of employment is what distinguishes low-income people from the middle class. Employment in a factory or "sweatshop" (even ones that are viewed as exploitative in that they provide low wages and poor working conditions) can provide stable employment (longer hours and more regular work). There is evidence of the positive influence of employment in sweatshops on women workers in that their children are less stunted in growth. The regular employment also seems to provide hope, and a better ability to plan for the future and invest in their children's education. Regular employment makes it easier to commit to future spending, easier and less expensive to borrow, makes it easier for schools to accept their children, and makes it easier to get expensive treatments from hospitals (since they know they will be paid). Good jobs are important. Some economists have been concerned that availability of good jobs implies that there will be fewer jobs for all. The authors feel that having fewer good jobs may be worth it due to its positive impact on children. In the developing world, good jobs are more often found in cities than rural areas; hence, there may be a need for migration to get a good job. Some feel that governments should step in with loans to get medium to large businesses started (unavailable via microfinance) so that they can provide good jobs. While the authors support the microfinance approach, they do not think it will result in a "mass exit from poverty." Other approaches, such as providing good jobs, are needed.

Regular, good jobs are important for low-income people.

### Policy and Politics

Does aid help a country? There is evidence that there is corruption so that aid dollars do not find there way to low-income people. How effective are aid dollars? William Easterly has criticized RCTs since he feels they are incapable of answering the "big questions" in development such as economy-wide effects of good institutions and macro-economic policies. He feels that the RCT approach results in a lowering of ambitions. Along these lines, some feel that you need to get the politics right and then good policies will follow, and hence have sweeping conclusions that "big questions" require "big answers" like the transition to an effective democracy. On the other hand, people like Sachs feel that corruption is a poverty trap (corruption promotes poverty and poverty promotes corruption) and suggests that the way to break out of the trap is to make people have higher income, which will result in a stronger civil society and a demand that governments maintain the rule of law. Indeed initiatives arising more from the grass roots have in one case been found to be effective: public exposure of corruption can result in a decrease in corruption.

There are many economists who feel that until political institutions are fixed (and that is difficult), development is not possible (e.g., see (Acemoglu and

Robinson, 2012)). Economic institutions shape incentives to get educated, save, invest, innovate, adopt new technologies, etc. Political institutions shape the ability of citizens to control politicians. Both lead a nation to fail or prosper. Some people feel that rich countries need to help low-income countries get better institutions (e.g., by aid to institutions or subcontracting out the running of their institutions), by force if necessary (yes, military intervention). Others feel that such top-down approaches should not be used; they support a bottom-up view and feel that changes should come from within the society. Banerjee and Duflo feel that much can be done "in the margin" locally (e.g., improve local community decision-making processes to be more inclusive). They feel that politics does not always have primacy over policy and that policy may lead to good politics.

**Five Lessons for Helping Low-Income People**

Banerjee and Duflo have the following five recommendations on how to help low-income people:

1. *Low-income people need better information:* About benefits of immunization, value of early-childhood education, effectiveness of fertilizer, how you can get infected with HIV, or an understanding of what politicians do.

2. *Low-income people are burdened with responsibility for too many aspects of their lives:* Keeping their water clean daily, making sure they get micronutrients, coping with difficulties in saving and getting a loan, coping with running a small business in a highly competitive environment, and coping with lack of regularity of employment.

3. *Markets are missing or unfavorable to low-income people:* They get a negative interest rate on their savings account, and no market for health insurance.

4. *Poverty and history do not doom a low-income country to stay low-income:* Many problems there are due to "the three I's, ideology, ignorance, and inertia."

5. *Expectations about what low-income people are able or unable to do end up being "self-fulfilling prophecies:"* Children give up on school if their teachers give up on them, low-income people don't pay debt if they think they will be right back in debt, nurses do not come to work since no one expects them to be at the clinic, and politicians have little incentive to help improve the lives of low-income people.

Finally, Banerjee and Duflo summarize their essential message:

> This book is, in a sense, just an invitation to look more closely. If we resist the kind of lazy, formulaic thinking that reduces every problem to the same set of general principles; if we listen to low-income people themselves and force ourselves to understand the logic

*Banerjee and Duflo provide five practical insights on how to help low-income people.*

of their choices; if we accept the possibility of error and subject every idea, including the most apparently commonsensical ones, to rigorous empirical testing, then we will be able not only to construct a toolbox of effective policies but also to better understand why low-income people live the way they do. Armed with this patient understanding, we can identify the poverty traps where they really are and know which tools we need to give low-income people to help them get out of those.

More information on their book is at Poor Economics.

**Lessons for the Engineer**

There are several important issues the engineer should take note of. First, their emphasis on understanding low-income people and the use of randomized control trials (both to avoid adverse impacts of ignorance and ideology) are quite important to an engineer developing and applying technologies to help low-income people. Their approach is, in fact, quite familiar to standard engineering practice if the proper broad view is taken. Engineers, often with the assistance of others (e.g., business people doing market/consumer research) come to understand the needs and preferences of their potential customers. They cannot be ignorant about the market. Moreover, via market and consumer research, and after products or processes are released, an analysis based on user acceptance, preference, and satisfaction is done both to sell an initial product, and to redesign and improve a product to capture more market share by raising customer satisfaction relative to a competitor's product. Of course, such assessments also include, where appropriate, studies of adverse impacts of a technology (e.g., health, safety, and impact on environment). For technology, use of RCTs means that functionalities or technological solutions are varied and outcomes (e.g., measures of customer satisfaction and reduction of adverse impacts) are measured. Statistical analysis is done to understand the performance of the technology, and this in turn informs engineers how to improve the technology. Now, if you replace "customer" with "low-income person" you get Banerjee and Duflo's basic approach, with an added emphasis on design iteration and re-design to mature a technology to help end poverty (engineers typically admit that they can't get it perfect the first time).

In their list of five lessons on helping low-income people, there are no specific technologies called for, however, any engineer can see many ways to help with at least items 1.-3. For 1., clearly education for improved technological capacity can help, as can specific information technologies (e.g., access to a cell phone or computer and internet), not to mention specific technologies (like the ones agricultural engineers design). For 2., several issues are simply assisted by a range of technologies as many technologies help reduce toil (e.g., for clean water, sanitation, water-hauling). For 3., electronics (e.g., a cell phone) can facilitate micro-savings implementation (as the authors mention earlier in the book) or micro-loans. Perhaps they could also assist with other financial

services like insurance. For item 4., technologies may help somewhat with facilitating solutions to these problems (with respect to ideology that is an optimistic statement), for example in gathering good data on impacts of technology solutions, and overcoming some types of inertia via computer automation of tasks. With respect to 5., I wonder if on-line education methods could improve the educational situation they describe, and whether electronic "time clocks" for monitoring employees could help.

## 3.3  Global Health Perspective

Global health focuses on public health at an international scale, and not individual healthcare (e.g., by doctors or nurses). Here, an up-close view is provided first. Then, world-level statistics and initiatives are discussed. This is followed by an overview of the key issues of health determinants (including social determinants), the socioecological model, environmental health (e.g., water, sanitation, and indoor air pollution), and technology for health. The inclusion of a health perspective is driven by the importance of health in human development (e.g., it is included as part of the Human Development Index discussed in Chapter 1).

### 3.3.1  Global Health Up Close

A video from the United Nations Development Program that shows a close-up view of the complex issues surrounding health is the YouTube (5:21)

> Beyond Scarcity: Power, Poverty, and the Global Water Crisis

from Dec. 12, 2008. This video shows up close the complex interconnections between water, sanitation, health, and education in Kibera, Nairobi, Kenya. In particular, the video shows:

- Poor sanitation pollutes water, including drinking water.

- Contaminated water results in health problems.

- Health problems adversely affects school attendance (see Section 3.4.4).

Health problems also result in lower work productivity that can affect income. Lower school attendance can (i) affect learning about hygiene, which can cause health problems, or (ii) lead to a lack of understanding about how to fix causes of health problems (e.g., poor sanitation). The issues of water, sanitation, health, and education are tightly coupled, where each one affects all the others. A holistic approach is needed to address situations like this one; health is, however, at the heart of the matter.

Another close-up view of health challenges is provided by the "PBS Rx for Survival" series. An introduction to this series is given in the (2:22) YouTube video

> PBS Rx for Survival

published Jan. 17, 2012. The full series, that includes a two-hour overview, is given in Problem 3.16.

### 3.3.2 Health Initiatives and Statistics: A View From a Distance

The

<div align="center">

World Health Organization (WHO)

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has a wide range of statistics on health (under "Data" and for specific locations, under "Countries") and addresses a wide range of "health topics," including drinking water, food and nutrition, sanitation, indoor air pollution, and others, all of which have relevant technological solutions. Of course, many of their other topics have relevant technologies that can assist, such as diagnostic equipment and medicines. These are covered under the health topic "Technology, Health." The health topic of "Poverty" discusses how (i) low-income people are exposed to more personal and environmental health risks, are less well-nourished, and have less information on, and access to, healthcare; and (ii) bad health reduces their savings, affects their ability to learn and be productive, reduces their quality of life, and therefore perpetuates or increases their poverty. WHO provides useful resources under "Publications," including "The World Health Report" and "World Health Statistics." Also, WHO has a wide range of "Programmes" and projects on many of the health topics.

The World Bank has statistics on world-wide health conditions. The

<div align="center">

Centers for Disease Control and Prevention

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(normally called the "CDC") has significant information on the US case, and on global health. Similarly, the OECD has related information. Of course, the UN has information and initiatives, the Food and Agriculture Organization (FAO), or the World Food Program (WFP), and these were discussed in Chapter 1.

### 3.3.3 Richard Skolnik: Global Health

Richard Skolnik has worked for over 35 years in education, health, and development. He has been a lecturer on global health at the George Washington University and Yale University. He has directed a variety of programs related to global health and served at the World Bank as the Director for Health and Education for South Asia. He has done other work for the World Bank, and also for the UN. He wrote the book (Skolnik, 2012), which most of this section is based on.

Global health is important to everyone as diseases can spread across any boundaries in our highly interconnected globalized system. It is also important due to the social justice dimension discussed in Chapter 2, as it is unacceptable to have such extensive suffering due to poor health in the world. Moreover, as mentioned above, poor health adversely affects economic and social development, and creates global security issues.

The WHO Constitution says

> Health is a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity.

In this section, the focus is on health of populations around the world, not the health of individuals (i.e., global public health).

Health affects economic development, and economic development affects health. The health and education of parents affect the health and education of their children. Health affects cognitive development and school performance, along with earnings potential. At the same time, education can help prevent illness. Costs for healthcare can be high, including transportation to a healthcare facility, and cause people to fall into poverty, or make their financial condition worse. "Healthier people can work harder, work more hours, and work over a longer lifetime than can those who are less healthy" (Skolnik, 2012). Due to this, health can have a signifiant impact on poverty. Nutrition is a key factor in health; however, it is not covered here (see Chapter 8 of (Skolnik, 2012)).

*Health strongly impacts other aspects of development like education and income.*

### Determinants of Health

Skolnik says that the key determinants of health are (from p. 19, Figure 2-1, of (Skolnik, 2012)), for an individual, their genetic make-up, sex, and age, and the health of an individual is influenced by all the following factors:

- Healthy child development.

- Healthy behavior and coping skills.

- Access to health services.

- Physical environment, including water, sanitation, and air pollution.

- Social environment, including socioeconomic status, education, social capital, culture, and gender norms.

- Employment and working conditions.

The physical environment will be discussed below. For the social environment, the "social determinants of health," according to the WHO, are defined as follows:

*Social determinants of health are responsible for health inequalities.*

> The social determinants of health are the conditions in which people are born, grow, live, work and age. These circumstances are shaped by the distribution of money, power and resources at global, national and local levels. The social determinants of health are mostly responsible for health inequities–the unfair and avoidable differences in health status seen within and between countries.

See

WHO Commission on Social Determinants of Health, Final Report

Health inequities are the *avoidable* differences in health between groups of people in a country or between countries. The lowest-income people have the worst health according to the WHO. "Less well-off people, with less social and political power, will generally enjoy less good health, poorer health services, and less financial fairness and protection in the financing of health services than those who are better off" (Skolnik, 2012). People in less-well-off groups typical include women, indigenous people, ethic minorities, religious minorities, low-income people, people living in rural areas, people working in the informal sector, people without much education, and people with low amounts of social capital (network of relationships with others).

**Socioecological Model**

Human behaviors affect health. The ecological perspective considers characteristics that influence behaviors relating to health, and is pictured in Figure 3.1. The diagram shows characteristics relevant to each level, from the individual to public policy, that affect behavior that promotes or degrades health. The key point is that social context matters in many ways in terms of the influences on an individual's behaviors that lead to good health. Moreover, it emphasizes human behavior and its connection to health (e.g., it is not just health technology that matters, it is healthy behaviors and behaviors that promote one's health). This socioecological model has been applied in a number of settings to health-related issues (e.g., by the CDC). It helps to create an integrated holistic program to address health issues.

The socioecological model identifies factors that influence human behaviors as they related to health.
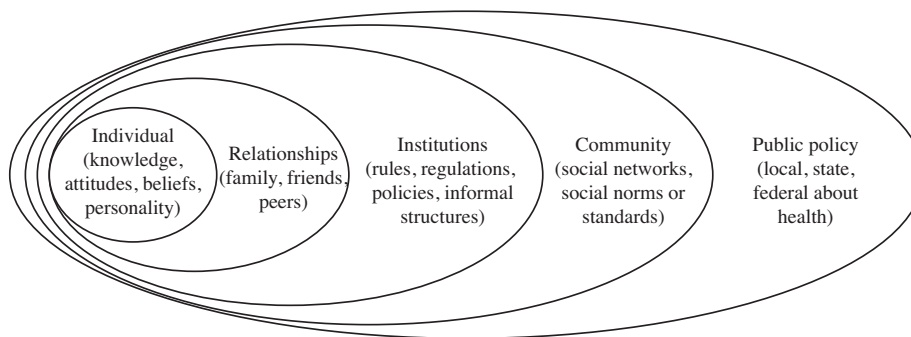


Figure 3.1: Socioecological model of characteristics that influence behaviors related to health (it is a diagram of an edit of information in Table 6-3 on p. 125 of (Skolnik, 2012)).

**Environmental Health: Air Pollution, Sanitation, and Water**

Environmental health focuses on how the natural and built environment affects health. Environmental health and environmental protection are intimately connected. A polluted environment can adversely affect health, and one reason to

protect the environment is to avoid adverse health impacts (see Section 1.3). In this section, we will focus on indoor air pollution, sanitation, and water.

**Indoor Air Pollution:** Coal, cow dung, wood, logging waste, and crop waste are used as fuels for cooking and heating by about half the people in the world (WHO). These can create significant indoor pollution. For instance, cooking is often done with open stoves without ventilation to the outside. Smoke from burning biomass can cause conjunctivitis, upper respiratory irritation, and acute respiratory infection and the carbon monoxide released can cause poisoning. Other gases and smoke can cause "cardiovascular disease, chronic obstructive pulmonary disease, adverse reproductive outcomes, and cancer" (Skolnik, 2012). Effects of outdoor air pollution on health were discussed in Section 1.3.3; however, for more details, see p. 144 of (Skolnik, 2012). Improved cooking methods, lower polluting fuels, better ventilation, better maintenance, and keeping children away from a cooking area can help. Also, better education on the problems of indoor air pollution could help. It has been determined, however, that the most cost-effective way to reduce indoor air pollution is to promote the use of better stoves and fuels (see pp. 154-155 of (Skolnik, 2012)). To come up with better approaches, it is recommended that women help assess needs and designs, at least for some areas (Skolnik, 2012).

Key environmental impacts on health include water, sanitation, and air pollution.

**Sanitation, Water, and Hygiene:** Proper disposal of human waste is associated with "reductions in diarrheal disease, intestinal parasites, and trachoma" (Skolnik, 2012) and improper disposal can contaminate water and food sources, and lead to the spread of parasitic worms. Solutions for better sanitation (e.g., toilets) are discussed on pp. 148-149 of (Skolnik, 2012). There are prevalent water-related infections, especially in low-income areas, including (i) waterborne, where a pathogen is in ingested water; (ii) water-washed (or water-scarce), that is person-to-person transmission due to lack of water that results in poor hygiene; (iii) water-based, where there is transmission from an aquatic host (e.g., fish); and (iv) water-related insect vector, where transmission is due to biting insects that breed in water (e.g., mosquitoes). Solutions for better water supply (e.g., boreholes, dug wells, and rainwater collection) are discussed on pp. 149-150 of (Skolnik, 2012), and can help with these issues, and reduce or eliminate the demands on women and children for carrying water from distant sites.

A wide range of technologies can be designed to promote health.

### Technology for Global Health

Technologies for water filtration, sanitation, and cookstoves, can have a broad and significant impact (see the last section). Technologies such as vaccines and drugs have had a significant impact on global health, as has the improvement of medical devices. Some desirable characteristics of such technologies, quoted from Table 6-1 of (Skolnik, 2012) are:

- *Diagnostics:* Affordable; specific and sensitive; provide quick and easy-to-interpret results; easy to store and transport; heat stable

- *Vaccines:* Affordable; safe and effective; require few doses; confer life-long immunity; easy to transport and store; heat stable

- *Drugs:* Affordable; safe and effective; not easy for pathogens to become resistant to; require small doses over a limited period; easy to store and transport; heat stable

- *Delivery devices:* Affordable; safe and effective; not invasive; easy to transport and store; heat stable

Working along these lines, science and technology can help address the highest burdens of disease in low- and middle-income countries.

### 3.3.4   Lessons for the Engineer

Improving health is a cornerstone of development. This can be seen via the fact that a measure of health (life expectancy) is used as a dimension index in the HDI in Section 1.1.2, particularly in Equation (1.4). Improving health improves quality of life, standard of living, makes people more effective at work and in earning money, and enables education. It is a basic human right from many persons' perspectives.

While determinants of health and the socioecological model are important considerations, specific issues strongly connected to engineering are also present. For instance, how can you design a cookstove so that indoor air pollution is reduced or eliminated? Engineering has a very important role to play in developing technology solutions for water, sanitation, and hygiene. Civil engineering in particular has invented and deployed technologies for these for many years (e.g., see (Amadei, 2014)). Moreover, when it comes to water filtration, many engineering disciplines can be relevant depending on the technological approach (e.g., civil-environmental engineering, chemical engineering, mechanical engineering, and electrical engineering). There are many other technologies that may be directly used by health care experts, including diagnostic tools and medicines, that may be within the domain of expertise of biomedical and electrical engineers.

## 3.4   International Education Perspective

In Section 1.1.2, the Human Development Index was discussed and it is used as one of the main ways to measure human development at the country level. The HDI has as one of its components educational attainment. This is a strong indicator of the important role that education has in human development, and the key reason why here we will discuss in more detail international education. Indeed, it is well known that increased levels of education generally lead to higher average earnings, help children escape poverty (Harber, 2014), and improved

health (e.g., via better hygiene or disease avoidance). Education has a central role in development, and is connected to many aspects of development.

In this section, there will be a special focus on STEM education at the international level, and this will set the context for Section 4.8 where it will be explained how humanitarian engineering can play an important role in international cross-cultural STEM education. Here, we begin by providing an overview of some history and major international education activities.

## 3.4.1  International Education Up Close

There are many videos available showing up close various educational settings around the world. The (3:24) YouTube video

<p align="center">More Teachers, More Learning in Cameroon</p>

from May 27, 2014 discusses problems of teacher pay, other finance issues, teacher development, and class size, and is by the Global Partnership for Education. The (3:00) YouTube video

<p align="center">India's Poor Go To School Under a Bridge</p>

from Sept. 13, 2013, shows one way a man is helping with education in India. It provides statistics and explains educational conditions in India. The (2:56) YouTube video

<p align="center">UNICEF USA: Bilingual Education in Guatemala</p>

from March 25, 2014 discusses the benefits of bilingual indigenous-Spanish education in Guatemala.

## 3.4.2  Education Initiatives and Statistics: A View from a Distance

There are many education initiatives around the world, and in particular, significant actives in STEM education.

**Jomtein/Dakar and Education for All**

An important juncture in the history of education for development was the 1990 Jomtein Conference and the

<p align="center">World Declaration on Education for All (EFA)</p>

that encompassed goals including early childhood development, universal access to and completion of primary education by the year 2000, improved learning achievement, improved adult literacy, a focus on basic skills needed by children and adults, and increased acquisition by all of knowledge, skills, and values for better living and sustainable development (see a summary on p. 129 of (Ansell, 2005)). The EFA supported locally-driven education to account

> "Education for All" is a major world-wide educational initiative.

for "culture, language, experience, and gender" in communities (Maclure et al., 2012). Along these lines, important initiatives highlighted are by the Bangladesh Rural Advancement Committee (BRAC) and Escuela Nueva community schools in Colombia. Interestingly, "throughout most of the post-Jomtein decade, external assistance generally accounted for less than 2 percent of the educational budgets of recipient countries" per UNESCO information. It is no wonder that grass roots efforts are popular among some.

Next, there were the

<div align="center">

Dakar Framework for Action

</div>

and the UN Millennium Development Goals. The Dakar framework promoted the "transformative" framework (see below) more than EFA, as did the Millennium Development Goals, but in a narrower way. In particular, six EFA goals were adopted in the Dakar framework that you can see by clicking here and are (quoted from that web site):

- Goal 1: Expanding and improving comprehensive early childhood care and education, especially for the most disadvantaged and vulnerable children

- Goal 2: All children, particularly girls, children in difficult circumstances and those belonging to ethnic minorities have access to free, quality and compulsory primary education by 2015

- Goal 3: Ensuring that the learning needs of all young people and adults are met through equitable access to appropriate learning and life skills programmes

- Goal 4: Achieving a 50 per cent improvement in levels of adult literacy by 2015, especially for women, and equitable access to basic and continuing education for all adults

- Goal 5: Eliminating gender disparities in primary and secondary education by 2005, and achieving gender equality in education by 2015, with a focus on ensuring girls full and equal access to and achievement in basic education of good quality

- Goal 6: Improving every aspect of the quality of education, and ensuring their excellence so that recognised and measurable learning outcomes are achieved by all, especially in literacy, numeracy and essential life skills

In some approaches to development, there is an emphasis on the education of girls and women (see more on this below), perhaps based on the old proverb "when you educate a man, you educate an individual; when you educate a woman, you educate a family" (Ansell, 2005). There is a movement to increase awareness of environmental degradation and sustainable development (see Chapter 8 in (Harber, 2014) and Section 4.8.5).

**Information and Statistics on International Education**

Detailed statistics on the status of education around the world are provided by the World Bank. Additional information can be obtained from UNICEF, UNESCO, and the

> UN Global Education First Initiative

which has a list of priorities (several in each of three categories, "Every child in school," "Quality of learning," and "Global citizenship"), and many good resources. See also the

> Global Champaign for Education

The

> United Nations Convention on the Rights of the Child

and the 1948

> UN Declaration on Human Rights, Article 26

assert that all people have a right to education, especially to lower levels of education and at no cost.

**International Mathematics, Science, and Technology Education**

Detailed statistics on education in these domains are provided by the World Bank. For instance, they have detailed information on many countries for, for instance, enrollment levels in engineering (tertiary, women and total) and science (tertiary, women and total), and there is the "Trends in International Mathematics and Science Study."

UNESCO has a range of activities in science and technology education, such as

> Science and Technology Education at UNESCO

and

> UNESCO "Toolkits" for Science and Technology Education

that may be useful for some classroom-based learning. See also

> Information and Communication Technology in Education at UNESCO

and

> UNESCO Inst. for Information Technologies in Education

There is an initiative by The New York Academy of Sciences called the

> Global STEM Alliance

*There are a range of statistics and initiatives in international education, including for STEM.*

### 3.4.3   Utilitarian vs. Transformational Perspectives

From  the historical and broad conceptual viewpoint there are two general competing perspectives on education for the developing world that mirror some attitudes in the developed world (Maclure et al., 2012):

1. *Utilitarian perspective:* For this, education is viewed as a financial investment with returns of economic growth, fostering political stability, transmitting skills to grow students into productive citizens in a "stable socio-economic order." This view is associated with maintaining the status quo, and often has a focus toward the free market and capitalism. Education should be directed toward these objectives.

2. *Transformative perspective:* In competition with the utilitarian perspective, a transformational perspective is often promoted. It is driven by the view that the overall political and economic framework/structure favors those with wealth and power, and hurts low-income people via discrimination and oppression. Education is viewed as a way to improve understanding of social injustices to empower disadvantaged populations to change and perhaps radically alter the structural foundations causing poverty, inequity, and oppression.

The process of world-wide educational development can be thought of as a competition between forces supporting these two perspectives, which often include forces from outside a particular community or country. Sometimes, the competition results in a compromise that includes both elements.

While the two perspectives often cannot be decoupled in a program, or even specific classes, some examples of approaches or topics in each of the two perspectives are:

1. *Utilitarian examples:* Education along these lines focuses on job-training programs, such as in vocational/technical education. Sometimes, there is a focus on training a workforce for a local industry, agriculture, tourism, or forestry.

2. *Transformational examples:* Education along the lines in (Freire, 1993) can be transformational. Also, existing programs discussed in the last section such as (i) aspects of the six goals adopted in the Dakar framework, (ii) the UN Global Education First Initiative priority called "Global citizenship," and (iii) programs promoting inclusion, such as for girls/women or minority education, can have transformational elements, even though they may be primarily utilitarian in classes.

The program in Section 4.8.5 has elements of both utilitarian and transformational objectives.

*Historically, there has been a competition between utilitarian and transformational approaches to education.*

### 3.4.4 Clive Harber: Education and International Development

Clive Harber is an emeritus professor of international education in the School of Education at the University of Birmingham, UK. He has extensive experience in education in several African countries. He wrote (Harber, 2014), and this section is based on that book.

"Formal education" (school- and classroom-centered) is a Western idea, partly spread by colonialism, that has taken root world-wide, and is viewed by many as a key to development (Harber, 2014). Often, schooling is viewed as an approach to modernization, development of families and a workforce (including for institutions and governments), reduction of poverty, and promotion of health and economic growth. Harber (Harber, 2014) says that while education can strongly impact people and have transformative impacts on society, he cautions, however, "against any automatic assumption that education directly or necessarily leads to benefits for individuals and societies in any straightforward manner" and quotes the

<p align="center">UN Human Development Report for 2010</p>

which found a "lack of significant correlation between economic growth and improvements in health and education" (Harber, 2014). As mentioned above, however, you could argue that the focus of education is not necessarily economic growth, but human development. Harber also says that many schools still contain remnants of of "colonial encounter" in that they remain elitist, lack relevance to local realities, and are often at variance with indigenous knowledge systems" (Harber, 2014). Whether educational systems should be designed to "modernize" a country (per the "modernization theory of development") towards a Western model is controversial.

**School Access and Attendance**

Access to primary education, poor attendance, drop-out rates, and low rates of transition to secondary education are affected by:

1. *Poverty:* Lack of ability to pay fees, buy uniforms and supplies (books, paper, writing utensils), pay travel costs, and at the same time lose a helper at home and in the fields, affects school attendance. Students may have other responsibilities at home, or lack sufficient light to be able to do homework and reading.

2. *Health, hunger, malnutrition, and disabilities:* Poor health adversely affects attendance (e.g., Malaria or HIV/AIDS), as does the need to take care of an ill parent or grandparent. Hunger and poor nutrition affects an ability to concentrate, if a student even makes it to school. Several countries have introduced school meal programs to improve attendance. Children with disabilities may not be able to be accommodated for in

There are many factors affecting school access and attendance, especially for marginalized individuals.

school facilities or there may be a social stigma that adversely affects school attendance.

3. *Harsh treatment at schools:* Children may not want to attend school, and may get their parents support for this, if they are treated harshly at school. Harber says that corporal punishment is wide-spread (Harber, 2014), as is bullying.

4. *Girl's/women's issues:* Parents' attitudes about girls attending school, such as that it is a waste of time and money, lack of separate toilet facilities for boys and girls, and (sexual) harassment from male students and teachers, can all adversely affect girls' attendance. Early marriage adversely affects school attendance. Pregnancy often results in a girl dropping out, and lack of childcare may ensure that they do not return to school. The level of education of a mother is "linked to the health and survival of her children" and fertility rates go down with increasing educational levels (Harber, 2014).

5. *Irrelevance and quality of teaching and curriculum:* The curriculum may be seen as irrelevant to local needs, for example, in an agricultural area, and some may not see education as a route out of poverty (e.g., if there are no local jobs available that require an education), especially if a local educated group of young people can get no jobs. The curriculum and teaching may be of very low quality, and hence school may be viewed as a poor investment by parents.

6. *School location and quality:* If school is too far away, attendance goes down. Nomads, pastoralists, and street children have difficulty attending school. Classrooms can be of low quality, lack heat or cooling, lack sufficient light, be too noisy (e.g., when it rains), and have no electricity. They may lack science equipment, and teacher ingenuity to develop and use it. Sometimes there is corruption in school, such as theft of funds by administrators.

7. *Governments and funding difficulties:* Some governments lack sufficient funds to provide free education for everyone. Some schools do not have adequate "buildings, textbooks, teaching materials, and toilets" (Harber, 2014), especially in rural areas. Sometimes, all that can be provided are "split-shift" programs (e.g., school in the morning for one group and in the afternoon for another). Is this sufficient?

8. *Armed conflict and emergencies:* Wars and other conflict adversely affect school attendance, as does an emergency such as a natural disaster. However, in such situations, education can help restore normalcy and stability.

To provide improved educational opportunities, there is a movement to provide "low-fee" public schooling, sometimes financed by a community.

**Educational Quality and Outcomes**

The quality of education at schools is of course a concern. Will children benefit from an education? Are sufficient literacy and numeracy (the ability to understand and work with numbers) outcomes all that is needed? How is sufficiency judged? Via an examination? What language should the children learn in? Evidence strongly suggests that better quality learning can be achieved if students' native language is used in primary and into secondary school; their "colonial language" should be used starting sometime in secondary school (Harber, 2014) if that is viewed as useful, for instance, in helping to get a job. Sometimes, such an approach is not taken for a number of reasons, such as there being no teaching materials in a local language.

Often, quality is "in the eye of the beholder;" however their are established viewpoints on what constitutes a quality education.

The definition of "quality" is often based on ideology; however, there are three related approaches to defining quality:

1. *Human capital:* In this approach, the focus is mainly utilitarian (see Section 3.4.3), directed at how education can promote economic growth and productivity, and is considered a key for a nation's development. Education is viewed as making people more productive, and able to develop industry. Investing in human capital is considered a good use of financial resources. There are a number of criticisms of human capital theory (Harber, 2014), including concerns that education is really just a screening process rather than a human development process, is a way for the elite to become "connected" to gain opportunities, and that it does not lead to economic growth, but the other way around–economic growth leads to development of an educational system.

2. *Human rights:* Here, the focus is on inclusion, "seeking out learners, acknowledging what the learner brings" (Harber, 2014), the learning environment, and the type of distribution of outcomes. This has elements of both the transformational and utilitarian perspectives discussed in Section 3.4.3.

3. *Social justice:* This is aligned with the human rights approach, and seeks to produce educational outcomes that result in enhancing the struggle against injustices (e.g., lack of participation, and reduction of inequalities, as discussed in Chapter 2). Per Section 3.4.3, this approach is largely transformational.

Significant data on educational outcomes is provided by several organizations (see Section 3.4.2 for references to web sites). Moreover, it should be noted that inequalities in a society are often reinforced by the educational system, rather than overcome by it. Socioeconomic origins generally drive academic success, with higher classes generally more successful at education; again, this can amplify or maintain social inequalities. Overall, educational systems are not meritocracies, with the most talented getting the most education and best jobs. Sometimes, inequalities arise due to the financial support of the parents, making sure that their children get a quality education (e.g., in an expensive private

Socioeconomic class of origin affects a student's educational outcomes.

school that has a quality instruction and curriculum, and via help, guidance, and encouragement). Low-income parents do not have the means to ensure that their children obtain a quality education. The overall effect of education can be to serve as a "socioeconomic reproduction system" (Harber, 2014).

Finally, note that achievement of higher levels of tertiary education in developing countries sometimes results in "brain drain" by individuals migrating from a rural area to an urban area where there may be more opportunities, or leaving their country altogether to find opportunities in a country in the developed world. This hurts localities and countries due to the loss of talent.

### Technical and Vocational Education and Training

Vocational education focuses on developing skills that make it easier for individuals to get a job. Foundational skills like literacy (speaking, reading, and writing) and numeracy can help someone get a job. Sometimes, learning another language such as English, or the dominant language of business in a country (sometimes the "colonial language"), can help also. Other skills, such as "problem-solving, communication, creative thinking, critical reading, use of information technology, and organizational and presentational skills" (Harber, 2014) can help.

The focus of technical and vocational education and training (TVET) is to provide skills for a particular job such as a tradesperson, computer technician, bricklayer, or auto mechanic. Usually, TVET starts at the secondary level, sometimes via a separate schooling or a blended approach with standard secondary education. It may occur in a standard school, a specially-focused private school, or via an apprenticeship at a business, perhaps with some time off for education at an institution.

Some parents view TVET as of lower status as it is sometimes viewed as being for less academically capable individuals, and parents understand that often to obtain an "aspirational job" like a lawyer, doctor, or teacher, a student has to take the traditional academic route. In some cases, this has led to rejection of TVET programs, and this is likely to continue unless the job market rewards the types of jobs that TVET persons can get. Sometimes, the sole pursuit of skills for one job via TVET can fail if the economy changes and jobs in that area go away; this is an argument for a general education that prepares the student for a range of jobs.

> Vocational training may help someone get a job; however, it does not provide a general education sufficient to provide flexibility in getting different types of jobs.

### Political Learning and Globalization

From a political prospective, education is needed to train the people to run the government (managers, bureaucrats, technical, and professional people). Also, there are three types of "political learning" for citizens:

1. *Indoctrination:* Political indoctrination attempts to "intentionally inculcate values and beliefs as facts or truths" (Harber, 2014). This may involve falsification or ignoring facts, or presenting issues in a biased manner.

Alternative viewpoints may be strongly discouraged, especially under a totalitarian regime.

2. *Socialization:* Socialization is "the learning of preferences and predispositions towards political values and attitudes, though often in contexts where other viewpoints are available" (Harber, 2014). For instance, in some schools there may be an emphasis on learning how to cooperate, and the benefits of cooperation. Yet, via examinations, rankings, awards, and some sports they learn that competition is more important that cooperation.

3. *Education for democracy:* This approach tries to "create a critical awareness of political phenomena by open, balanced discussion of a range of evidence and opinions... ...and encourages individuals to make up their own minds about issues after considering the arguments and evidence" (Harber, 2014).

Connected to these issues, is the approach of Freire (Freire, 1993), where he is concerned that students are just knowledge depositories who do not develop a critical consciousness about their surroundings and simply accept things as they are (including their role in society) and thereby pose no threat to an oppressive order. Freire is concerned that education controls thinking and thereby actions and he advocates "education as the practice of freedom" (Harber, 2014).

Finally, there are relationships between globalization and education, and in particular Harber says that there are five common high-level policies across China, India, Sri Lanka, and Kenya with respect to achieving good global economic engagement (quoted exactly from p. 20 of (Harber, 2014)):

1. High quality mass education;

2. Planned expansion of secondary, technical and higher education to create the skills necessary for sustained economic growth;

3. The development of communication skills that facilitate international economic transactions;

4. The equitable expansion of education to enhance its contribution to social equality; and

5. The awareness of the potential of schooling to promote both positive and negative contributions to national unity and social cohesion.

### 3.4.5 International Mathematics, Science, and Technology Education

Work has been done to determine what every child in the world should learn and along these lines, this section overviews (UNESCO-Brookings, 2013), but only the parts on numeracy, mathematics, science, and technology. Domains that (UNESCO-Brookings, 2013) identifies as those that every child should learn,

but are not discussed here, are physical well-being, social and emotional, culture and arts, literacy and communication, and learning approaches and cognition.

### Numeracy and Mathematics

One rationale for teaching numeracy and mathematics is to promote economic development (e.g., countries with more engineering students have faster-growing economies than those with more lawyers) (UNESCO-Brookings, 2013). Other rationales include that these help people make better daily decisions and perform everyday calculations, enable a move into science, social-studies, engineering, technology, business, and government, and enable success in a complex technological society. Early understanding of mathematics is a good predictor of later reading and mathematics performance.

Standards for what every child should learn in numeracy, mathematics, science, and technology have been established.

At the early childhood level (0-8 years old) numeracy and mathematics education should include number sense and operations, spatial sense and geometry, patterns and classification, and measurement and comparison (see p. 41 of (UNESCO-Brookings, 2013)). At the primary level (5-15 years old), children should learn number concepts and operations, geometry and patterns, and the application of mathematics (see p. 43 of (UNESCO-Brookings, 2013)). At the postprimary level (10-19 years old) the following should be learned: numbers, algebra, geometry, applications to everyday calculations, personal finance, being an informed consumer (to assess products in terms of numerical information), and data and statistics (see p. 44 of (UNESCO-Brookings, 2013)). These learning goals, that are keyed to ages, provide useful information on what you can expect a child to learn.

### Science and Technology

"The notion that high-level performance in science and technology areas is highly desirable for national economic performance has been widely accepted for some decades" (UNESCO-Brookings, 2013), yet the same report says that these are just emerging for early childhood education at the international level. Even at the primary level there is disagreement on the inclusion of technology competencies due to the lack of technologies in many countries. For science and technology education, there is a problem of having properly trained and prepared teachers. Moreover, there is concern that "the deprived, low-literacy home environments also do not provide any support for developing such skills" (UNESCO-Brookings, 2013). Yet, "many of the challenges that the world faces in health, the environment and energy resources will require thinking and solutions that are informed by knowledge of science and engineering" (UNESCO-Brookings, 2013); it seems clear that laying a foundation for this makes sense, even early in life. Assessing how well children in the developing world are mastering science and technology is difficult due to a lack of studies outside the developed world. Such education lags in the developing world, but technologies, most notably the cell phone which is found even in households without electricity, show that technology has a global foothold; this creates a demand for

understanding technology.

During early childhood, children should learn inquiry skills, awareness of the natural and physical world, and technology awareness (UNESCO-Brookings, 2013). At the primary level, children should learn scientific inquiry, life science, physical science, earth science, and gain an awareness and use of digital technology (interact with information and communication technologies). At the post-primary level, children need to learn biology, chemistry, physics, earth science, scientific approaches, environmental awareness, and digital learning (UNESCO-Brookings, 2013).

### 3.4.6   Lessons for the Engineer

Like health, improving education is a cornerstone of development. This can be seen via the role of education in the SDGs, and the fact that a measure of education (mean number of years of schooling and expected number of years of schooling) is used as a dimension index in the HDI in Section 1.1.2, particularly in Equation (1.4). Improving education improves quality of life, standard of living, makes people more effective at work and in earning money, and can positively impact health (e.g., by learning about hygiene). Education is a basic human right from many persons' perspectives.

There are a number of international efforts at developing STEM education, and these are aimed at basic literacy in these areas, and helping people get jobs. The utilitarian and transformational perspectives on education both work for STEM education, and simply change the focus. See Section 4.8. The issues of school access and attendance help the humanitarian engineer understand the context of international education. TVET is quite relevant to STEM education. Basic STEM ideas, plus practice, form the foundation for TVET. Section 3.4.5 on "what every child should know" about STEM is useful for the engineer helping create and run a STEM program in an international setting. The goal of that section is to try to help the engineer have realistic expectations of students so that teaching and learning is effective.

## 3.5   Social Business Perspectives

Here, the perspectives from two books, one by Prahalad (Prahalad, 2010), and the other by Polak and Warwick (Polak and Warwick, 2013) are overviewed. Also included are some ideas from an earlier book by Polak called "Out of Poverty" (Polak, 2009).

### 3.5.1   C.K. Prahalad: Eradicating Poverty Through Profits

Social business focuses on having positive social impact and making a profit at the same time ("double bottom line"). When considering generally smaller

businesses and the need for innovation people may call this "social entrepreneurship." Here, only part of this field is covered: the portion that is more focused on selling technologies as this is most relevant to engineering (though many social businesses, could, of course, benefit from technologies in their solutions–for example in microfinance as mentioned above). In this section, (Prahalad, 2010) is covered.

Coimbatore Krishnarao Prahalad, born in India, was a professor of business at the University of Michigan (he uses "C.K." in his book publications). This section is based on his book (Prahalad, 2010) (and quotes in this section are from that book). Prahalad feels that low-income people need to become "active, informed, and involved customers" and that poverty eradication can occur from "co-creating" (that is, low-income people, richer business people, and/or low-income and richer business people together) a market centered on the needs of low-income people (creating new business models and markets, not using existing ones). He advocates "inclusive capitalism" to involve the 5 billion people at the bottom of the pyramid (BOP) as underserved consumers and markets (Bill Gates calls this "creative capitalism"). He views people at the BOP as deserving respect as individual consumers, and via co-creation views these consumers as "equally important joint problem solvers." He says that BOP consumers "get products and services at an affordable price, but more important, they get recognition, respect, and fair treatment." He claims his private-sector approach will build self-esteem and entrepreneurial drive, give voice to low-income people, will force us to understand the low-income people's needs, and will stop us from making assumptions about how low-income people feel. He acknowledges that not all accept the idea of using his approach, and does not feel that the private sector can solve all the problems, but says it can bring "technical and financial resources, the disciplines of organization, accountability, and entrepreneurial drive to bear on the problems." He feels that the BOP micro consumers and micro producers are a significant market and are an "engine of innovation, vitality, and growth." He says the goal is to build capacity for people to escape poverty via a self-sustaining market-based approach. He cites the cell phone as an example of a successful product for low-income people (e.g., in Bangladesh) that is quickly spreading throughout the developing world. The cell phone is not only used for communications (e.g., finding out distant market prices) but also computing, entertainment, remittances, delivery of financial services (micro loans and savings), and healthcare. The cell phone example shows that low-income people accept and effectively deal with relatively sophisticated technology. Companies selling these phones have made significant profits and have shown that there is real market at the BOP. He provides a list of companies who have successfully sold to low-income people for a range of products and services, and asks why this approach is not used more.

**A Retrospective Overview of the Approach**

Based on the progress since the release of the first edition of his book (in 2004), Prahalad identifies some practical guidelines for companies for the BOP (as of

2009):

1. *The innovation sandbox:* The BOP must be converted from an unorganized set of consumers with inefficient local monopolies (e.g., moneylenders) to an organized efficient private sector where consumers are aware of new products and services. Key ingredients to market development are awareness, access, affordability, and availability. He says we need to start with an "innovation sandbox" which is a set of critical non-negotiable constraints to market development. It must be designed "for the firm, its target segment, and the business." It will include: (i) Scalability so that many people's lives can be changed, and respect the fact that the business is "low margin, high volume, high return on capital" (volume sensitivity makes scalability critical); (ii) A new "price-performance envelope" (or new value proposition) is important; the key problem of affordability demands that "we start with Price-Profit=Cost and not the traditional Cost+Profit=Price" (of course these equations are algebraically equivalent, but what he means is that in design there is a need to focus on low costs and low profits to obtain a low price for low-income people); (iii) Dramatic cost reductions are not possible without good use of "modern science in the development of products, services, and information technology in the delivery of those services;" and (iv) international standards of "quality, safety, ecological sustainability, and aesthetics" as appropriate.

2. *Build an ecosystem:* BOP markets are local and fragmented. For scalability, micro entrepreneurs are needed for sales, distribution, support services, production, etc. Also, large firms, small to medium size enterprises, civil society organizations, and the public sector may be needed. He calls the group of all these the "ecosystem." He says that ecosystems create investment capacity and that the skills and knowledge available from the ecosystem are critical to success (he says "don't go it alone").

3. *Co-create solutions:* BOP markets are sophisticated and demanding; you can't just create inexpensive products. You need "local knowledge and local trust" and solutions must be "locally responsive." He says that there is a "global-local tension" (need to provide products that are widely sellable but also ones that sell well in a specific village). He says that a very lean business is required (low overhead, lean organization, and low capital intensity) and that firms have to "rapidly learn about local consumers, their needs, and their aspirations at low cost." The approach to all these issues is co-creation–that is, involving low-income people. He says that collaborative capacity (in co-creation) leads to investment capacity. Co-creation leads to others sharing more in the investment and helps to reduce risk.

4. *A new concept of scale:* Prahalad says that new ideas of scaling are needed. He says that decentralized origination, centralized processing, and marketing "seem to be the key." He calls this a "nodal organization" and says it leads to investment capacity.

5. *Use technology:* The BOP market is high-tech. "The use of information technology to manage the logistics and manufacturing infrastructure is widespread." Information technology provides real-time information on inventories, receivables, and patterns of consumption. It is clear that innovative high technology (not just information technology) is needed for products and services, including to reduce costs.

6. *Innovations will lead to sustainability:* Constraints from the developing world, such as interruptions to electrical power and low water supply, demand technological innovation (e.g., via renewable energy).

7. *The challenge is market development:* There often are not existing markets, so new ones have to be created. This is what happened for microfinance and cell phones.

8. *The markets are evolving rapidly:* BOP markets are changing fast. Prahalad feels it is best to use "life-style measures" to determine what low-income people aspire to, and hence want to invest in. You cannot assume what a low-income person wants or needs and hence what choices they will make. These issues are essential to understand to achieve market success.

Prahalad calls for a "democratization of commerce" via "bringing the benefits of globalization to all micro consumers, micro producers, micro innovators, micro investors, and micro entrepreneurs." He feels that everyone has a right to the benefits of globalization, to participate in the global market, and as a minimum everyone must be treated with dignity and self-esteem as micro consumers. Everyone must be respected, have choices, and have access to world-class goods and services. The goods do not need to be luxury goods, and he says that treating people as consumers "is not the same as creating a wasteful consumer culture." Low-income people can become "self-reliant, confident, and capable of understanding investment and returns, credit, and profit." Access to information enables democratization of commerce; "information asymmetry has always been at the heart of poverty" (e.g., low-income people not having market information). Access to regional and national markets helps low-income people get a fair wage, especially if low-income people are organized and connected. He says that it is too early to declare success in his BOP market approach, but feels that there are good indications that it may be successful.

### The Market at the Bottom of the Pyramid

Prahalad calls for us to "stop thinking of the poor as victims or as a burden and start recognizing them as resilient and creative entrepreneurs and value-conscious customers" so that "a whole new world of opportunity can open up." He feels that a fresh approach is required to reduce poverty considering the failures of past methods. He supports the approach of using innovations to create opportunities for low-income people, to give them choices, and to promote self-esteem. He acknowledges that sometimes large firms and multinational

There is a large market at the bottom of the pyramid.

corporations undermine efforts of low-income people to improve their prospects, but feels that a bigger problem is that in the past they have ignored low-income people. He supports "free and transparent" private-sector competition, unlike local village and shanty-town monopolies controlled by "slum lords." The BOP market provides "a new growth opportunity for the private sector and a forum for innovations."

Prahalad says that the "dominant logic" of multinational corporations about the BOP is:

1. Low-income people are not target customers since they cannot afford products and services (their "cost structure" does not fit with the BOP).

2. Low-income people have no need for products from the developed world (products cannot be adapted or innovated).

3. Only developed countries demand technological innovations (the BOP does not need technological innovations, and they will not pay for them, so the BOP is not a source of technological innovation).

4. The BOP market is not critical for long-term growth and vitality (BOP is at best an attractive distraction).

5. The "intellectual excitement is in developed markets" so it Is difficult to recruit managers for BOP markets (so do not assign your best people to develop BOP markets).

Prahalad supports the idea of having firms "innovate from the BOP up" and not take the old approach of making minor changes to products created for the top of the pyramid and trying to sell them to the BOP. Prahalad says that "most charitable organizations also believe that the private sector is greedy and uncaring and that corporations cannot be trusted with the problem of poverty alleviation" (i.e., profits and poverty alleviation do not mix). Yet, he claims that aid agencies are moving toward accepting the use of the private sector for poverty alleviation.

Some features of the BOP market include:

1. There is money at the BOP. Basically, there are a lot of people (4-5 billion) at the BOP, many with a little to spend (a lot times a little still equals a lot–unlike relying on the 10% at the top of the pyramid where essentially relatively few people can spent a lot–either at the bottom or top there is a product and the result is a big number). By virtue of people having a low income, they suffer a "poverty penalty" in that they pay more than they should for products and services due to local monopolies, inadequate access, distribution problems, and strong traditional intermediaries. Essentially, they are paying too much for products and services so there is an opportunity to compete.

2. People with a low income have a different set of priorities. They may not spend disposable income on sanitation, clean water, or improved housing

(e.g., if they do not own their home or land it sits on). They may instead spend it on what are sometimes considered luxuries.

There are a number of issues connected to the accessibility of BOP markets to large firms:

1. The people-density intensification in low-income urban areas makes distribution easier.

2. Access to rural markets is more difficult since they may not have radio or television signals for marketing. However, using Prahalad's notion of a wide-spread "ecosystem" may help.

Prahalad says that people with low incomes are very brand-conscious and demand great quality at prices they can afford. He says that it is important to provide "aspirational products" at affordable prices. Moreover, BOP consumers are increasingly using information technology to get connected and learn (e.g., the cell phone). He also says that BOP consumers readily accept advanced technology (e.g., wireless devices, computer kiosks, and personal digital assistants).

*Markets must be developed via the right products.*

Prahalad says that there are a number of ways to address the imperative of developing markets:

1. *Affordability:* He says we must create the capacity to consume. Since people who have low incomes have unsteady income streams they should be offered small-sized versions, such as single-serve versions–of products since they are less-expensive in total cost (the rich may purchase a larger version since it is more convenient and lower cost per volume). But, in such an approach, quality or efficacy should not be sacrificed.

2. *Access and availability:* Distribution of products and services must take into account where people who have low incomes live, and work patterns. Most BOP consumers must work the whole day before they have the money to purchase necessities for that day. Store hours must consider this. People who have low incomes cannot easily travel long distances; stores generally should be a close walk away. When low-income people are able to purchase, they generally cannot wait or they will not be able to keep the cash for a later purchase; hence, product and service availability is important. You may need to offer credit, even to the lowest-income consumers.

Prahalad says that involvement with the BOP can lead to opportunities for the development of new products and services. He feels that when low-income people are turned into consumers, they get better access to products and services and gain the "dignity of attention and choices" from the private sector that used to be only focused on the top of the pyramid. He acknowledges, however, that large firms and BOP consumers have in the past not trusted each other; he feels that the onus is on the firms to create trust. He cites an example of where default rates on loans are lower in the BOP than in the top as a reason for firms to trust people who are in the BOP.

**Products and Services for the Bottom of the Pyramid**

Many products and services have been priced and developed for Western markets so they are often not in reach of BOP markets. Prahalad says that the "feature-function set has often been inappropriate" and hence penetration of the BOP market has been difficult. Aid agencies have tried to "replicate developed country models at the BOP with equally unsatisfactory results."

Prahalad says that the basic philosophy of product and service development is different for the BOP: "basic economics of the BOP market are based on small unit packages, low margin per unit, high volume, and high return on capital employed." He says that the "infrastructure" in place in the target country cannot be assumed to be the same as in the developed world (e.g., consistent availability of electricity as opposed to frequent "brown-outs," availability of credit, basic level of literacy, access to phones and refrigerators, availability of a reliable telecom and internet structure, and "clean electricity supply" so that power from wall sockets may need to be filtered or regulated).

Prahalad identifies what he calls his "twelve principles of innovation for BOP markets" (that may affect developed world markets also):

1. Price performance is the combination of price and performance of a product or service. High affordability combined with high performance is needed to penetrate BOP markets.

2. Satisfying BOP consumers will not occur with old technologies. "Most scalable, price-performance-enhancing solutions need advanced and emerging technologies that are creatively blended with the existing and rapidly evolving infrastructures."

3. In order to scale up beyond one locale, critical in order to access a very large existing market to make low-cost products profitable, and considering the very large size and geographical distribution of the BOP market, it is very important to design solutions so that they are easily adaptable to different countries, cultures, and languages.

4. The level of resource waste (e.g., in packaging) cannot be carried over from the developed world to the BOP or significant environmental degradation will occur. Products and services must be eco-friendly.

5. Small changes to products for the developed world will not work (e.g., considering the impact of infrastructure). Needs of BOP consumers may not be clear, either to firms or consumers. Consumers may not know what can be achieved with a new technology, and firms need to gain a clear understanding of the needs of the consumer.

6. Both process and product innovations are needed as a reliable logistics infrastructure cannot be assumed (e.g., manufacturing, access to customers, or the need to educate customers).

7. Products and services must be "deskilled" as you cannot assume the same skill levels as in the developed world.

8. It is important to educate customers on products and services, even when customers may not have radio or TV. He suggests considering traveling vans with TVs mounted on the side, or low-cost theatrical productions.

9. Products must work in harsh environments, with noise, dust, temperature variations, humidity, unsanitary conditions, abusive treatment, ability to cope with poor infrastructure (e.g., lack of availability of clean, reliable, and non-fluctuating electricity or clean water).

10. Diversity of the BOP consumer base in terms of "language, culture, skill level, and prior familiarity with the function of feature" demands significant innovation on "interfaces" between products and services and the consumer. Interfaces must be easy to learn and use as this may be the first time a consumer is interfacing to the technology.

11. Methods must be developed to access the consumer in dense urban areas and sparse rural areas.

12. Features and functions of products and services can change fast in BOP markets. BOP markets invite us to challenge conventional paradigms (e.g., electricity supply via the grid).

Prahalad feels that if a firm simply modifies its practices, products, and services for the BOP market it will fail. If, however, they modify these and their business model for the BOP, they may innovate in ways that are also useful for the top of the pyramid market (e.g., for better price performance or business model); see Section 4.10.4. BOP market focus and the demand for extreme affordability and performance forces firms to look at all elements of cost and to innovate.

Based on the above treatment, it should be clear that there is a need for a market-oriented "ecosystem" for wealth creation and social development that has at its heart a business system. Prahalad says that there is a symbiotic relationship between pieces of the private sector and social institutions that can help develop BOP markets (with differing importance of each of these depending on the developing country). Prahalad also discusses the importance of "transaction governance capacity," the importance of respecting contracts (based on trust), and the importance of making everything as transparent as possible and consistently enforced to avoid corruption.

*An ecosystem for product delivery, sales, and marketing must be developed.*

Prahalad says that his approach can transform current poverty reduction approaches from subsidies and aid to entrepreneurship and wealth, while having BOP consumers "reap the benefits of respect, choice, and self-esteem and have an opportunity to climb out of the poverty trap." Prahalad closes his original book with the statement: "Given bold and responsible leadership from the private sector and civil society organizations, I have no doubt that the elimination of poverty and deprivation is possible by 2020."

**Lessons for the Engineer**

Prahalad demonstrates a lack of understanding of the role of engineering in several places in the book (analogous to the misunderstandings of the economists Sachs and Easterly identified earlier). For instance, when he says: Dramatic cost reductions are not possible without good use of "modern science in the development of products, services, and information technology in the delivery of those services." Science is concerned with discovering new knowledge, and is not generally concerned with producing low cost products, services, and information technology; this is the central role of engineering (of course some could consider "computer science" to be a counter-example to this claim, however not all would agree as they would say that it is "software engineering" within computer science that is what he is talking about).

In his discussion on market-oriented ecosystems, one is left wondering what role "ethnic markets" play (relatively closed markets common in the developing world based on involvement of only one ethnic group as discussed by Easterly). Do they coexist comfortably with the ecosystems he is talking about? Compete? Make penetration of the market impossible?

Prahalad claims this approach is alleviating poverty but provides no evidence of that (e.g., via quantitative/statistical method showing that incomes of persons raise as the result of low-income people purchasing products or services he identifies). Also, he always discusses the "BOP" but never identifies the income levels of who is purchasing various products and services. This leads to the question of whether the "bottom billion" will benefit from this approach, when it seems that they are malnourished, hungry, often without clean water or electricity, and have no disposable income to spend since they earn around less than \$1/day. Indeed, one should consider the analysis of Banerjee and Duflo on the success of microfinance to get a "reality check" on any exaggerated claims of success of a business approach to eradicating poverty. It seems that more study needs to be done to evaluate the overall effectiveness of the approach.

While not treated here, Prahalad covers many examples of companies engaged in business at the BOP, and in particular, ones that are developing, deploying, and selling technologies. The interested reader should see the book for more details; however, the reader may also want to see the comments below by Polak and Warwick in Section 3.5.2 about the lack of success of the companies Prahalad talks about.

Next, I personally have some concerns about this "double bottom line" approach, with profits and social impact (the same ideas apply to the "triple bottom line" where the environment is included). How can people be expected to use a capitalistic approach and be guaranteed to produce good for the weak? How can people be realistically expected to reduce their achievable profits in order to have social impact? What is an acceptable level of profit in social business? A few percent? Is that really viable for everyone? How can social impact be *quantified* so that firm statements can be made about the relative amounts of profit vs. social impact? Is just a little social impact enough? Will the social impact claims unrealistic or over-stated? Often, in a company it is going to be

easy to loose control of the double bottom line in search of financial "success" for a company as defined by some key stakeholders, ones who may not share the philosophy about how large the social impact should be. Is there a way to set up some institutional structure that could regulate the double bottom line to assure that the weak are not exploited (history has shown significant exploitation of people, especially those most exploitable)? In some countries in the developed world this is possible; however, are the same approaches really possible in the developing world? Or, can the developing world regulate (with teeth) business people from the developed world trying to do social business? Or, will corruption allow just about anything in spite of laws? Should there be a cap on profits? One that is relative to social impact, something that is very difficult to quantify? In connection to this issue, in many states in the US there are "public benefit corporations" (PBCs) that do regulate the issues addressed above. Also, there is B Corps which promotes benefit corporations and regulates them also. How successful and prevelant are PBCs relative to traditional corporations? The critical question is, however, do such approaches exist in the developing world, and have the force of law behind them? I am not the only one concerned with the social business approach. A paper that critiques Prahalad's approach is (Karnani, 2006). Karnani feels that Prahalad's argument is filled with fallacies and says that the right approach to alleviating poverty is to *buy* from low-income people at the "bottom of the pyramid," not to sell to them at a profit.

Please do not misinterpret my concerns. I am not generally opposed to profits, business, social entrepreneurship, or social business. I am, however, quite concerned with how to it right from a social justice perspective: my concerns are about ones of the *process* of how social business operates in reality and I use ideas from Chapter 2 as a foundation for my concerns. It may be that social business is the only way to achieve long-term scalable success in development; hence, it certainly cannot be ignored. Regardless, a number of my concerns, and Karnani's, can perhaps be addressed using the "participatory social business" approach described in Section 4.10.3 where individuals from the local country get firmly involved.

### 3.5.2   Polak and Warwick: The Business Solution to Poverty

In this section, the perspective of Polak and Warwick from (Polak and Warwick, 2013) is covered, including some elements of Polak's earlier book (Polak, 2009). Paul Polak is co-founder and CEO of Windhorse International a for-profit social venture, founded D-Rev, a non-profit that seeks to create a design revolution in products for low-income people, and founded the non-profit International Development Enterprises. He was educated as a psychiatrist. Mal Warwick is an entrepreneur and impact investor, and was a consultant for many years for the non-profit sector on marketing and fund-raising, and for the private sector advocating socially and environmentally responsible policies and practices. Only the parts of (Polak and Warwick, 2013) that are quite relevant to humanitarian engineering are covered. Hence, the examples of people living in extreme poverty

are not covered (they are similar to what the other authors covered in this chapter describe, of course), his example of low-cost drip irrigation design is not covered, his analysis of the problems with Amy Smith's MIT D-Lab project on charcoal is not covered since he only uses it as a cautionary tale (it is discussed in Problem 4.26), the treadle-pump application is not covered nor the Spring Health case study. There is significant overlap with (Polak, 2009), but (Polak and Warwick, 2013) is more bold and visionary. Also, all quotes in this section are from (Polak and Warwick, 2013), including some subsection titles.

### The Business Approach

Polak and Warwick say that if you are in big business, you are probably finding that there is not much room for growth via your traditional markets, and may be considering emerging markets. If you are a social entrepreneur, they say you are probably finding it difficult to raise funds to support your endeavor (partly since some "impact investors" are concerned that social entrepreneurship has brought about change). They say "the field needs to get unstuck." Indeed, later they say that Prahalad's case studies from (Prahalad, 2010) that were used to illustrate his ideas, "with their focus on customers earning $5 to $10 per day, failed to do so with one exception (Aravind Eye Care System, a nonprofit organization in India)." Then, they go on to say "Still, perhaps inspired by the magical promise of "the bottom of the pyramid," many of the world's largest and most successful companies tried to enter emerging markets–with generally mixed success at best." They say that these companies typically adjusted their existing products and services (e.g., getting rid of features, using inexpensive materials, lowering quality, and "rebranding" more inexpensive) but the products failed to meet "needs, expectations, and aspirations of poor customers." Most of those companies focused on customers earning $5 to $10 per day; here, the authors' focus is on persons earning less than $2 per day.

If you are an anti-poverty professional, they say you are probably facing on-going challenges with getting funds and proving that what you are doing is having global impact. Also, they say you may be aware of market-based approaches' successes but may be reluctant to try this approach due to the history of capitalistic approaches exploiting low-income people and damaging the environment. They say that if you are involved in the area of "design for the other 90%" that you will see how to set that in a business context in the developing world.

They say that businesses should be interested in ending poverty because: (i) there is a huge waste of human talent due to people being locked in poverty; (ii) ending wide-spread poverty could lower the level of conflict in the world; (iii) poverty causes a range of environmental problems; and (iv) poverty results in over-population. Also, solely from a business perspective they give the following reasons for ending poverty:

*There are good security, environmental, and business reasons to try to end poverty.*

1. *Market opportunity:* They focus on persons making less than $2 per day, or about 2.7 billion people in the world (in spite of migration to cities

world-wide, most of them live in rural areas). More than a billion of these people live on less than $1 per day. Even at that low income, the large numbers imply significant purchasing power "at the bottom of the pyramid" (the way they define it).

2. *Crowded developed world markets:* The large multinational corporations currently make more and more from the emerging markets compared to their traditional (home) markets, and feel that these markets are going to be critical for their future.

3. *Disruptive forces:* History shows that business is volatile and influenced by frequent, sometimes "disruptive change," and that no company with global reach can overlook new market opportunities.

4. *Growing interest within big business:* They claim that some large corporations can beat competitors and move "down market" by providing products and services to the middle class in emerging nations; they feel they may be forced to take the next step and "serve" $2 per day customers also. The elite in the developing world, who "share cosmopolitan values of Europe and North America," do not comprise a large market.

5. *Access to scarce resources:* Low-income people live next to some of the greatest world resources and we need their help to gain access to those resources (e.g., fresh water).

They seek to utilize "mainstream capital markets to fund large-scale, global enterprises" to solve problems of clean water, renewable energy, affordable housing, health care, education, and jobs. They say that entrepreneurs or existing multinational corporations working along these lines must set a

> "10-year goal of building a customer base of at least 100 million, achieving revenues of $10 billion or more per year, and realizing sufficient profitability to attract both indigenous and international commercial investors while minimizing its environmental impact to the greatest extent possible."

## Zero-Based Design

They call their approach "zero-based design." They base the term on "zero-based budgeting" where rather than tweaking numbers from the previous year's budget, a completely new budget is introduced. In zero-based design you throw away all your old assumptions from your past experience and start over from a position of "assumed ignorance." You seek inputs from the customers, low-income people, about what will best meet their needs. In particular, they identify "eight keys to ending poverty:"

1. *Listening:* Do not look at low-income people as beggars or bystanders; they are your customer. Seek "purposefully listening to understand thoroughly the specific context of their lives–their needs, their wants, their fears, their aspirations."

There are eight keys
to ending poverty
via social business
approach.

2. *Transforming the market:* Try to make a new market, not compete in an existing one.

3. *Scale:* Focus on "designing for scale" with a goal of hundreds of millions of sales to low-income people. Your goal is a global enterprise, profitable and sustainable, not just the product or service.

4. *Ruthless affordability:* Create and implement highly affordable technologies (e.g., an order of magnitude cheaper than prices in the developed world) and extremely efficient business processes.

5. *Private capital:* Create a generous profit margin to attract private-sector market forces to help expand your venture, and draw on the large pool of private capital (bigger than philanthropic or government-sponsored programs).

6. *Last-mile distribution:* Create a decentralized approach that easily takes care of the last mile (and "last 500 feet") distribution of the product or service by employing local people at local wages in marketing, sales, and distribution to reach everyone.

7. *Aspirational branding:* They feel that this is very important for their bottom of the pyramid as low-income people need to be convinced to pay a premium for products that are claimed to make their lives more rewarding.

8. *Jugaad innovation:* "The Hindi term *jugaad* connotes improvisation, working with what you have, and paying unflinching attention to continuous testing and development." Basically, it is tinkering.

Polak and Warwick do not believe that "any business can thrive over the long term unless, in addition to pursuing a meaningful social mission, it sells high-quality goods and services, pays livable wages to its employees, and avoids any harmful environmental impact." They call this "stakeholder-centered management."

**Only Business Can End Poverty**

**The Customer:** Polak and Warwick start by discussing the lives of some people who live in extreme poverty, then describe five differences from what it is like to be rich and live in a rich country:

1. *Low-income people just get by:* Low-income people are just trying to survive every day, but the rich indulge in luxuries and still save for the future.

2. *Low-income people receive little news:* While the rich are inundated with information, low-income people receive information only from family, neighbors, friends, and perhaps via a radio with little influence from national or global news.

3. *Low-income people rarely travel:* Low-income people often live and die and the same place, at most visiting nearby villages/cities, and hence are not exposed to new ideas and opportunities.

4. *Low-income people have very few choices:* World-class education, healthcare, and food/clothing/transportation choices, or a good legal system, are not available. Low-income people have one in five infants die of preventable illness and are very vulnerable due to inferior healthcare, bad food, dangerous transportation, or corrupt police of village leadership.

5. *Low-income people live with misfortune never far away:* While we all live with uncertainty, for low-income people uncertainty is "more personal, and more immediate." Their income is irregular and unpredictable. Can you survive if the rains do not come? Will the "doctor" really cure an ailment? Will market prices be high enough to get a profit?

**Problems and Successes with Traditional Development Approaches:**
To solve these problems, Polak and Warwick claim:

1. *True development rarely comes from the outside:* They say that "top-down" programs rarely work due to corruption, bureaucratic inaction, distance between planners and beneficiaries, etc. They say that "true development" (meaningful community-wide lifestyle changes) "comes almost exclusively through the mechanism of the market" via buying and selling products and services.

2. *Giveaways breed dependence and self-doubt instead of change:* "We can't donate our way out of poverty."

3. *Traditional approaches are ill-suited to fight poverty:* They say that traditional approaches do not work since there is not enough money to support the good ones to the extent that they can have global impact. They discuss the controversy over whether progress has been made (e.g., as measured by the UN Millennium Development Goals) and in the end come down on the side of Easterly that not much has been achieved for the amount of money spent.

Polak and Warwick do highlight some things that government and philanthropy can do. First, they say that in public health and primary education "official efforts have undeniably borne fruit." They cite UN progress in eradicating smallpox and nearly eliminating polio, and efforts at fighting the spread of HIV/AIDS (but they do highlight remaining problems with malaria, diarrhea, and tuberculosis). Also, they point out literacy has increased significantly and primary school education is at around 90%; and conclude that UNICEF, UNCF, foreign aid providers, and many NGOS have done so well that they should continue (but do suggest raising teacher salaries). Next, they point out that it is undeniable that "the percentage of the world's people living at or below the subsistence level has declined during the more than 60 years since the

bulk of this effort began." Yet they still say that "we keep trying the same thing that is failing." For instance, they point out that much of US aid is actually for military programs, but that other European countries have a different approach. They acknowledge some successes, but say that none are providing large global impact.

Polak and Warwick say (as does Polak in his earlier book) that: "Poor people themselves tell us that the main reason they are poor is that they don't have enough money." They want to focus on that issue. They say that the large-scale rich-nation efforts use "indirect" methods including: (i) trying to enhance the economic environment to grow GDP; (ii) providing infrastructure; (iii) providing large foreign aid; and (iv) exporting developed-country goods and services. They say that these methods have little effect beyond making the ruling elite in the target country wealthy (e.g., by them giving contracts to family and friends or using the money on the police or military to protect their position of power). They also highlight large INGO (international nongovernmental organizations) efforts, like World Vision, CARE, Save the Children, and Catholic Relief Services (from the US) and Oxfam (UK), Doctors without Borders (France) and BRAC (Bangladesh). They said all these, and smaller "community-based organizations" (CBOs), in almost all cases have significant problems with fund-raising. They say, that while the amount of work by all these groups is significant, that most of it is focused on rich countries. They say that they have "undoubtedly bettered tens of millions of lives and strengthened thousands of communities world wide." Their complaint, however, is that they are operating on a small scale, not making a large global impact. They are also concerned that small NGOs (secular or faith-based) "continue to engage in simple giveaways, treating poor people as objects of pity."

With respect to microfinance, they say that while there are certainly some successes, experiences of the microfinance institutions of Grameen Bank and BRAC "has shown that loans are largely used for purposes other than business development, such as staving off starvation or paying for religious ceremonies" (they quote some evidence that as many as 90% of the loans are not used for business development, but consumption). They say that "evidence is quickly mounting that many for-profit providers, as well as some nonprofits engaged in the $70 billion microcredit industry, practice fraud, demand usurious interest rates (sometimes even greater than those of moneylenders), and in at least two celebrated cases have made huge fortunes for their investors at the expense of their clients." This has resulted in terrible results, with debt-ridden low-income people, and in a case in India "a wave of dozens of suicides brought on by aggressive debt collectors." The claims that microcredit would transform low-income people, creating new businesses and jobs, "have been overblown." They say that in some local cases, screening is done to guide money into business development, but overall this is not a large number of loans (they call for more such screening by the entire industry). But, even in cases where a loan is used to develop a business, such businesses do not grow to create jobs outside the family.

The social enterprise approach has grown over the years since the early 1980s.

They cite Ashoka, the Acumen Fund, Unitus, Gray Ghost Ventures, ResponsAbility Social Investments, Aavishkaar, Skoll Foundation, etc., and highlight the group called the Aspen Network of Development Entrepreneurs with 200 members working in more than 150 countries. But, they say that their progress has been minimal, that is, none has reached "scale."

They feel that the ideal roles for the "citizen sector" (foundations, trusts, NGOs, CBOs, etc.) is:

- Organizing to monitor and publicize government failures, errors, corruption, violence to stifle dissent.

- Policing predatory business activities by the rich and powerful to keep the market free.

- Pioneering innovative market-based service-delivery models.

- Building a civil society by making it easy to form citizen groups, monitor success of NGOs (for transparency and accountability).

As an example, they site Dr. Paul Farmer's "Partners in Health," but question his approach essentially saying that he should be studying how to solve root economic poverty causes so they would not have so much illness to treat, and apparently they think he could then charge patients to become "economically sustainable and scalable."

**Why Business is Best for Development:** The three advantages that private business has to address the poverty challenge are (quoting):

The best way to end poverty is via business.

- Profitable businesses attract substantial capital.

- Successful businesses hire lots of people.

- Successful businesses are capable of reaching scale.

They say that these are the three "foundational truths" on which their business approach to poverty alleviation is based, but that the following factors are also important:

1. Businesses can bring together needed expertise in "design, financial management, marketing, and other fields" typically not found in the public or citizen sector.

2. Businesses are generally less influenced to political pressure than governments, multilateral institutions, and many citizen-sector groups.

3. Profitable businesses stimulate economic growth in the communities where they do business.

They say that lower cost products and services than they have will help save low-income people money relative to their costs now. They use the example of having clean water and the savings due to avoiding health problems, and getting more education and its well-known positive impacts (e.g., hygiene, jobs, nutrition). They do acknowledge that ending poverty is not simple or easy citing problems of "loss of hope, caste or class barriers, alcoholism, drug addiction, adherence to self-defeating religious beliefs, the subjugation of women, the lasting effects of childhood malnutrition, and severe physical or mental limitations–not to mention usurious moneylenders and landlords or corrupt and oppressive governments."

They try to emphasize that they are not proposing a panacea. They say it will take "massive resources, inspired and carefully targeted business activity, significant improvements in governance in many nations, and a lot of time." The believe, however, that the approach they are proposing "will eventually reduce the incidence of poverty around the world in a very dramatic way." They say it will take hundreds or thousands of businesses like they propose in their book to do this. They say that this will not happen with "business as usual," but a new generation of multinational corporations "built to provide products and services expressly designed to meet the needs of the poor," each with the capacity to achieve the goals stated above.

## Zero-Based Design and the Bottom Billions

They say that the most important step is to listen, and then summarize their "don't bother trilogy" as:

1. "If you have not talked to at least 100 customers in some depth before you start, don't bother." You must understand their needs, aspirations, ideas for how to fulfill them, and then you can begin designing something for them that is likely to be attractive enough for them to part with some of their money.

2. "If your product or service won't earn or save three times the customer's investment in the first year, don't bother." Finding something that will increase their income is difficult, but the only way to reduce poverty.

3. "If you can't sell 100 million of your product or service, don't bother." This is the only way to really help end global poverty.

You must start your design with scalability in mind as it influences design factors such as price, benefits to customers, a replicable manufacturing process, and "last-mile" distribution. They say not even to go forward with design if it does not show great potential for scalability. You must design for a large profit margin, or you will not be able to "energize private-sector market forces" to help you expand. They say that such investors will look at: (i) ratio of debt to equity ("how much your enterprise has to pay back to lenders compared with the amount you received in exchange for a piece of the action"); (ii) "the number of months it will take for your business to turn cash positive" (when sales revenue is

greater than all outlays); and (iii) the measure of net profit called the amount of free cash flow ("the amount of money your business has available after paying for personnel, overhead, interest on loans, and any necessary investments in developing new products, purchasing new assets, or opening new markets).

Products and services you design must be affordable for the client (be a good value) and this demands you "pursue ruthless affordability." You have to use inexpensive materials and "identify the trade-offs to achieve affordability that are acceptable to your customers." Your business must be extremely efficient, with as low of overhead as possible. Moreover, you have to design for the last-mile distribution problem, considering use of local employees as discussed above, and also aspirational branding per the above discussion.

Polak and Warwick next discuss in a bit more detail the idea of "design for the other 90%", highlight a few places where it is happening (Stanford and MIT D-Lab), but also point out that it is not a new idea. They say that desired products cannot "work poorly, break quickly, and look cheap" as low-income people are discerning customers when they are considering parting with a portion of their money. But, to design for the other 90% you must pay significant attention to affordability: (i) figure out what the key contributors are to cost and figure out solutions to them based on acceptable customer trade-offs; (ii) reducing product weight will often reduce cost; (iii) "making redundancy redundant" means removing any "over-kill" in design that may result from, for instance, legal concerns (see concerns on this point below); (iv) do not add any superfluous features or functionality that is not a significant value to the customer ("bells and whistles"); (v) reconsider the history of the evolution of technology design for some solution, and in particular an early design that could be modified; (vi) make the design infinitely expandable so that the customer can afford a piece, then profit from it, to purchase more of it; (vii) use locally available materials; (viii) to bring economic benefit to the local economy outsource manufacturing at least initially; (ix) use the standard principle of "interchangeability of parts;" (x) realize that durability may not be as highly valued to your customer; (xi) keep your product small ("right-sized"); (xii) make the "last-mile delivery" very affordable; and (xii) test, redesign, and iterate.

### Marketing and Business

Polak and Warwick say that if you succeed at the difficult task of "designing a transformative, radically affordable technology, you will have only addressed 25 percent of the problem. The other 75% of the challenge rests with marketing." For the market:

1. *Price-point from the customer:* Design to a customer-specified price point, and then make sure they can get their money back within 5 months ("200-300% return on investment most poor customers look for").

2. *Price-effectiveness trade-offs from the customer:* Make the product functionality as specified by the customer's trade-offs to fit their price point.

3. *Proof-of-concept prototype:* Create and test.

4. *Prototype for small number of customers:* Create a prototype and let 10 customers use it, and give you feedback so you can improve it.

5. *Design and implement last-mile delivery infrastructure:* In the field, set up your last-mile local support system and test it.

6. *Aspirational branding:* Design an aspirational branding and marketing strategy that fits the local culture and environment.

7. *The media:* Use all available local media to promote the product or service.

8. *Field test:* Conduct a field test of the technology, last-mile distribution, branding, and marketing strategy.

9. *Scale up:* Scale up systematically to reach millions of customers.

10. *Impact of culture:* Keep in mind problems with going global such as cultural impact on your marketing strategy.

They highlight the need for good training programs, rolling out/scaling up a product/service in "waves," and the importance of on-going monitoring and evaluation which includes feedback from customers.

They envision a local in-country entity to "adjust to culture, economic realities, and competitive circumstances," a holding company with small central staff to "maintain a controlling position in every national business," a responsive decentralized management model, an emphasis on hiring locally in-country, and staff organized into specialized teams at each level with a single CEO in each country that "answers to the holding company." As mentioned earlier, this will be designed as a stakeholder-centered management for the following reasons: (i) employees will be easier to recruit and retain; (ii) to make more money; (iii) reducing environmental impact is profitable; (iv) customers seek companies of this sort; (v) innovation is encouraged in such companies; and (vi) some investors are seeking companies like this. They then highlight the importance of some "practical considerations" that lead to challenges: (i) the need to pay market rates for talented employees; (ii) problems with public relations if you exploit people or the environment; (iii) the importance of good community relations in-country; (iv) the legal environment may be lax and corruption or politics may make it impossible to do business; (v) corruption via bribes, kick-backs, nepotism, theft, etc. must be guarded against in your company as it can "eat up your profits;" and (vi) you will need to cope with the issue of language barriers.

At the end of the book they highlight some opportunities that basically look similar to the list of data on the major problems of development in the world (irrigation; information; crop, health, and accident insurance; food; shelter; latrines/toilets; electricity; schools; healthcare; cooking and heating methods).

**Lessons for the Engineer**

Many of the comments in Section 3.5.1 also apply here (e.g., the problem of regulating the double bottom line). Past failures of Prahalad (as claimed by Polak and Warwick), along with the fact that while Polak has lots of experience (Polak, 2009), he himself and no one else has achieved the goals he is setting for the large social enterprises, is cause for significant concern. There seem to be some proven successes, but nothing on the scale the main message of their book is talking about. Certainly, there is no RCT (see Section 3.2.4) for evaluating their success so show that the social impact is realized. Indeed, if there were so many failures for the customers making in the range of $5 to $10 per day, per Prahalad's approach, as Polak and Warwick claim, why would the less than $2 per day income range be easier (is the IDE example of the pump he provides so compelling as to convince you that this would work in many other cases)? People at that income, per Sachs's and others' description, can hardly get by, let alone buy products. Of course, it may be possible to sell the products to the aid establishment who could provision it for free or at a subsidized cost.

The idea of "zero-based design" is certainly nothing new to an engineer who understands the complete engineering design methodology. Of course, if you have done 20 designs of a related product, over the last 20 years, you are influenced by your past successes and failures. Certainly, there is a need to start-over when there is a drastic change of some sort (like a new customer base or availability of a new constituent technology, etc.), but the value of past experience should not be ignored: (i) the principles of engineering design do not change, just constraints, trade-offs, objectives, etc.; and (ii) it will certainly be highly valuable to have the same engineer (or engineering team) work on revisions of a technology after they have been deployed in the market as is standard engineering practice (of course this involves getting customer feedback). This respects the value of nonzero-based design: you simply do not always start over. Of course, that makes no sense.

In their list of eight keys to ending poverty, items 1-4 and 8 are standard engineering design ideas (see Chapter 4). Items 5-7 are business ideas. Each of these business ideas gives me reasons for concern. With such high profitability, will the workers (e.g., the ones working locally in the distribution network) be paid a fair wage? Is aspirational branding honest? Engineers are often significantly bothered by how the technologies they create are "hyped up" by the business people who market, advertise, and sell them. Sometimes, the border of honesty about a product's specification is crossed due to the profit motive. It is difficult to see how this classic problem will not also arise in the social enterprises the authors envision for the developing world; indeed, there are reasons to think that this problem might be greater there.

Also, what they are seeking are global solutions, while ignoring ones tailored to the local needs of a community, city, region, or country that could also be very useful, and more successful locally as products and services can be tailored to the local population. Indeed, likely that is the best approach to get such a global enterprise started (which they do discuss); what I am questioning

is their insistence on only focusing on making large global impact. If many make many local impacts, that adds up fast! Moreover, it fits better with the philosophy of meeting local needs by adapting to local context (and is more feasible) rather than a product or service that on average meets global needs but then of course does not meet anyone's local needs as well. Connected to this, they propose to ignore products that cannot be scaled; however, such products may have fantastic local effectiveness. Other criticisms along these lines are given by Toyama (e.g., p. 93 of (Toyama, 2015)), for example, in his "Tech Commandments," and the second commandment of "do only those things that affect millions of people," an idea he firmly rejects.

Polak and Warwick explain a number of troubling features about the failures of the social business of microfinance that they seem not to recognize are cause for significant moral concern (from a social justice perspective, per Chapter 2) about their own approach:

- *Exploitation?* How can exploitation of the type they describe in the microcredit industry be avoided in the social enterprises they describe? See the discussion in Section 3.5.1. Greed and power are very strong forces. How do you limit your profits, which in many people's views is a requirement of the microfinance industry, and survive in a free market?: that is contrary to free market principles–if the market will support it, someone will charge it, won't they? They raise the concern about the companies they envision exploiting low-income people in the section at the end of the book called "What we say to critics" and agree that it is a concern. Their answer to the concern is that the social enterprises they are going to set up with a social mission will have it in their "DNA" to do the right thing; the market will regulate their price and quality; and that to be sustainable "it must fulfill enduring needs shared by large numbers of people." These reasons and arguments are quite weak. Did the microfinance institutions that behaved badly start that way? Price points do not imply fairness, just like if someone will agree to work at some wage does not mean that it is a "fair wage" (see Chapter 2) it just might be the only thing they can do to survive. This issue is connected to them addressing, at the end of the book, the concern of others that it is "immoral to make profits off the poor," which they counter by basically saying you cannot exploit low-income people because they are smart. They might be trying to be respectful, but consumers are exploited all over the world all the time. Also, this only partially addresses the point. Clearly, you can be smart, yet still be in a situation where you are exploited because you have no other options (i.e., you are vulnerable). Businesses that exploit people and the environment can survive a very long time in a profitable manner. Polak and Warwick seem to think that exploiters will die out, but they do not say how fast and that is crucial. How long can the exploitation be tolerated?

- *Rights vs. profits:* There is indeed a very strong connection between loans given by microcredit institutions and some of the products and services

that Polak and Warwick say large social enterprises should focus on. Consider just one example that they give: clean water. First, many view water as a human right and one of the "public goods" not something that a free market was even intended for. Aside from that, as Polak and Warwick witnessed, it is hard to argue to a mother that she should not take out a loan to feed her starving children. How is a large international corporation going to withstand the pressure to give clean water to that mother who also wants to avoid having her children get ill and die (e.g., from cholera)? Can you imagine the headlines: "XYZ company would not give away a 5-cent bottle of water to such a mother!" Clearly, there is a relationship to the issue of large rich pharmaceutical companies in the developed world being asked to give away medicines for diseases that they invested millions in for their development. Ethical or not, will a large enterprise even want to venture into such perilous waters and tarnish their name at home and abroad? Of course, a small part of the equation on this changes if the business is completely home grown from the bottom of the pyramid up, with no outsiders at all (except, e.g., in an initial advisory/education role, as in "participatory social business" discussed in Section 4.10.3), but that does not really seem to be what Polak and Warwick are necessarily proposing as they never say that in the book (though elements of an idea like that are in Polak's original book (Polak, 2009) where he says he wants to teach low-income people to be better business people).

Polak and Warwick also completely ignore the possibility that their multi-national corporations will destroy local home grown competitors. There may be no concern that microfinance institutions put moneylenders out of business, but for the businesses they discuss this could be an issue. The free market is efficient, but many feel there need to be regulations on it. Of course, aid has also been shown to drive companies out of business in some cases, but everyone knows that strong global businesses generally put small local businesses out of business. Will Polak and Warwick's approach result in more concentration of wealth in the multinational corporations and simply change who the local low-income people are working for, including not working for themselves? Some would wonder if there is a way to take away the "sharp edges" off such global capitalism (what Sachs calls "enlightened capitalism" (Sachs, 2006)), and in many ways that is what Polak and Warwick are arguing they want to do (in the last section of the book in responding to their critics they show clear concern about morality, compassion for low-income people, and concern for the environment). Some would say that the solution is to generate new ideas (e.g., via the donor community funding engineering teams), then teach the locals how to start a business (see Section 4.10.3). Could many "repeats" of such a grass-roots approach have significant global impact, with fewer adverse long-term impacts?

Next, there is a *significant* problem with their view of how to design for extreme affordability in their idea to "make redundancy redundant." With their example claiming that in a developing country you can lower cost since you do not have as much of a risk to get a lawsuit, they are making a critical error and

showing a significant lack of understanding of both complex technology design and the importance of the trade-offs between safety and cost (see discussion in Section 2.3.3 on the engineering ethics perspective on this most basic issue in engineering ethics). First, "safety factors" are built into technology designs for good reasons. Engineers acknowledge that they do not know perfectly the specifications on the materials they use for design and hence sometimes must "over-design" to ensure the safety of the public (recall the statement from Section 2.3.3 that engineers "hold paramount the safety, health, and welfare of the public"). Of course, many engineers have negative views of laws, but experienced engineers accept the wisdom of safety factors, if not for financial reasons (like a lawsuit), but for ethical reasons. To even hint that we do not need to be just as concerned about the health, safety, and welfare of the "public" in the developing world as we have learned to do for the developed world is highly problematic to say the least. Certainly, there could be some products where there is not a problem with reducing some redundancy (e.g., when there is no safety issue), but likely any redundancy that exists is there for a good reason: engineers' basic task is always to make a low cost product or service (developed world or not), so if it is there, it is likely there for a good reason (e.g., reliability, if that is needed). Moreover, it is of particular concern to hear this viewpoint when the authors are saying at the same time that their social enterprises are aiming at such safety/health-critical products as water, energy, housing, or healthcare. In almost all cases for these there are significant safety and health concerns from the basic technologies.

Polak and Warwick say that "appropriate technology" (see Section 4.6.3) is *dead* since it "was led by well-intentioned tinkerers instead of hard-nosed entrepreneurs designing for the market." Some current humanitarian engineers may partly agree with this assessment for the early history, but call their current designs "appropriate technologies" that appropriately take into account costs, market, manufacturing, scale-up, and other issues. Hence, quite a number of current engineers would not consider "appropriate technology" to be dead, but to have evolved and improved. Polak and Warwick's statements about appropriate technology are clearly out-of-step with the field of humanitarian engineering, and what is happening on the ground by engineers.

Their point about the potential to save low-income people money via low-cost products and services, lower than what they have now, is good argument for getting such products to low-income people in some way. The question is, however, what is the best way to do that? Their business approach? Another social business model? The one discussed in Section 4.10.3? Or, is there another way? I am not opposed to profits; I just support doing this in a way that respects the basic principles of social justice. For example, could an NGO with an engineering team and donor dollars, provide products or services at a subsidized rate for the lowest-income people? Or, is there some other public-private partnership that could avoid some of the problems listed above but still effectively provide products and services?

Finally, others have significant concerns with the social business approach besides those discussed here and in Section 3.5.1. In particular, Toyama has

significant criticisms for social business on pp. 82-87 in (Toyama, 2015).

## 3.6 Models, Dynamics, and Analysis of Development Strategies

The effects of "poverty traps" representing that the "rich get richer and the poor get poorer" per economic growth are studied. Special attention is paid to the effects of improving the quality of technology and the rate of adoption of new technologies on economic growth in the presence of poverty traps. Also, an environmental policy control approach is introduced and, via computational analysis, it is shown how it can be used to avoid the tragedy of the commons even in the case of population growth.

### 3.6.1 Technology, Economic Growth, and Poverty Traps

In a "neoclassical" model of macro-economic growth (e.g., at the country level) the capital output per capita at some time $t$, $t \geq 0$, is defined by a "production function"

$$pf(c(t))$$

where $p$, $p \geq 0$, is the "total factor productivity" (which you can think of as the quality of available technology) and $c$ is the "capital-labor ratio" (amount of capital owned by each individual). Here, "capital" is the part of wealth that can produce more wealth. The function $f$ represents the relation between capital and the ability to make money from capital. Assume that $c(t) \geq 0$, $t \geq 0$. If $c(t) = 0$ then $pf(c(t)) = 0$, and the production function depends on the capital-labor ratio, with higher capital-labor ratios generally leading to higher production so that as $c(t)$ increases so does $pf(c(t))$. The value of the scalar $p$ simply scales the amount of production, with high values of $p$ representing high productivity (technology that produces that high productivity). Let the national savings rate be denoted by $s$ and $g$ denote the rate of population growth (both of these could be positive, zero, or negative). Let $d$ denote the rate of capital depreciation in the population. Given these, the rate of capital accumulation is

$$\frac{dc(t)}{dt} = spf(c(t)) - (g+d)c(t) \tag{3.1}$$

Assume $s > 0$, $g > 0$, and $d > 0$, the usual case. Then, the first term on the right side of Equation (3.1) is positive and contributes to increasing capital accumulation while the second term is negative and reduces capital accumulation. The capital-labor ratio stays constant (at "equilibrium") when $\frac{dc(t)}{dt} = 0$ or when $c(t) = c$ for all $t \geq 0$ such that

$$spf(c) - (g+d)c = 0 \tag{3.2}$$

If $c(0) = c = 0$, this equation holds (e.g., there will be no capital-labor ratio growth if there is no capital). This is called an "equilibrium point." Depending

on the shape of $f(c)$ as a function of $c$, the equality may hold at other values of $c$ as we will see below.

**Common View of Economic Growth**

Suppose that

$$f(c(t)) = 1 - \frac{1}{ac(t) + 1} \tag{3.3}$$

where $a$, $a > 0$, represents how fast productivity increases as a function of the capital-labor ratio $c(t)$. Notice that

$$\frac{df(c)}{dc} = \frac{a}{(ac + 1)^2}$$

so we see that at $c = 0$, the "marginal" increase in productivity is $a > 0$, and that as $c$ increases, the slope (derivative) of $f(c)$ *decreases*.

This is a common view of how increasing capital for fixed labor results in increased productivity: increasing capital always results in more productivity and hence capital accumulation. Substituting Equation (3.3) into Equation (3.2) and solving for $c$ values that produce equilibria gives, after a little algebra, that $c = 0$ is one equilibrium (as discussed above) and another is when

$$c = c^E = \frac{spa - (g + d)}{(g + d)a} \tag{3.4}$$

where $c^E$ is used to denote the equilibrium. Since $c(t) \geq 0$, the only way this equation holds is if $spa > g + d$. Notice that if all parameters are constant but $s$, and $s$ increases, then $c^E$ increases, representing that if the savings rate goes up, a higher level of capital-labor ratio is achieved. The same type of relationship holds for $p$: higher technology represented by an increased $p$ will result in higher ultimate capital-labor ratio $c^E$. Notice that $a$ quantifies the marginal increase in productivity per capital-labor ratio. If $a$ is high enough that $spa > g + d$, then $c^E$ will increase as $a$ increases, but only up to a point. Clearly, both $g$ and $d$ increasing will result in $c^E$ decreasing: increased population growth rate and capital depreciation rates will make a country have less capital.

Suppose that $s = 0.1$, $p = 30$, $a = 2$, $g = 1$, and $d = 0.1$. Figure 3.2 plots the two terms on the right side of Equation (3.1) when Equation (3.3) is used; the blue line is $spf(c)$ and the red line is $(g + d)c$ for a range of values of $c$ on the horizontal axis. The points where the two plots intersect, at $c = 0$ and $c = c^E$, are the equilibrium points. If the initial condition $0 \leq c(0) \leq c^E$, then $c(t) \to c^E$ by increasing (see the blue plot in Figure 3.3 for one example); such growth occurs with the smallest amount of initial capital. The capital-labor ratio increases for $0 \geq c(t) \leq c^E$ since the blue line in Figure 3.2 is above the red line so that $\frac{dc(t)}{dt} > 0$. On the other hand, if $c(0) \geq c^E$, then $c(t) \to c^E$ by decreasing (see the red plot in Figure 3.3 for one example). The capital-labor ratio decreases for $c(t) \geq c^E$ since the blue line in Figure 3.2 is below the red line so that $\frac{dc(t)}{dt} < 0$.

The common, optimistic, view of economic growth says that even with very low amounts of capital economic growth will occur.
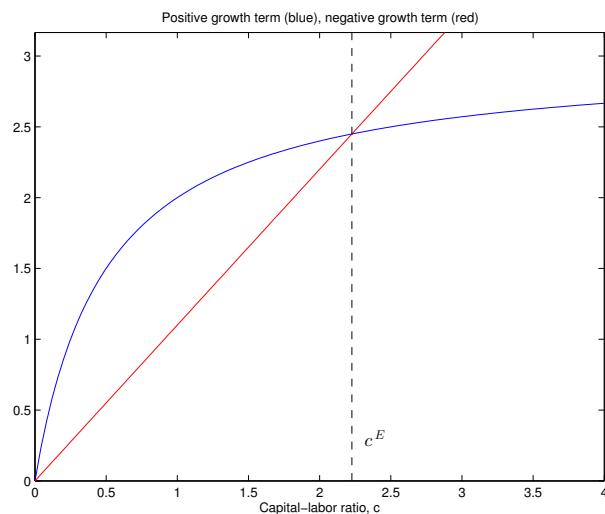
Figure 3.2: Terms in growth equation and equilibria.
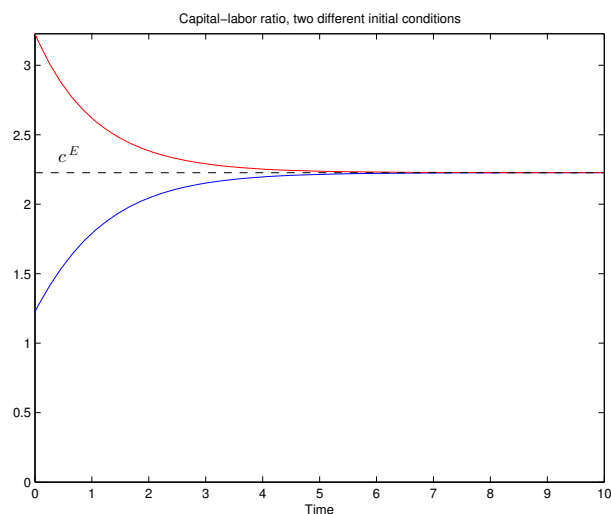


Figure 3.3: Capital-ratio dynamics for initial conditions below and above $c^E$.

The equilibria $c = 0$ and $c^E$ above are given special names. The equilibrium $c^E$ is called "stable" since if you perturb off the equilibrium a small amount, either above or below it, then $c(t)$ returns to $c^E$ as $t \to \infty$. The equilibrium $c = 0$ is called "unstable" since for arbitrarily small *feasible perturbations* (which

must be above it), $c(t)$ moves away from $c = 0$ (i.e., it increases).

### Effects of Technology Quality on Growth Dynamics Induced by Poverty Traps

The problem with the analysis in the last subsection is that the production function $pf(c(t))$ with $f(c(t))$ defined as in Equation (3.3) does not always represent what happens in reality. The assumption with Equation (3.3) is that even with *very small values of* $c(t)$, there is relatively high productivity that increases capital-labor ratio growth (i.e., the $spf(c(t))$ term in Equation (3.1) is has slope $spa$ at $c(t) = 0$ as discussed above), enough to overcome the effects of population growth and capital depreciation (i.e., the $-(g + d)c(t)$ term in Equation (3.1)).

**Poverty Traps: Low Capital, Savings, and Demographic:** In reality, when $c(t)$ is very small:

1. *Minimum Capital Stock Threshold: Low Capital Trap:* The "marginal" productivity of capital (the derivative of productivity function $f(c(t))$) tends to be very low, not like the nearly infinite marginal productivity represented by the $f(c(t))$ function in Equation (3.3). Typically, a minimum threshold of capital is needed before many production processes can be started (e.g., infrastructure). However, once the basic infrastructure and human capital are in place (i.e., $c(t)$ is big enough), then the marginal productivity can be very high. To represent this, suppose that

$$f(c(t)) = 1 - \frac{1}{ac^2(t) + 1} \qquad (3.5)$$

and note that in this case,

$$\frac{df(c)}{dc} = \frac{2ac}{(ac^2 + 1)^2}$$

so we see that at $c = 0$, the "marginal increase" in productivity (derivative) is zero. At $c(t) = 0$, $f(c(t)) = 0$, but that as $c(t)$ increases so does $f(c(t))$. The values of $s$ and $p$ affect how fast capital will accumulate. For instance, for lower savings rates $s$ it will accumulate slower, but for better productivities represented by better technologies $p$ it will accumulate faster. Notice that if you substitute Equation (3.5) into Equation (3.1) and let Equation (3.1) be equal to zero, you can solve for the equilibrium points. First, $c = 0$ is an equilibrium, and it is stable. There are either one or two other equilibria depending on parameter values. Suppose parameters are set so that there are two equilibria values; these are found by solving the quadratic equation in $c$

$$-(g + d)ac^2 + spac - (g + d) = 0 \qquad (3.6)$$

> The poverty trap perspective on economic growth says that if capital is very low, economic growth will not occur.

(which is Equation (3.1) set to zero) for two roots. Suppose that the lower magnitude root of this equation is called $c^T$ and the higher magnitude one, $c^E$. If $c(0) = c^T$ or $c(0) = c^E$, then $c(t) = c(0)$, $t \geq 0$, stays constant at those values (they are equilibria). Now, if the $spf(c(t))$ term for $0 < c(t) < c^T$ is below the $(g+d)c(t)$ term, then the amount of capital will decrease for all values of $c(0)$ in this range as the right side of Equation (3.1) is negative in that case (stuck in the low capital trap). However, for $c^T < c(t) < c^E$, the $spf(c(t))$ term may be above the $(g + d)c(t)$ term making the right side of Equation (3.1) positive so that capital accumulates (out of the low capital trap). Hence, perturbing $c(0)$ slightly above or below $c^T$ results in $c(t)$ moving away from $c^T$; $c(0) = c^T$ is an unstable equilibrium. Typically, though for further increases in $c(t) > c^E$ the $spf(c(t))$ term will be below the $(g + d)c(t)$ term so that the right side of Equation (3.1) becomes negative and capital decreases back to $c^E$ where it will stay constant (i.e., $c^E$ is a stable equilibrium).

2. *No Savings Below a Threshold Capital: Low Savings Trap:* The saving rate can be low (or negative) if $c(t)$ is very low as very low-income people must use all their income to survive; however, once basic needs are met, households can save increasing amounts as capital increases. Suppose that in the $spf(c(t))$ term in Equation (3.1) we replace "$s$" by $s(c(t))$. Then, for most choices of $f(c(t)))$ if we pick $s(c(t))$ to have the same form as in Equation (3.5) we get the desired effect: low savings when capital is low, but higher savings as capital increases. Now, if the $s(c(t))pf(c(t))$ term, for low $c(t)$, is below the $(g+d)c(t)$ term, then the amount of capital will decrease for all values of $c(t)$ less than that cross-point (the low savings trap). For values of $c(t)$ above that cross-point, capital will increase up to a point. We get the same type of dynamics as for the low capital trap.

3. *Population Growth Rate Higher for Low Capital: Demographic Trap:* It is well known that fertility rates are highest in the lowest-income countries (see (Banerjee and Duflo, 2012) for an economic analysis of why this is the case). In this case, $g$ is a function of capital, $g(c(t))$, and at low $c(t)$ values, it takes on larger values than at higher $c(t)$ values. This means that the term $(g(c(t)) + d)c(t)$ will no longer be a line, but will have a "bump" upward, for low $c(t)$ values (and possibly settle to a line). Now, if that bump pushes up above the $spf(c(t))$ term for low $c(t)$ but below it for larger $c(t)$, and possibly back above it for even larger $c(t)$ there will be a "demographic trap" with dynamics analogous to those for the low capital and low savings traps above.

The savings and demographic traps, and one other capital trap, are studied in homework problems below (see Problem 3.26 and Problem 3.27). Here, we primarily study the low capital trap.

**Technology Quality, Poverty Traps, Provisioning, and Growth:** Suppose that $s = 0.1$, $g = 1$, and $d = 0.1$. Figure 3.4 shows the positive terms

(blue) and negative terms (red) on the right side of Equation (3.1) when Equation (3.5) is used with $a = 0.75$, and for values of $p = 30$ (low technology) and $p = 40$ (high technology). In the plot, the values of $c^T$ and $c^E$ are solutions of the quadratic equation in Equation (3.6). Note that the effect of increasing the quality of the technology is to lower $c^T$ (make a smaller poverty trap) and increase $c^E$ (increase higher ultimate capital-labor ratio).

Available technology affects economic growth.
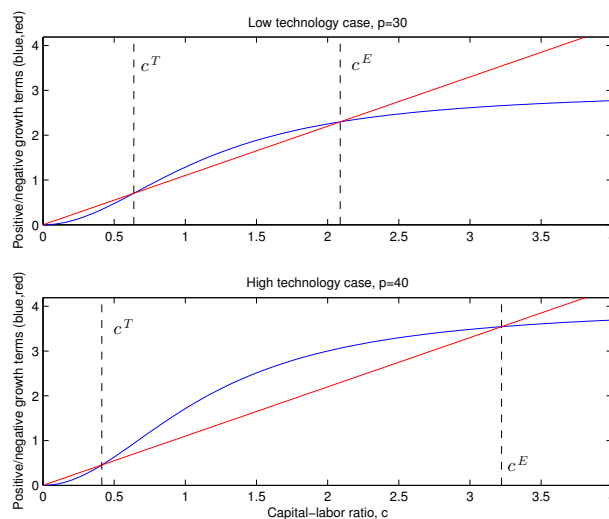


Figure 3.4: Terms in growth equation and equilibria for low and high technology cases.

Figure 3.5 shows the dynamics of the capital-labor ratio for three initial conditions (just above and below $c^T$ and just above $c^E$) and low and high technologies ($p = 30$ and $p = 40$ cases). Notice that if the initial condition $c(0) < c^T$, the capital-labor ratio decreases, but if $c^T < c(0) \leq c^E$, the capital-labor ratio increases to $c^E$. If $c(0) \geq c^E$, then the capital-labor ratio decreases to $c^E$. Note, however, that the poverty trap is smaller and more significant growth occurs in the high technology case.

The basic idea of Sachs in (Sachs, 2006) is that to "break the poverty trap" you have to provision (e.g., via healthcare, education, infrastructure, etc.) to give each person $c(0) > c^T$ (if they do not already have it) so that they can climb up "one rung of the ladder" so that they can then reach $c^E$ on their own. Clearly, high technology would reduce the amount of capital needed to achieve this, and make the achievable level of capital accumulation $c^E$ higher (allow them to climb to a higher point).
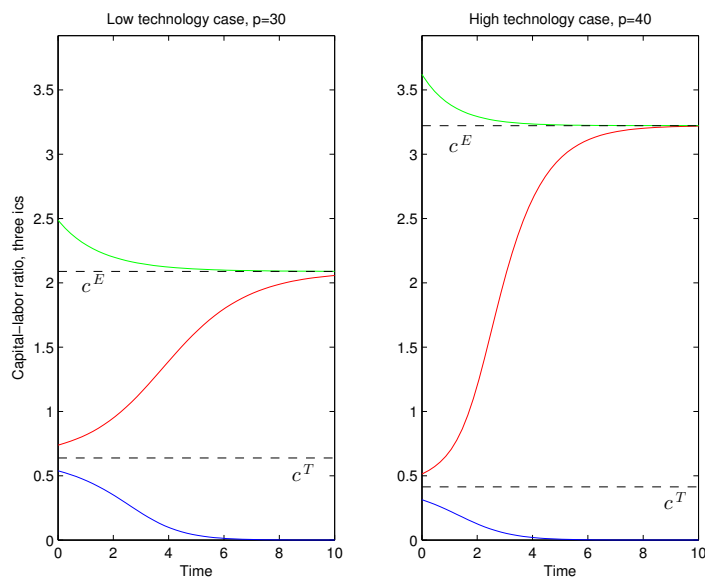
Figure 3.5: Capital-labor ratio dynamics for three initial conditions and low and high technology cases.

### 3.6.2 Sensitivity Analysis for Models of Economic Growth

Sensitivity analysis studies how a change to an input or parameter of a system affects the change in some output, where "input, parameter, and output" are broadly defined. There are many applications of sensitivity analysis, a number of which will be considered in this book. In this section, we will consider its application to study models of economic growth, and in particular we will focus on how sensitivity analysis can be used for these to determine how to allocate investments to promote economic growth. There are a number of strategies to perform sensitivity analysis and here we will consider two: mathematical and computational.

**Mathematical and Computational Approaches to Sensitivity Analysis**

There are a wide number of uses for sensitivity analysis in analytical and computational studies. Suppose that a "model" includes either an analytical model (e.g., one of the above ordinary differential equations), computational model (a computer simulation of some system, e.g., the computational studies of the last two chapters), or data from a system (in this case, the perturbations can only be to valid available data for which both perturbations have corresponding output data). The uses of sensitivity analysis includes: (i) determining how one model parameter will affect another model parameter (e.g., the above example

where we study how $p$ affects $c^T$ or $c^E$, as studied below); (ii) determining how an input (e.g., income) will affect an output (e.g., spending or wealth) as we did in the Monte Carlo simulations in the previous chapters; (iii) determining whether or not, or how strongly, some input will affect some output; and (iv) determining if there is a nonlinear relationship between some input or parameter and some output.

For the mathematical approach to sensitivity analysis, consider the case where the input or parameter is a scalar $x_i$ (a real number) and the output is also a real scalar $y(x_i)$ for some $i$. The change in $x_i$ is with respect to some value (which some call the starting value) $x_0$. Sometimes, an analytical ("local") approach can be taken where you find, if it exists,

$$\left. \frac{\partial y(x_i)}{\partial x_i} \right|_{x_0}$$

so you find the partial derivative with respect to $x_i$, then evaluate the partial at $x_0$ which is sometimes denoted by

$$\frac{\partial y(x_0)}{\partial x_i}$$

where it is understood that the derivative is taken *first*, then the value of $x_0$ is substituted in the resulting partial and this is denoted by $y(x_0)$. As an example, in Equation (3.4), notice that $c^E$ is a function of $p$ and denote this by $c^E(p)$ and you can find

$$\left. \frac{\partial c^E(p)}{\partial p} \right|_{p_0}$$

This "sensitivity function" will give you a formula for how $c^E$ changes (e.g., positive or negative) as a function of when $p$ makes infinitesimally small changes, or "perturbations" from $p_0$. If you want to know the sensitivity of $c^E$ at $p = p_0$ you simply substitute $p = p_0$ in the formula that results from finding the partial derivative. As shown below, such an approach can also be used for studying how $c^T$ changes as parameters change via solving Equation (3.6) for $c^T$. Sometimes symbolic math solvers can be useful in finding the partial derivative.

Sometimes, for more complex cases, or if an analytical (formula) is not known that relates $x_i$ to $y_i$ (e.g., if only a computer program relates these two), it becomes impossible to analytically determine the partial derivative. In this case, the normal approach is to use a computational approach of some sort. In a direct approach you may simply put in different $x_i$ values near (e.g., above and below) $x_0$ and compute the resulting $y(x_i)$ values and then simply test if they increased or decreased. One approach like this is to approximate the partial derivative with a "central difference formula"

$$\left. \frac{\partial y}{\partial x_i} \right|_{x_0} \approx \frac{y(x_0 + \frac{1}{2}h) - y(x_0 - \frac{1}{2}h)}{h}$$

for some small $h > 0$. Here, $(x_0 + \frac{1}{2}h)$ and $(x_0 - \frac{1}{2}h)$ are "perturbations" around the $x_0$ point and $h$ is the size of the total perturbation. In many applications, it

The change in an output due to a change in the input is the sensitivity of the output to the input.

is relatively easy to compute the central difference (a scalar) and plot it versus a range of values of the scalar $x_0$ in order to find the sensitivity as a function of the input parameter.

There are a number of approaches to computational sensitivity analysis that are used in this book:

- *Monte Carlo simulations for stochastic sensitivity analysis:* Monte Carlo simulations are used in a number of parts of this book to gain insight into the effects of parameters on performance measures or other variables. In several cases, the means and standard deviations are plotted as a function of a parameter and these plots provide a way to do *stochastic* sensitivity analysis. For instance, to consider the effects of the generosity parameter $G$ on performance measures for the wealth distribution policy Monte Carlo simulations were used to generate Figure 2.8 . Here, you can, by inspection, see the effects of increasing $G$ on the means and standard deviations in each column of plots. The slopes of these plots provide the sensitivities.

- *Project/technology evaluation:* Quantitative evaluation and comparison of projects and technologies are discussed in Section 4.5.2 and Section 4.6.5, respectively. There, both mathematical and computational approaches are considered. For the computational approach, a spreadsheet or Matlab program is used to compute and compare project/technology feature assessments and qualities. Also, these are used to automate sensitivity analysis for studying how changes in importance parameters and assessments can affect the project/technology quality assessments and the ranking of such qualities.

The next section provides an analytical and computational approach to sensitivity analysis for how to reduce the size of poverty traps.

### Example: Development Investment Allocation Decisions Via Sensitivity Analysis

Assuming appropriate values of the parameters, the two roots of Equation (3.6) specify $c^T$ and $c^E$ such that $0 < c^T < c^E$ (without appropriate parameter values, these two roots may not exist). From the earlier analysis, we want $c^T$ small as it measures the size of the poverty trap, and we want $c^E$ large as it measures the value of the achievable wealth. Using the quadratic equation for Equation (3.6), the roots are

$$c^T = \frac{sp}{2(g+d)} - \sqrt{\frac{s^2p^2}{4(g+d)^2} - \frac{1}{a}} \tag{3.7}$$

and

$$c^E = \frac{sp}{2(g+d)} + \sqrt{\frac{s^2p^2}{4(g+d)^2} - \frac{1}{a}} \tag{3.8}$$

Analytical or computational sensitivity analysis can be used to determine how to allocate development investments.

The values of $c^T$ and $c^E$ are plotted for $p \in [28, 45]$ (when $g = 1$, $d = 0.1$, $a = 0.75$, and $s = 0.1$) and $g \in [0.3, 1.1]$ (when $p = 30$, $d = 0.1$, $a = 0.75$, and $s = 0.1$) in Figure 3.6. This confirms the above analysis, showing that as $p$ increases (top plot) the poverty trap shrinks and the ultimate wealth goes up, and that as $g$ *decreases* the poverty trap shrinks and the ultimate capital goes up.
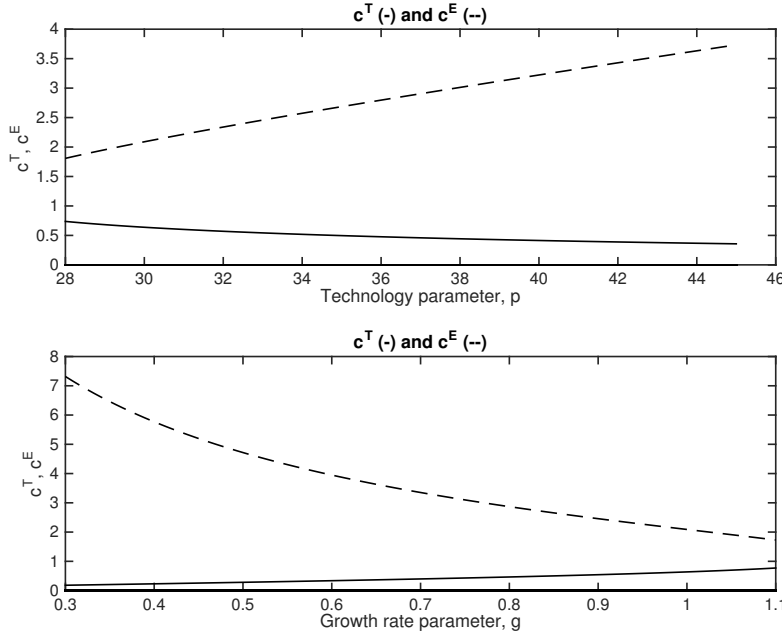


Figure 3.6: Values of $c^T$ and $c^E$ when $p$ (top plot) and $g$ (bottom plot) are changed.

For analytical sensitivity analysis, for the parameter $p$ that is proportional to the quality of the technology,

$$\frac{\partial c^T}{\partial p} = \frac{s}{2(g+d)} - \frac{s^2 p}{4(g+d)^2 \sqrt{\frac{s^2 p^2}{4(g+d)^2} - \frac{1}{a}}}$$

and

$$\frac{\partial c^E}{\partial p} = \frac{s}{2(g+d)} + \frac{s^2 p}{4(g+d)^2 \sqrt{\frac{s^2 p^2}{4(g+d)^2} - \frac{1}{a}}}$$

For the growth rate parameter $g$,

$$\frac{\partial c^T}{\partial g} = -\frac{ps}{2(g+d)^2} + \frac{s^2 p^2}{4(g+d)^3 \sqrt{\frac{s^2 p^2}{4(g+d)^2} - \frac{1}{a}}}$$

and

$$\frac{\partial c^E}{\partial g} = -\frac{ps}{2(g+d)^2} - \frac{s^2 p^2}{4(g+d)^3 \sqrt{\frac{s^2 p^2}{4(g+d)^2} - \frac{1}{a}}}$$

Of course, as pointed out above, the parameters on the right-hand-sides of these four equations have to be set appropriately so that the left-hand-sides are appropriately defined.

Consider the $c^T$ case; the $c^E$ case is similar. For small but finite perturbations off the "nominal" parameters (e.g., $p$ value for the existing technology denoted by $p_0$, and the existing $g$ value, denoted by $g_0$)

$$\left.\frac{\partial c^T}{\partial p}\right|_{p=p_0} = \frac{\Delta c_p^T}{\Delta p}$$

where $\Delta c_p^T$ is the change from the existing poverty trap threshold value and $\Delta p$ is the change from the existing $p$ value (i.e., $\Delta p = p - p_0$). Suppose we consider improvements to technology, that is, $p \geq p_0 = 30$. Similarly,

$$\left.\frac{\partial c^T}{\partial g}\right|_{g=g_0} = \frac{\Delta c_g^T}{\Delta g}$$

where $\Delta c_g^T$ is the change from the existing poverty trap threshold and $\Delta g$ is the change from the existing $g$ value, $g_0 = 1$ (i.e., $\Delta g = g - g_0$). Suppose we consider reductions in the growth rate, that is, $0 \leq g \leq g_0 = 1$. Rearranging, for the $p$ case, and assuming evaluations of partials at the nominal so we can drop that part of the notation,

$$\Delta p = \frac{\Delta c_p^T}{\frac{\partial c^T}{\partial p}}$$

All the variables are greater than or equal to zero. The cost of the $\Delta c_p^T$ change due to enhancing technology is $c_p \Delta p$ where $c_p$ is the per unit cost of improving technology, $\Delta p \geq 0$, and the total cost is

$$c_p \Delta p = \frac{c_p \Delta c_p^T}{\frac{\partial c^T}{\partial p}}$$

Under the above assumptions, this quantity is greater than or equal to zero. The total cost, $c_p^{tot}$, to obtain $\Delta c_p^T$ improvement in the poverty trap threshold, in terms of the cost per unit change in technology quality $c_p^{tot}$, is

$$c_p^{tot} = \frac{c_p \Delta c_p^T}{\frac{\partial c^T}{\partial p}} \tag{3.9}$$

Similarly, the total cost $c_g^{tot}$ to obtain $\Delta c_g^T \geq 0$ improvement in the poverty trap threshold, for $\Delta g \leq 0$ is

$$c_g^{tot} = -\frac{c_g \Delta c_g^T}{\frac{\partial c^T}{\partial g}} \tag{3.10}$$

where $c_g$ is the per unit cost of reducing growth, and given the negative sign in front and the negative denominator, the left-hand-side is positive. Suppose you want to achieve some desired change in the poverty trap threshold, $\Delta c_d^T$, and that you would like to know how much it costs to get this same change for either case, that is you want to know the costs of achieving

$$\Delta c_d^T = \Delta c_p^T = \Delta c_g^T$$

by investing in *either* technology improvement or growth reduction, but not both. To determine which of the two approaches, invest in improving technology or invest in reducing growth, is the best, you compare the values of both Equation (3.9) and Equation (3.10), with substitutions for all parameter values. The lower cost investment is

$$\arg\min\{c_p^{tot}, c_g^{tot}\}$$

where the arg returns with "$p$" or "$g$" indicating which to invest in. Problem 3.28 studies sensitivity analysis further for development investment allocations.

The above approach is based on a (local) slope at the nominal values, and hence is approximate for finite variations off the nominal values. Typically, if variations are small, the approximations will be valid. The above approach also uses only single-parameter variations in the sensitivity analysis even though simultaneous variations of both $p$ and $g$ affect the poverty trap threshold $c^T$ as seen in Equation (3.7). The above allocation approach is binary: invest all money in technology improvement or growth reduction. While a multivariate sensitivity analysis is possible (e.g., using the Jacobian), to address the approximation and multivariate issues, here, in the next section, we study an optimization approach to the analysis of economic models.

### 3.6.3   Optimization for Models of Economic Growth

Sensitivity analysis is a "local" method in the sense that it holds for small perturbations off the nominal, that is, there the derivative is computed. Here, the optimization methods to not have this basic limitation. Moreover, optimization methods provide a rich approach to analysis for a wide array of problems; here, we will only study a few ways that optimization can be useful in development studies.

**Optimization and Monte Carlo Simulation**

When Monte Carlo simulations are performed, if there are metrics computed (e.g., means and standard deviations), you may be able to see by inspection what parameter values give the minimum or maximum (as desired) of the metric and these values can be interpreted differently for various applications. For instance, suppose that for the Monte Carlo simulation results in Figure 2.21 that you want to know the value of $I$ (inequality) that results in the person 1 spending the least on themselves. This can be read directly off Figure 2.21, top upper-left

plot. Sometimes, it is best to aggregate measures into another measure. For instance, suppose you want to find the value of $I$ that results in maximizing the sum of the spending of the three individuals (left-hand column plots). To do this, it would be convenient to compute the sum and plot it. This will allow you to find the maximizing value of $I$ directly. Similar remarks hold for the right-hand side column of plots in Figure 2.21. You would have to be careful in the case of the center-column of plots in Figure 2.21 as all donations are received so some ways of summing the variables will end up with zero values, independent of $I$.

As another example, consider Figure 4.21. In all cases but one (resources case, right-hand side, middle plot), the measures (plotted values) increase as $p$ increases. In the resource case, more resources are needed with increasing values of $p$ so its value degrades. Hence, optimizing the measures is in conflict, which is often the case. The usual approach to this to create a measure that aggregates all the measures into one and use it to judge what $p$ value is best. In the case of Figure 4.21, this is the approach used with the sustainable community development index $SCDI$ in the bottom-right plot, where is is clear that to maximize $SCDI$, you want to maximize $p$.

### Example: Optimization for Continuous Development Investment Allocations

For Equation (3.7), denote $c^T$ by $c^T(p, g)$ to emphasize that it is a function of $p$ and $g$. The formulation in the last section in terms of costs will be used here also. The poverty trap threshold $c^T(p, g)$ is plotted for $p \in [28, 45]$ and $g \in [0.3, 1.1]$, when $d = 0.1$, $a = 0.75$, and $s = 0.1$, in Figure 3.7. The black vertical line with red circles at the ends in the top plot is the point $p = p_0 = 30$ and $g = g_0 = 1$ in the horizontal plane, extended upwards just for clarity; it corresponds to the red dot in the upper-left-hand corner of the bottom plot. The white line in the bottom plot is a contour, a curve of constant $c^T$ value, in this case corresponding to $c^T = c_d^T = 0.3$, the desired poverty trap threshold; hence, any $(p, g)$ pairs that lie on this white line give $c^T = 0.3$. In the top plot, notice that if you increase $p$ above $p_0 = 30$, the value of $c^T$ decreases (color goes from yellow to green) showing that higher technology leads to a lower poverty trap threshold (the opposite holds for decreases in $p$ below $p_0 = 30$ as seen in the yellow part of the plots). Similarly, if you decrease $g$ below $g_0 = 1$, the value of $c^T$ decreases showing that lower growth leads to a higher poverty trap threshold (the opposite holds for increases in $g$ above $g_0 = 1$ as seen in the yellow part of the plots).

In the bottom plot of Figure 3.7, notice that the labeled contour lines are curves of constant $c^T$, so generally if you were to move the red dot down and to the right, $c^T$ will decrease and the color goes from yellow to darker green. Anywhere you move the red dot so that it lies on the white line corresponds to a value of $c^T = c_d^T = 0.3$, with each point on the white line corresponding to a different (continuous) allocation of funds for investment in technology improvement or growth reduction. For instance, if you place the red dot on the
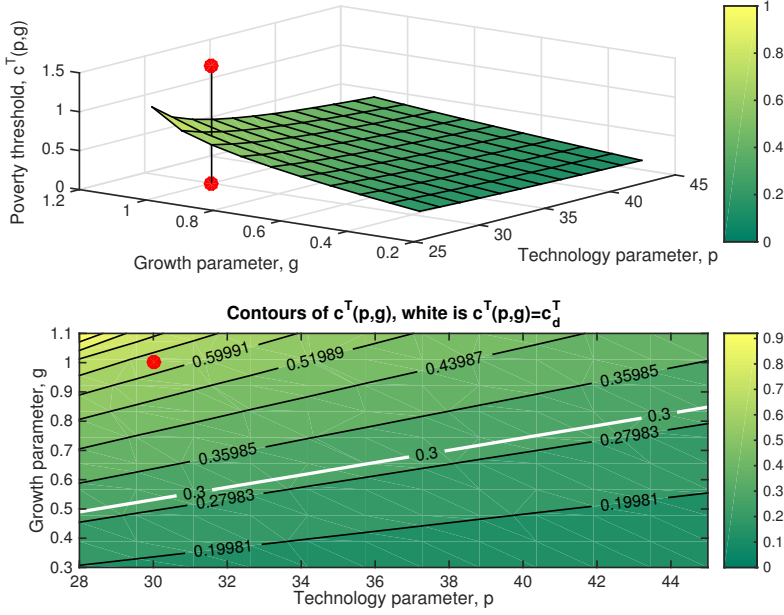
Figure 3.7: The poverty trap threshold $c^T(p,g)$ (top) and its contour plot (bottom).

white line at $(p, g)$, then the investment amounts for technology improvement and growth reduction are

$$c_p(p - p_0)$$

and

$$c_g(g_0 - g)$$

and the total amount invested is

$$c^{tot}(p,g)\big|_{(p,g)} = c_p(p - p_0) + c_g(g_0 - g)$$

where $p_0 = 30$ and $g_0 = 1$ here. Next, we will consider two optimization problem formulations, the solution of which each provides a solution to the continuous investment allocation problem.

**Minimize Poverty Trap Threshold for a Fixed Development Investment:** In this problem we will seek an investment allocation that will minimize the size of the poverty trap threshold for a given fixed investment amount that is available. In particular, when $c^T$ is defined via Equation (3.7), and $c^{tot}$ is a

Development investment decisions can be formulated as optimization problems.

fixed numeric value, we seek a solution to the optimization problem

$$\min c^T(p, g)$$

*such that*

$$c^{tot} = c_p(p - p_0) + c_g(g_0 - g)$$
$$p \geq p_0$$
$$0 \leq g \leq g_0$$

An optimal solution for this problem is denoted by $(p^*, g^*)$, and usually all that can be guaranteed is that it is a local minimum. To solve this optimization problem, you vary $p$ and $g$ to minimize $c^T(p, g)$ *constrained* by the list of "constraints" beneath "such that" (i.e., any valid solution to the optimization problem, $(p^*, g^*)$, must satisfy all these constraints). Here the constraints are a linear equality and some linear inequalities. These constraints must be met since it does not make sense to lower the technology quality or increase the growth rate, and the $c^{tot}$ constraint represents that a fixed investment is to be made, no more or no less (of course, a linear inequality constraint, rather than the linear equality constraint, may be used to represent that spending less than a fixed cap is allowed).

Since this is only a two-dimensional optimization problem, it can be solved graphically. In Figure 3.8, a contour plot of $c^T(p, g)$ is shown, and the white line shows $(p, g)$ values that meet all the constraints. A solution to the optimization problem must lie on the white line and minimize $c^T(p, g)$; this is given by labeled black contour line with the lowest label value (is in the darkest possible green region) that intersects with the white line. No line perfectly does this on the plot, but it is clear that the solution is $p^* = 45$ and $g^*$ is about 0.65 (by simple inspection). These values can be substituted in the cost equations above to determine the specific investment amounts for technology improvement and growth reduction.

**Minimize Development Investment to Achieve Desired Poverty Trap Threshold:** In this problem we will seek an investment allocation that will minimize the total amount of investment to achieve a specific poverty trap threshold. In particular, when $c_d^T$ is a fixed numeric value, we seek a solution to the optimization problem

$$\min c^{tot}(p, g) = c_p(p - p_0) + c_g(g_0 - g)$$

*such that*

$$c_d^T = c^T(p, g)$$
$$p \geq p_0$$
$$0 \leq g \leq g_0$$

(3.11)

In this problem, the first-listed constraint is nonlinear in $p$ and $g$. This problem can also be solved graphically. In Figure 3.9 (labeled similar to Figure 3.8), a
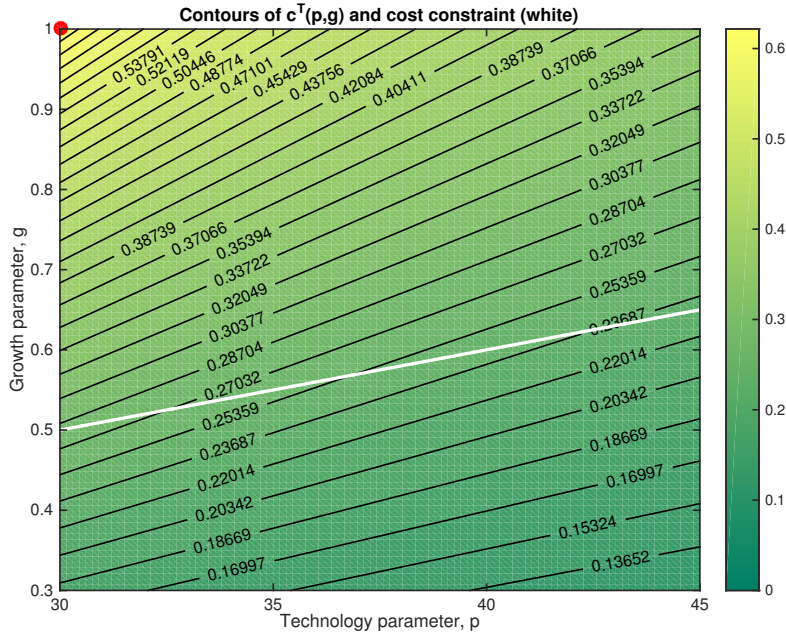
Figure 3.8: Contour plot of the poverty trap threshold $c^T(p, g)$, white curve is constraint, red dot is $(p, g) = (p_0, g_0) = (30, 1)$.

contour plot of $c^{tot}(p, g)$ is shown, and the white line shows $(p, g)$ values that satisfy all the constraints. Note that in this case the total cost $c^{tot}(p, g)$ increases as you go from the top-left corner (where the red dot is) to the bottom-right corner that corresponds to a high $p$ value and low $g$ value. A solution to the optimization problem must lie on the white line and minimize $c^{tot}(p, g)$; this is given by labeled black contour line with the lowest label value (here, 0.30161) that intersects with the white line. The solution is $p^* = 45$ and $g^*$ is about 0.85 (by simple inspection). These values can be substituted in the cost equations above to determine the specific investment amounts for technology improvement and growth reduction. Notice that the optimal investment amounts are different here, compared to above.

## Optimization Algorithms for Investment Decisions

In practical optimization problems, the number of optimization variables can be greater than two so that a graphical solution is typically not possible. In some cases, with a high number of optimization variable dimensions, such as when the function to be minimized is *convex*, it is possible to develop an analytical solution, that is, one that has a specific known mathematical formula that specifies the optimal values. However, in many important problems the
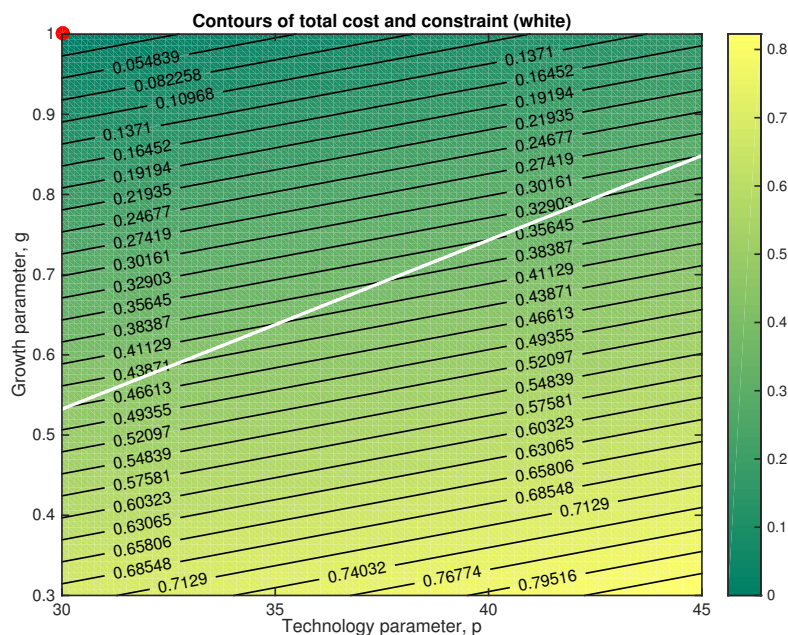
Figure 3.9: Contour plot cost, white curve is constraint, red dot is $(p, g) = (30, 1)$.

form of the optimization problem is such that the function to be minimized is nonlinear, non-convex, and dependent on a high number of optimization variables. Moreover, the constraints can be nonlinear and either in the form of equalities or inequalities. A common approach to solve such problems is to use "optimization algorithms" that iteratively guess at and improve solutions. For instance, they may take the red dot in Figure 3.9 as an initial guess, and move the red dot down the gradient of the optimization function until it hits the white line. Sometimes, this point it hits, or perhaps when it "slides" along the white line, will end up being a *local* optimum point for the function to be minimized. For the problems in Section 3.6.3 and also in Equation (3.11), a typical numerical approach would be to use Matlab's Optimization Toolbox, and in particular the function `fmincon` that can cope with minimizing nonlinear functions subject to nonlinear equality and inequality constraints (note, however, that there are many free computer packages that perform function optimization available on the internet). Underlying some such methods for constrained nonlinear optimization are "Lagrange multiplier algorithms" (e.g., sequential quadratic programming) and a good source for such methods, and optimization theory in general, is (Bertsekas, 1999).

Finally, note that the sequence of "estimates" (or values) of the optimization

Optimization theory and algorithms provide solutions to general problems in analysis of economic models.

variables specified by an optimization algorithm can have a natural interpretation in terms of development investments. If the nominal values of $p$ and $g$ represent values at the initial point, then the sequence of iterates could be a sequence of investments over time (e.g., months or years) to provide for development. Of course, another approach to specify the sequence would be to simply draw a line between the nominal values and the optimal values (i.e., $(p_0, g_0)$ and $(p^*, g^*)$) and points along that line could be the investment amounts at each time. Of course, with such approaches it may be natural to improve the underlying economic model over time and recompute the optimal point and path to it; this is a type of feedback strategy related to "model predictive control" (Garcia et al., 1989; Camacho and Alba, 2007; Rawlings and Mayne, 2009) that will be discussed some in Chapter 4.

## 3.6.4  Effects of Technology Diffusion on Poverty Dynamics

Technology and ideas ("innovations") may *diffuse* in a society and around the world after their introduction and this can positively affect economic growth. Diffusion depends on how information on the innovation is communicated (e.g., word of mouth, the press, other advertisements) and various factors (e.g., how wide-spread the innovation is) affect whether the innovation is sustained. The "rate of adoption" of the new innovation is driven by the percentages of "innovators" (ones who quickly adopt the new innovation), "early adopters" (ones who relatively quickly adopt the innovation), "early majority" (a large percentage of people who are relatively early to adopt), "late majority" (a relatively large percentage of people who are slower to adopt the innovation), and "laggards" (ones very slow to adopt an innovation) (Rogers, 2003). Rogers says that there are five factors that influence an individual's decision to adopt or reject an innovation: (i) how improved the innovation is over the last generation; (ii) compatibility with assimilating into an individual's life; (iii) how simple/complex it is to adopt the new innovation; (iv) how easy it is to perform a trial use of the new innovation (to convince the adopter); and (v) how visible the innovation is to others (more visibility will encourage peers to adopt).

### Dynamical Models of Diffusion of Innovations

Let $N(t)$ denote the total number of adopters of an innovation by time $t \geq 0$. A classical model of diffusion of innovation is (Rogers, 2003; Kijek and Kijek, 2010)

$$\frac{dN(t)}{dt} = \left( \alpha + \frac{\beta}{K} N(t) \right) (K - N(t)) \qquad (3.12)$$

Here, $K > 0$, $\alpha \geq 0$, and $\beta \geq 0$. There are different types of models of diffusion which are pieces of this basic model or a composition of the pieces to get the whole model:

*Diffusion of technology can be modeled and incorporated into models of economic growth.*

1. *Externally-driven model of diffusion:* In this case, $\beta = 0$ and Equation (3.12) becomes

$$\frac{dN(t)}{dt} = \alpha(K - N(t)) = -\alpha N(t) + \alpha K$$

In this case, $\alpha K$ is the external driver of diffusion, and the term $-\alpha N(t)$ reduces diffusion as the number of adopters increases (once someone has adopted the technology they are out of the pool of potential adopters). It is assumed that the initial number of adopters is $N(0) = 0$. As $t \to \infty$, $N(t) \to K$, the total ultimate number of adopters. The shape of the $N(t)$ curve is such that there is an immediate rise in $N(t)$ and the slope of $N(t)$ diminishes until $\frac{dN(t)}{dt} = 0$ as $t \to \infty$ and $N(t) \to K$.

2. *Internal-influence model of diffusion:* In this case, $\alpha = 0$ and Equation (3.12) becomes

$$\frac{dN(t)}{dt} = \frac{\beta}{K}N(t)(K - N(t)) = \beta N(t) - \frac{\beta}{K}N^2(t)$$

In this case, the $\beta N(t)$ term causes more adoptions for an increasing number of adoptions (a positive feedback) but as $N(t)$ increases, the number of adoptions is regulated by the $-\frac{\beta}{K}N^2(t)$ term as the $N^2(t)$ term grows faster than the $N(t)$ term. The $N^2(t)$ term represents the reduced number of adopters that are available after many have adopted the product. As above, it is assumed that the initial number of adopters is $N(0) = 0$ ad as $t \to \infty$ $N(t) \to K$ the total ultimate number of adopters, just like the above case. The shape of the $N(t)$ trajectory is an $S$-shaped function, where at $N(0) = 0$ the slope is zero, the slope slowly increases to a maximum level, then decreases until $\frac{dN(t)}{dt} = 0$ as $t \to \infty$ and $N(t) \to K$.

3. *Mixed-influence model of diffusion:* In this case, $\alpha > 0$ and $\beta > 0$, and the relative magnitude of the above effects depends on the sizes of these two parameters. Regardless of the parameter values, if $\alpha > 0$, $\beta > 0$, and $N(0) = 0$, as $t \to \infty$, $N(t) \to K$, as in the two above cases.

**Integrating Technology Diffusion and Poverty Trap Models**

To combine the poverty trap and technology diffusion models use

$$\begin{aligned}
\frac{dc(t)}{dt} &= s\left(p + p_n N(t)\right) f(c(t)) - (g + d)c(t) \qquad (3.13)\\
\frac{dN(t)}{dt} &= \left(\alpha + \frac{\beta}{K}N(t)\right)(K - N(t))
\end{aligned}$$

Here, in the bottom equation you see the technology diffusion equation from above, and it is assumed that there is no explicit influence of $c(t)$ on this equation. From one perspective, it makes sense for higher values of $c(t)$ to have a

positive influence on the rate of diffusion since then people can more easily buy the technology, and in a wealthier society it may be that there is more infrastructure to support the diffusion (e.g., radio, television, internet or other media, or more mobility in travel so people can learn about innovations). Here, the assumption is either (i) that the bottom equation already represents these issues at an abstract level in that the shape of the $N(t)$ curve will not change much if $c(t)$ influences are included, or (ii) that the cost of the technology is zero (i.e., it is an idea that can be used with existing resources to improve productivity) or very low so that lack of funds does not significantly affect diffusion. It is also possible that low values of $c(t)$ could be modeled as influencing the bottom equation to *reduce* $N(t)$: this would represent that low capital is used but is not sufficient to support technology diffusion, that is, that there is a level of capital that has to be in place for technology to diffuse. Furthermore, it makes sense that there can be a "technology diffusion trap" like there is a poverty trap, and this could be added with a nonlinearity that is analogous to the one used in the $c(t)$ differential equation. this additional trap could represent aspects of the technological capacity trap that is discussed in Section 2.1.2. Further consideration of these options is left to the reader.

Returning to our integrated model, the top equation in Equation (3.13) is influenced by the bottom equation. Notice that the factor $p$ that was used to represent the quality of technology above is now replaced with

$$p + p_n N(t)$$

Hence, $p$ represents the base technology level of a country, and the term $p_n N(t)$ represents the introduction of a new technology. When $N(0) = 0$ this represents that at time $t = 0$ the new technology was not introduced. Then, since as $t \to \infty$, $N(t) \to K$, so that the $p_n K$ represents a full realization of the technology impact after diffusion has occurred. To represent an increment of $\Delta p$ to $p$ to achieve a higher technology to $p + \Delta p$ we will let

$$p_n = \frac{\Delta p}{K}$$

so that as $t \to \infty$,

$$p + p_n N(t) \to p + \Delta p$$

Notice that the effect of the additional $p_n N(t)$ term is to add another $f(c(t))$ term, a positive term, that enhances economic growth. However, it too has the feature of zero slope for low capital values; hence, it will not reduce the width of the poverty trap zone. This is especially the case since when $N(t)$ is small for the initial phase of technology adoption when the $p_n N(t)$ value is small and hence does not have the ability to eliminate the trap.

### Economic Growth with a Poverty Trap and Technology Diffusion

Suppose that $s = 0.1$, $g = 1$, $a = 0.75$, $p = 30$, and $d = 0.1$ as for the top plot in Figure 3.4. To simulate Equation (3.13) with Equation (3.5), suppose

$\alpha = 0.01$, $\beta = 1$, $K = 10,000$, and $\Delta p = 10$. Since $p = 30$, this means that $p + p_n N(t) \to p + \Delta p = 40$ which is the high technology case considered in the bottom plot of Figure 3.4. Hence, here we study not the immediate introduction of a better technology but its *gradual* introduction via diffusion. Figure 3.10 shows the dynamics of Equation (3.13) for $N(0) = 1$ adopter and a range of initial values $c(0)$ (shown at $t = 0$ in the top plot). In Figure 3.10, notice that as $c(0)$ increases above zero, the capital-labor ratio decreases over time, but above some point $c(0)$ will result in the capital-labor ratio increasing to some maximum point. This illustrates how if initial capital is high enough, the poverty trap can be broken. Notice that as $c(0)$ increases further, there is increasing economic growth, but above another point, the capital-labor ratio *decreases* before it increases to the final value. This decrease is due to the slow diffusion of the technology that is seen in the bottom plot (red): At early times, where diffusion is low, the capital ratio moves toward the final value that would result for a low technology case ($p = 30$) but as the technology diffuses, it recovers and moves upward to where it would end for the high technology case ($p = 40$).
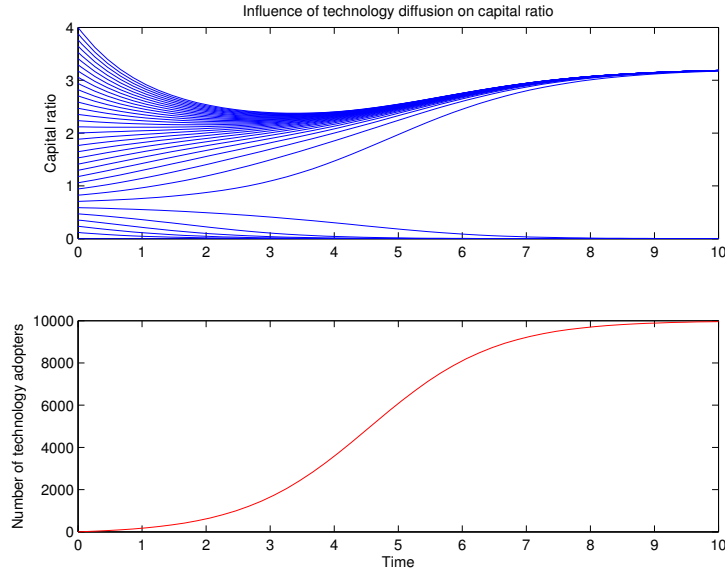


Figure 3.10: Capital-labor ratio and number of adopter dynamics for a range of initial capital-labor ratios and on initial adopter.

Next, compare the results to Figure 3.5 and you can see that the threshold for guaranteeing an increasing capital-labor ratio is at the value for the $p = 30$ case since the technology at that point was not diffused, but that the ultimate economic growth goes to the value for the $p = 40$ case since by then the technology is fully diffused. Basically, if you have to provision in order to break

a poverty trap, if you provision with better technology you may not lower the threshold at the $N = 0$ case, but people will be able to climb to a higher level of economic well-being as the technology diffuses.

To see this in another way, consider Figure 3.11 that shows the "phase plane" for Equation (3.13), that is the trajectories $(c(t), N(t))$ pairs over time, $t \geq 0$, for various starting points $(c(0), N(0))$. This simply provides a different view of Figure 3.10. There is an equilibrium on the top left that corresponds to $[0, K]^{\top}$ and it is a stable equilibrium as you see trajectories in the vicinity of it converging to it. There are also two other equilibria, ones for $N = K$ for the high technology case, that is where, $p = 30 + 10 = 40$, so the higher level of wealth is achieved via convergence to the point where $c$ is a bit above three, that is a stable equilibrium (what value is this?). The point near a $c$ value of around 0.2 (what exact value is it?) and $N = K$ is *to the left* of the point on the $N = 0$ axis that divides where $c(0)$ will result in a decrease or increase of $c(t)$ (this dividing point is affected by the low technology case); this point is an equilibrium of a special type called a "saddle point." Notice that the phase plane reveals an interesting feature of the dynamical system: the behavior of the system in the vicinity of this saddle point is such that to the left of it, trajectories tend to $[0, K]^{\top}$ and to the right of it they tend to the point discussed above. Also, you can see that as technology diffuses (i.e., as $N$ gets large) there are fewer initial conditions where the capital ratio will go to zero, showing that the poverty trap shrinks.

Diffusion of high technology can shrink a poverty trap.

### 3.6.5 Breaking Poverty Traps

The PID spending strategy from Section 1.6.4 is used with only one change, a percentage of the money that is spent by the individual is invested in "capital" (here we think of this as all resources associated with an investment, some money, technology, equipment, etc.). We will study what percentage of spending must be spent on capital investments in order to break a poverty trap. Next, we will assume that the level of investment in capital is not possible due to the need to spend money almost entirely on survival (e.g., food) and risk avoidance (e.g., having a small amount of money available for a health emergency). We introduce various levels of "provisioning" (e.g., from some aid agency) and study how much provisioning is needed to break a poverty trap. In each of these cases, we also study the effects of a democracy voting on a wealth distribution strategy; hence, we think of some development organization (internal or external or both) helping put in place a democracy *before* individual capital investment or provisioning to see what effects democracy has on the breaking of poverty traps *by the whole community.*

#### Capital Accumulation Model

We build on the capital accumulation model in Equation (3.1), and use

$$\frac{dc(t)}{dt} \approx \frac{c(kT) - c(kT - T)}{T}$$
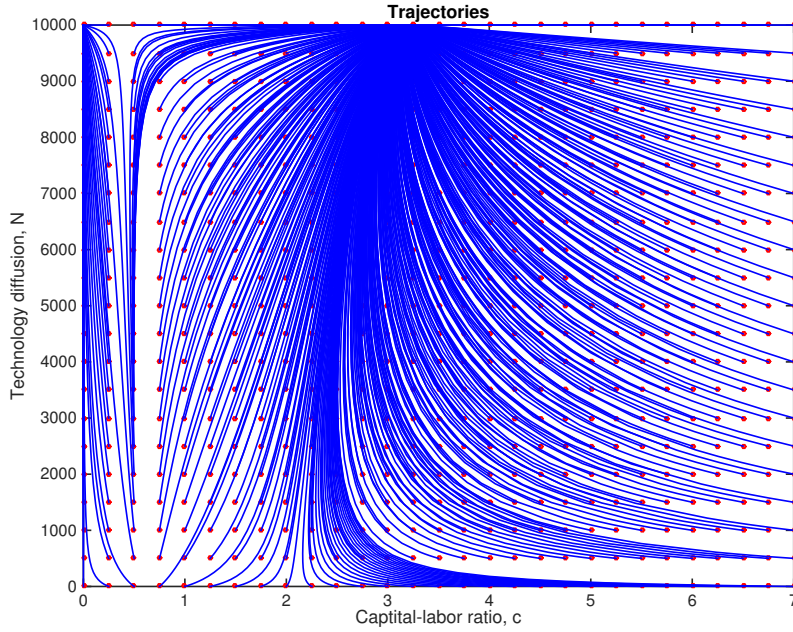
**Trajectories**

Figure 3.11: Phase plane for Equation (3.13). Blue lines are trajectories for various initial conditions indicated by red dots.

where $T = 1$ day to approximate the derivative. Next, it is assumed that the model for the country-level capital-labor ratio dynamics is converted to the individual level. Hence, the capital-labor ratio is simply capital in possession of an individual and the other components of the dynamics are appropriately interpreted (e.g., the production function is for the individual). Also, since we are considering an individual, $g = 0$ in Equation (3.1). Use

$$c(k + 1) = c(k) + \underbrace{spf(c(k)) + I_r c(k)}_{\text{Two income sources}} - dc(k) + c^i u(k) + p_r(k) \qquad (3.14)$$

where $spf(c(k))$ has $s$ and $p$ parameters defined as above, Equation (3.5) is used, $c(k) \geq 0$, and capital depreciation is as above, $-dc(k)$. Suppose that $u(k)$ is the total amount that the person wants to spend on day $k$. Suppose that $I_r c(k)$ is the return on investment on day $k$ ($I_r \geq 0$), $c^i u(k)$ is the capital investment by the individual spent on day $k$ ($c^i \geq 0$ and $u(k) \geq 0$), and $p_r(k) \geq 0$ is the amount provisioned by an aid agency. The term $-dc(k)$ has the same effect as $-(d + g)c(k)$ Equation (3.1). The term $I_r c(k) + c^i u(k) + p_r(k)$ will increase capital accumulation, making it easier to break the poverty trap. Relative to Chapter 2, the only change is that what the person spends per day is *split* into two parts:

Capital accumulation and provisioning can break a poverty trap.

1. *Spend on self:* The person spends $(1 - c^i u(k))$ on her/himself and this is subtracted as before from the person's total income, including the average of $1 per day, donations, and return on investment $I_r c(k)$, to get the net income for the day that is stored (e.g., in their pocket).

2. *Capital investment:* The person spends $c^i u(k)$ as a capital investment for day $k$ and this amount is not then stored in their pocket.

After a bit of tuning, parameters were chosen as $d = 0.004$ (about 15% capital depreciation per year), $a = 0.001$ (adjusted so that it is possible for the person to save and break a trap; if this value is decreased to $a = 0.0001$ that is very difficult), and $I_r = 2(1/250)$ (this last value was chosen as capital accumulation is typically under 250 so this value limits the return on investment to under $2 per day). The product $sp$ was set to $sp = 1$; adjusting $p$ up (higher technology) and down (lower technology) has a similar effect to above. All parameters from the wealth distribution policy and democracy from Section 2.4 are used unchanged.

**Capital Investment Rate to Escape Poverty Trap: Without and With Democracy**

We will consider a community of three people, first in isolation, then with a democracy choosing the wealth distribution policy. To turn off the democracy, in `PovertyTrapDemocracyPlotter.slx`, set `Gflag=0` and to turn it on set `Gflag=1`. Assume that there is no provisioning so $p_r(k) = 0$, $k \geq 0$, for all three people. Assume that the $c^i$ values for persons 1, 2, and 3 are 0.01, 0.035, and 0.04, corresponding to spending 1%, 3.5%, and 4% of total daily spending on capital investments. First, consider the case with no democracy and no wealth distribution. Figure 3.12 shows that person 1 does not invest enough in capital to see any significant return on the investment. Person 2, on the other hand, investing 3.5% of their daily spending on capital, can accumulate enough capital so that the return on investment is noticeable; see the first column plot showing the increment in income that is due to the investments that broke the poverty trap as seen in column 4. While the person suffers more to make that level of investment, her/his return on investment has a number of positive influences on the individual, including increased spending and capital investment (see the column 2 plot) and a reduction in variance of the wealth error so that risk is reduced (see column 5 plot). Person 3 invests in capital at a rate of 4% so s/he *more quickly* accumulates capital than person 2 and realizes all the benefits quicker.

Next, we add the democracy that votes on a wealth distribution policy to financially couple the individuals. We do not consider the possibility that capital is shared among the individuals, though in reality this will often be the case (e.g., a road or some types of farm equipment). Figure 3.13 shows how the results change from Figure 3.12 by introducing the democracy and wealth distribution policy. Notice that when the democracy is added, all incomes are
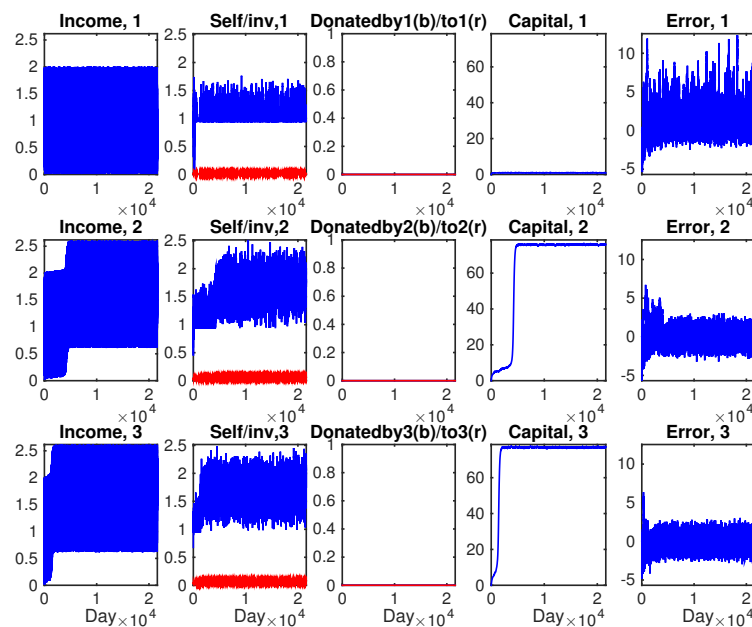
Figure 3.12: Effect of capital investment rate on escaping poverty trap (no provisioning). Each row of plots corresponds to an individual, persons 1, 2, and 3. The first column of plots shows the persons' incomes per day, the second column the amount spent on her/himself (blue) and their capital investment (red), the third column is the total donated by the persons' to their neighbors (blue) and total received from all their neighbors (red), column 4 is capital accumulation $c(k)$ per day $k$, and column 5 is the error (desired wealth minus actual wealth held in pocket).

generally higher, that persons 2 and 3 (who climb out of the poverty trap) donate a bit more than they receive whereas person 1 receives more than they donate, variances on the wealth error generally decrease for all due to increasing generosity, and person 2 climbs out of the trap faster than without the democracy. However, persons 2 and 3 do not donate enough to person 1 to pull her/him out of their poverty trap.

To understand the dynamics of the democracy better, see Figure 3.14 and notice that in the beginning, when the traps are not totally broken all persons vote to increase the generosity parameter, but that when the traps are broken and persons 2 and 3 become wealthier, those two generally vote against more generosity. In spite of this, as seen in Figure 3.13 there are a number of benefits to having the democracy.
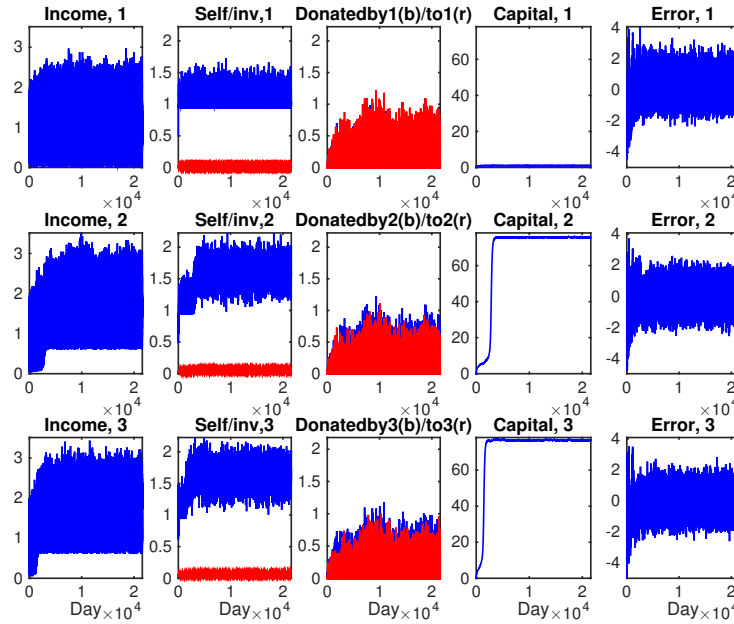
Figure 3.13: Effect of democracy and capital investment rate on escaping poverty trap (no provisioning). See Figure 3.12 for an explanation of the plots.

### Provisioning to Escape a Poverty Trap: Without and With Democracy

Again, we will consider a community of three people, first in isolation, then with a democracy choosing the wealth distribution policy. Assume that the $c^i$ values for persons 1, 2, and 3 are *all* 0.01 (at this value the three people cannot break the poverty trap). For provisioning, which we denote with $p_r(k)$, we let $p_r(k) = 0$, $k \geq 0$, *except* at $k = 10,000$ we let $p_r(10,000) = 10$, 12, and 15 for persons 1, 2, and 3. Figure 3.15 shows that persons 1 and 2 do not get a large enough provision in capital to see any significant return on the investment (their small capital investments and that provisioning are used for overcoming capital depreciation and investment return). Person 3, on the other hand, gets a large enough provision to break the poverty trap, and an increase in their income and spending, and reduction in the variance on their wealth error.

Next, we add the democracy and wealth distribution policy to financially couple the individuals for the same $c^i$ values and $p_r(10,000)$ values above. Figure 3.16 shows how the results change from Figure 3.15 by introducing the democracy and wealth distribution policy. Notice that when the democracy is added all incomes and spending are generally higher, that person 3 (who climbs
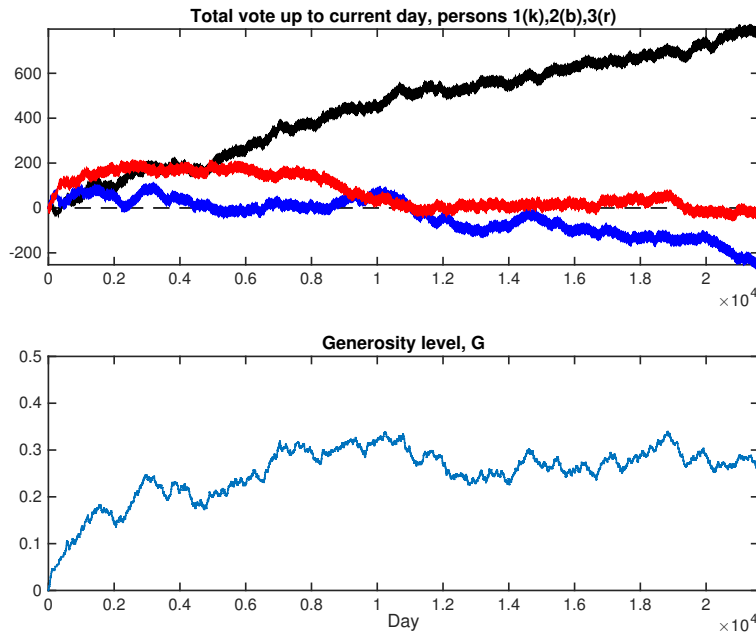
Figure 3.14: Total voting by each person and generosity parameter for each day.

out of the poverty trap) donates more than s/he receives, whereas persons 1 and 2 donate and receive about the same amount, and variances on the wealth error generally decrease for all after only person 3 climbs out of the trap. The donations are not, however, significant enough to pull persons 1 or 2 out of their poverty trap. The voting and generosity parameter evolution are as expected, with all voting for more generosity until person 3 climbs out of her/his trap, when they start voting to, a bit more often, decrease generosity.

### 3.6.6   Resource Utilization Control for Sustainable Development

In Section 1.6.7, and also Section 2.4.5, modeling and analysis of the dynamics of the tragedy of the commons was studied. Continuing with those studies, here we will consider the feedback control of utilization to steer resource levels so that the tragedy of the commons is avoided. Development may end poverty, but is likely to increase resource utilization. To obtain "sustainable development" we need environmental justice policies that can cope with increases in utilization and population and allow for development and population increases. This is the focus of this section.
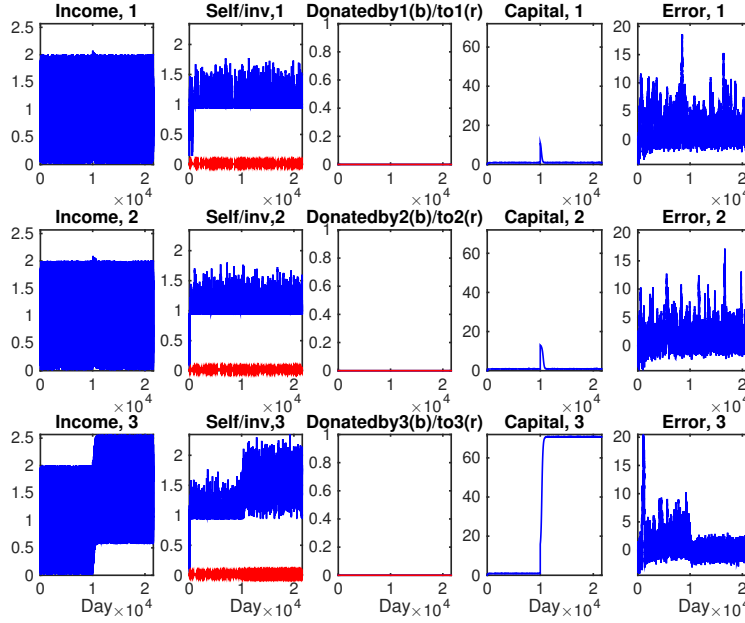
Figure 3.15: Effect of amount of provisioning on escaping poverty trap (low individual capital investment) when there is no democracy and wealth distribution. See Figure 3.12 for an explanation of the plots.

The general scheme is shown in Figure 3.17. Here, the process is defined by the utilization and resource dynamics. The "disturbance" is the number of users $N$ which could go up or down. The input to the process is $u_c(k)$ which is a key parameter of the environmental justice policy (EJP), defined in Section 2.4.5. The other parameter of the EJP is $\alpha$. Next, for Figure 3.17, the $R_s$, $R_s > 0$, value is set to $R_s > R_d$, the point where the tragedy of the commons occurs. The value of $R_s$ is a "safety value" that is set to be above $R_d$ so that even if there are fluctuations of $R(k)$ such that it goes below $R_s$, $R(k)$ will not go below $R_d$ where the commons are destroyed. The "error" $e(k) = R_s - R(k)$. The "policy adjuster" (feedback controller) is designed to use $e(k)$ to adjust $u_c(k)$ to make $e(k) \to 0$ so that $R(k) \to R_s > R_d$ as $k \to \infty$. In the next section such a controller will be designed and evaluated.

Feedback control for environmental policy adjustment seeks to control utilizations to avoid the tragedy of the commons.

### Feedback Control for Resource Level Maintenance

The policy adjuster is defined by

$$u_c(k+1) = \max \left\{ 0, \left( u_c(k) - \beta \mathrm{sign}(R_s - R(k)) \right) \right\}$$
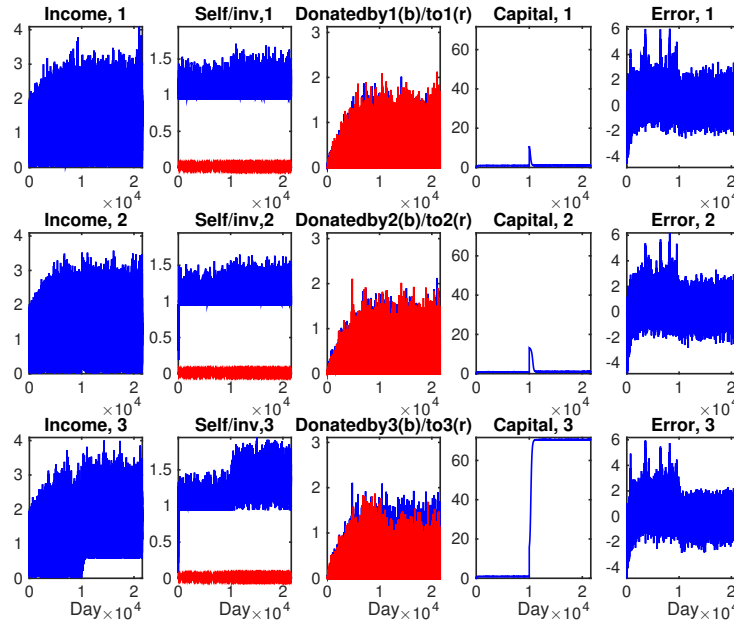
Figure 3.16: Effect of democracy and provisioning on escaping poverty trap (low capital investment). See Figure 3.12 for an explanation of the plots.
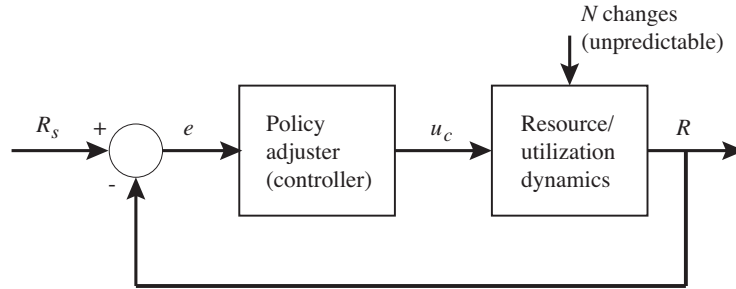


Figure 3.17: Feedback control for avoidance of the tragedy of the commons.

The "max" is used to make sure that $u_c(k)$ is not adjusted to be negative. The "sign" function simply tests if its argument, $R_s - R(k)$, is positive or negative and returns $+1$ or $-1$ respectively. If the argument, $R_s - R(k) = 0$, $\text{sign}(R_s - R(k)) = 0$. The value of $\beta > 0$ is used to set the amount of change to $u_c(k)$ at step $k$ to produce $u_c(k+1)$. Hence,

1. If $R_s - R(k) > 0$, then the resource level is below the safety level (a dangerous situation) so $u_c(k)$ is reduced by $\beta$ to produce $u_c(k+1)$. This will have the effect to reducing utilization via the EJP.

2. If $R_s - R(k) < 0$, then the resource level is above the safety level (a safe situation) so $u_c(k)$ is increased by $\beta$ to produce $u_c(k+1)$. This will have the effect to increasing utilization via the EJP.

3. If $R_s - R(k) = 0$, then the resource level is at the safety level (a safe situation) so $u_c(k)$ is not changed so utilization will not change via the EJP.

Here, let $R_s = 30$ and use the $R_d = 20$ value from Section 2.4.5. Also, use $\beta = 0.00001$ and $u_c(0) = 0.001$, the value from Section 2.4.5.

The feedback strategy seeks to adjust utilizations to maintain resource levels.

The results when this feedback control strategy are used, with $N = 200$, are shown in Figure 3.18. In the top plot, the black line is $R_d$ and the dashed line is $R_s$, $R_s > R_d$. The initial value $R(0) = 50$. The blue line shows $R(k)$ vs. $k$. Notice that the value of $R(k)$ approaches $R_s$ and the tragedy of the commons is avoided. The adjustments to $u_c(k)$ made by the feedback controller to achieve this are shown in the middle plot via the green line (compare to Figure 2.25 where $u_c(k)$ is held constant) and initially $u_c(k)$ goes up, which will allow utilization to go up, but once (around $k = 37$) $R(k)$ dips below $R_s$, $u_c(k)$ is adjusted down so that resources will not further decrease. Indeed, you can see that after $k = 40$ the value of $u_c(k)$ goes down, then up, then down: the controller is finely adjusting the policy so as to make $R(k)$ "track" $R_s$. The effects of changes of $u_c(k)$ on the values of $u_i(k)$, $i = 1, ..., N$, are shown in the bottom plot in Figure 3.18. Notice that after about $k = 10$, after the over-utilizers have had their utilizations reduced to about the value of $u_c(k)$, and then the value of $u_c(k)$ defines an upper bound on all users' utilizations. In this way adjusting $u_c$ down results in an overall reduction in utilization so that $R(k)$ will rise (or not fall). Adjusting $u_c(k)$ up allows users, with their natural drive to do so, to raise their utilization values.

**Impact of Population Growth**

The value of $N$, the number of users (population size) can change unpredictably. If $N$ goes down, there will generally be less utilization and it is easier to avoid the tragedy of the commons. On the other hand, if $N$ goes up unpredictably, this will result in an overall increase in utilization, a reduction in resources, and will raise the possibility of destroying the commons. While it is not difficult to consider small $N$ variations, or $N$ variations as a function of $k$, here we will simply consider a major increase of $N$ from $N = 200$ to $N = 400$. This is the case considered in Section 2.4.5 where in the $N = 400$ case, with or without the EJP, the tragedy of the commons occurs. Figure 3.19 shows the results for the $N = 400$ case when feedback control is used where all other parameters are kept the same as in the last section. In the top plot, the blue line shows $R(k)$ vs. $k$, and that the resource level dips below $R_s$ but then later recovers and is

A properly designed feedback strategy can cope with significant population size variations and still avoid the tragedy of the commons.
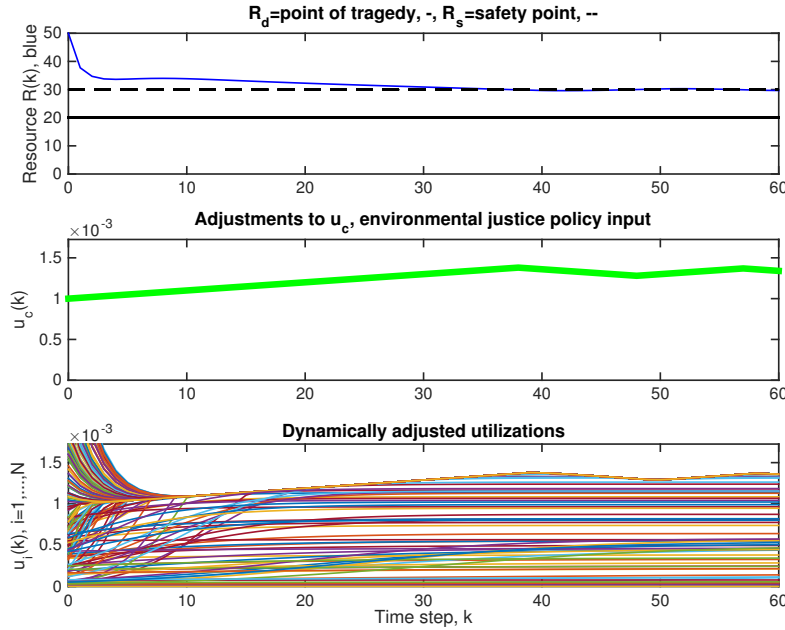
Figure 3.18: Feedback control for the tragedy of the commons, $N = 200$.

regulated near $R_s$. In this case, $R(k)$ never dips below $R_d$ so the tragedy of the commons is avoided, unlike the case in Section 2.4.5 when the policy is not adjusted by changing $u_c(k)$. The bottom plot of Figure 3.19 shows the $u_i(k)$, $i = 1, ..., N$, values and how after about $k = 10$ they stay below $u_c(k)$. Smaller changes in $N$, such as $N = 300$, result in a similar pattern in the plots, and $R(k)$ does not dip so low to be close to $R_d$. Finally, however, note that there is an element of randomness in running the simulations due to how $K_{u_i}$, $r_{u_i}$, and $u_i(0)$ were chosen randomly; the above results were for *one* simulation run so clearly other runs may result in at least slightly different results.

Overall, the feedback controller seems to nicely regulate the policy so that the tragedy is avoided, even in the face of significant uncertainty in population size. This type of feature is a key reason for considering environmental justice policies that are dynamic and based on feedback from the environment.

## 3.7 Conclusions

The broad conclusions for each section of this chapter are:

1. Historically, and throughout the world, technology has had a major impact on development. It is a crucial characteristic that distinguishes the
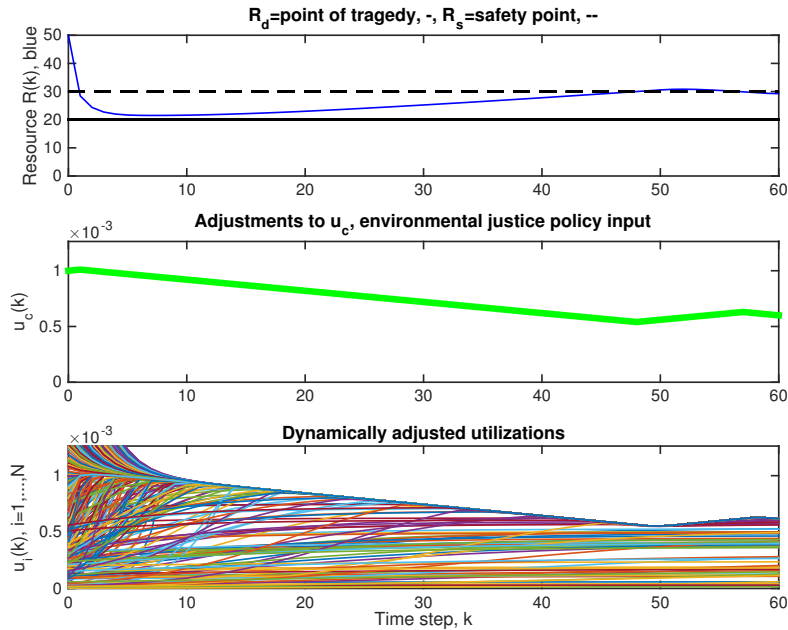
Figure 3.19: Feedback control for the tragedy of the commons, $N = 400$.

developed from the developing world.

2. Development economists have a broad and deep perspective on development. While they do not always agree on what is the best approach to development, each has useful ideas for the humanitarian engineer.

3. Global public health provides useful perspectives on how health impacts development, and suggests technologies that can be useful.

4. The international education perspective shows how education affects development, and suggests standards for global STEM education.

5. The social business perspective explains how business can be a solution to poverty.

6. In the analytical approaches, economic models can be used to gain insights into the dynamics of growth, such as in the presence of a poverty trap or when there is technology diffusion. They can also be used, via sensitivity and optimization analysis, to set development policy. Feedback control can be used to adjust an environmental justice policy so that it properly reacts to development and population increases.

## 3.8   Homework Problems

**Problem 3.1 (Can We End Poverty?):** After reading the section based on (Sachs, 2006):

(a) Read the article (Economist, 2013) entitled "Poverty: Not Always With Us."

(b) Read the report (Chandy et al., 2013) that part of the Economist article (Economist, 2013) is based on.

(c) Write down answers the following questions: What is neocolonialism? What is neoliberalism? What is the Washington Consensus?

(d) View the movie The End of Poverty? which is also at YouTube, here. The video is (1:44:34), is by Cinema Libre Studio, and features Amartya Sen, Joseph Stiglitz, and others. You should take notes while you view this video. Identify and discuss the root causes of poverty. What is good or bad about neocolonialism, neoliberalism, and the Washington consensus? Compare and contrast all four.

(e) At Coursera, view (Sachs, 2014), Lecture 5, Chapter 1, "The reasons to believe that extreme poverty can be ended" (15:56), summarize his main points.

What do you think? Can we ever end poverty? If so, by when and what kind of poverty? Consider in your discussion the SDGs in Section 1.3.8 and in particular, SDG: Goal 1.

**Problem 3.2 (Donate or Direct Project Help?):** Summarize and critique (Matthews, 2013). Do you agree with their approach? Why or why not? Discuss the advantages and disadvantages of donating to an NGO vs. the cost for you to perform a project (e.g., airfare) by doing a project yourself.

**Problem 3.3 (Poverty, Money–and Love):** Summarize and critique the (18:33) TED talk by Jessica Jackley

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Poverty, Money–and Love

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that was released in Oct. 2010. Identify the principles of social justice at work in her viewpoints and approaches.

**Problem 3.4 (Development Organizations, Institutions, and Government Initiatives):** Write less than a five-sentence description of the mission for each of the following three types of organizations (total response for this question is 15 sentences): (i) Organizations: CARE, Save the Children, UNICEF, Oxfam, Catholic Relief Services; (ii) Foundations: Gates Foundation and Ford/Chrysler/GM Foundations; and (iii) Government institutions: US-AID, US Peace Corps, AmeriCorps, and Teach for America.

**Problem 3.5 (Science, Technology, and Development):** Read the following: (i) Executive summary of (Juma and Yee-Cheong, 2005), summary of (HDR, 2001), (ii) executive summary of (Watson et al., 2003), and (iii) executive summary of (Palis and Serageldin, 2004). Make a list of policy changes that (i)-(iii) recommend developing countries should make to use science and technology to enhance development (i.e., integrate the lists). For technology policy, you may also be interested in (Bank, 2010).

**Problem 3.6 (Millennium Villages Project):** View, at Coursera, (Sachs, 2014), Lecture 5, Chapter 5, "Designing Practical Interventions: The Case of Millennium Villages" (18:52). Sachs says this is a practical way to achieve MDGs. What does he mean by holistic? Summarize the video. What are the key successes? What has happened with respect to gender equality? With respect to healthcare? How? For what? What is the role of the cell phone? What is the role of technology?

**Problem 3.7 (Sachs's Perspective on Useful Technology):** Read Section 3.2.1. Make a list of the technologies that Sachs identifies as being useful for development.

**Problem 3.8 (Sachs vs. Easterly):** Read Section 3.2.1 about Sachs's work and Section 3.2.2 about Easterly's. Overall, who do you agree with more, and give specific reasons why. Use Banerjee and Duflo's treatment in Section 3.2.4 to justify your points.

**Problem 3.9 (Collier's Perspective):** Read Section 3.2.3. Summarize the main points of Paul Colliers perspective covered in the chapter.

**Problem 3.10 (Banerjee and Duflo's RCTs Applied to Technology):** Read Section 3.2.4. Restate the basic RCT approach, but explain how it would work for a technology. To be concrete suppose that the technology is a newly designed water pump. What are some candidate variations of a pump design that may need to be evaluated (i.e., aspects of the technology to evaluate to choose the best approach)? What are some candidate outcomes that could measure success of a water pump? How many different pumps would have to be evaluated? Over how many different installations? These last two questions are generally difficult to answer, but assume that you are consider two alternative pump designs, and if your metric is the mean of some outcome variable (for two alternative designs), then if you do two tests for each design (4 tests total), then

compute the mean of the two outcome variables for each case, you at least know more about "variability" of pump performance than had you only done one test for each design. Tests are generally costly; hence, you want to minimize the number of tests but get a good measure of true mean pump performance. Can you say how many tests you should perform in order to get a good evaluation?

**Problem 3.11 (Aid for Africa?):**

(a) View the (22:14) TED talk on Africa, aid, and business by Ngozi Okonjo-Iweala

<div align="center">

Aid vs. Trade

</div>

from June 2007. Summarize and critique the talk.

(b) View the (17:11) TED talk by Andrew Mwenda

<div align="center">

Aid for Africa: No Thanks

</div>

from June 2007. Summarize and critique the talk.

(c) View the (17:47) YouTube-TEDxBrussels talk by Dambisa Moyo (a Zambian economist) that is from Nov. 23, 2009. Summarize and critique the talk. What does she feel is the world perception of Africa? What does she say that we all agree on (three things)? Has aid contributed to disfunctionality? Where? What types of disfunctionalities? What are the three types of aid according to her? How does she feel about each of these? Why is giving large amounts of aid to Africa a problem in her opinion? What are the reasons why aid is not working? What does she feel is the biggest problem with the aid culture? Does she think anyone believes that Africa will ever succeed? Optional: Read (Moyo, 2010), summarize her main points, and critique her book in the context of the talks in (a) and (b) and other work in this chapter, especially Section 3.2.1 that covers Sachs's perspective.

**Problem 3.12 (Acumen Fund):** View the (17:05) TED talk by Jacqueline Novogratz,

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A Third Way to Think About Aid

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from June 2009. Summarize the main points of the talk. Critique the approach. (If you search on Novogratz's name at the TED web site you will find several more good talks by her.)

**Problem 3.13 (Digital Humanitarianism):** See the web page and report

Humanitarianism in the Network Age

Summarize the basic ideas put forward in the report. For more information on this subject, see (Meier, 2015).

**Problem 3.14 (Open Data and Aid):** Summarize and critique the (15:17) TED talk by Sanjay Pradhan

How Open Data is Changing International Aid

that is from June 2012. Explain what he means by "open" (three aspects, define and explain each). What is geo-mapping? Why is it useful? Is it a humanitarian technology? What is a "public budget"? Why could it be useful for a country? What does CheckMySchool do? Why could that be useful?

**Problem 3.15 (Influence Diagram Model for Issues in Kibera, Nairobi, Kenya):** Read Section 1.6.1. View the United Nations Development Program (5:21) YouTube video

Beyond Scarcity: Power, Poverty, and the Global Water Crisis

from Dec. 12, 2008. This video shows the complex interconnections between water, sanitation, health, and education.

(a) Draw an influence diagram with strengths for the specific situation described in the video. Be sure to include all the influences between water, sanitation, health, and education (the nodes).

(b) Is there any way you can effectively address this situation as an engineer without considering the interactions between the issues that are modeled with the arcs?

(c) Explain aspects of the real physical situation in Kibera that are *not* represented in your influence diagram; for these pick the most important ones first.

**Problem 3.16 (PBS Rx for Survival):** View the two-hour special "The Heros" from

PBS Rx for Survival

Summarize the main points of the video and critique it. In particular, focus on the engineer's work on providing clean water in Uganda.

**Problem 3.17 (Country-Level Health Statistics):** Read Section 3.3. Using the web sites referenced in Section 3.3.2, choose a country from the developing world and summarize the major health statistics for that country. What is most striking to you?

**Problem 3.18 (Principles of Global Health):** Read Section 3.3.

(a) Define what is mean by a social determinant of health and give at least three examples of such determinants.

(b) In the socioecological model in Figure 3.1 name two ways each for why relationships affect individual behaviors related to health. Do the same for institutions (e.g., schools), communities, and policy.

(c) Name the major cause of indoor pollution. Name at least two water-related infections and explain how they are transmitted.

**Problem 3.19 (Country-Level Education Statistics):** Read Section 3.4. Using the web sites referenced in Section 3.4.2, choose a country from the developing world and summarize the major education statistics for that country. Include in your statistics some information on science, technology, engineering, or mathematics education. What is most striking to you?

**Problem 3.20 (Principles of International Education):** Read Section 3.4.

(a) Define what is meant by a utilitarian and transformational perspective on education. Give specific examples for each.

(b) Name five factors that adversely affect school access or attendance.

(c) Give at least one reason why educational outcomes are unequal among people, in particular, focus on socioeconomic factors.

(d) Give one advantage and one disadvantage of TVET.

(e) Give at least two reasons/rationales for mathematics, science, and technology education.

**Problem 3.21 (Prahalad: Eradicating Poverty Through Profits):** Read Section 3.5.1, summarize his main points in less than one page, and then assess his approach compared to the one by Polak and Warwick in Section 3.5.2: (i) What is different in the two approaches? (ii) What is the same in the two approaches? (iii) Do you see sound reasons for why Polak and Warwick's approach will succeed when Polak and Warwick claim that Prahalad's failed?

**Problem 3.22 (Polak and Warwick on Social Business: Effective or Exploitative?):** Read Section 3.5.2. Present and defend your view on the prospects for social business to end global poverty according to the approach

of Polak and Warwick. Use ideas from the other development perspectives, *and* ideas from social justice. In particular, based on Section 3.5.1, and also Section 3.5.2, present and defend your perspective on whether the social business approach is likely to result in significant injustices resulting from exploitation of the vulnerable by large companies.

**Problem 3.23 (What Non-Profits Can Learn from Coca-Cola):** View the (11:44) TED talk by Melinda French Gates

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What Non-Profits Can Learn from Coca-Cola

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from Sept. 2010. Write down her main points. Compare and contrast her ideas to those of Easterly in Section 3.2.2.

**Problem 3.24 (Why Business Can be Good at Solving Social Problems):** View the (16:28) TED talk by Michael Porter

<div align="center">

Why Business Can be Good at Solving Social Problems

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that is from June 2013. Write down his main points.

**Problem 3.25 (Development Strategies: Lessons for the Engineer):** There are eight sections in this chapter that are titled "Lessons for the Engineer" that aim to summarize the key points from each development perspective for the engineer. In this problem, you will read these sections and summarize their main points. Your summaries should be less than one paragraph each.

(a) Read Section 3.1.3. Summarize the main points of that section.

(b) Read the "Lessons for the Engineer" section in Section 3.2.1. Summarize the main points of that section.

(c) Read the "Lessons for the Engineer" section in Section 3.2.2. Summarize the main points of that section.

(d) Read the "Lessons for the Engineer" section in Section 3.2.4. Summarize the main points of that section.

(e) Read Section 3.3.4. Summarize the main points of that section.

(f) Read Section 3.4.6. Summarize the main points of that section.

(g) Read the "Lessons for the Engineer" section in Section 3.5.1. Summarize the main points of that section.

(h) Read the "Lessons for the Engineer" section in Section 3.5.2. Summarize the main points of that section.

**Problem 3.26 (Poverty Trap for a Different Production Function):**
Read Section 3.6.1. Get the code `PovertTrapHWprobPlotter.m` from the web
site. Suppose that

$$f(c(t)) = 1 - \frac{1}{a(c(t) + \epsilon)^2 + 1}$$

is used instead of Equation (3.5), where $\epsilon > 0$ is a a small value representing
that capital will not decrease to zero when in the poverty trap. For this case,
let $\frac{dc(t)}{dt} = 0$ in Equation (3.1) and find the third order polynomial in $c$ with
coefficients defined by the parameters of the system. Find parameter values
such that there are three positive roots to the polynomial (pick values and
use `roots(·)` in Matlab) and name these three equilibria $c^\epsilon$, $c^T$, and $c^E$ where
$c^\epsilon < c^T < c^E$. Draw a diagram like the ones in Figure 3.4 to show the three
cross points representing the equilibria (a hand sketch is sufficient, a Matlab
plot better). Next, explain what happens to $c(t)$, that is, what is $c(\infty)$, if $c(0)$:
(i) $c(0) < c^\epsilon$, (ii) $c^\epsilon < c(0) < c^T$, (iii) $c^T < c(0) < c^E$, and (iv) $c(0) > c^E$.
Explain whether each equilibrium, $c^\epsilon$, $c^T$, and $c^E$, is stable or unstable. Is it
still appropriate to call $c^T$ the poverty trap threshold? Is it appropriate to call
$c^\epsilon$ the "threshold capital to survive"? Can you more appropriately name this $c^\epsilon$
parameter and explain why you think it could arise in real situations?

**Problem 3.27 (Savings and Demographic Traps and the Effect of
Technology):** Read Section 3.6.1. Assume Equation (3.3) is used in Equa-
tion (3.1) and consider: (i) Savings trap: Find a function $s(c(t))$ that will result
in a poverty trap and demonstrate this by drawing a plot like in Figure 3.2
and explaining what happens to $c(t)$ when $c(0)$ starts inside and outside the
trap; and (ii) Demographic trap: Suppose that rather than $(g + d)c(t)$ in Equa-
tion (3.1) the function $(g(c(t)) + d)c(t)$ is used to represent the dependence of
population growth on capital. Sketch a plot like Figure 3.2 for this case, with the
straight line $(g + d)c(t)$ replaced with a function of your choice $(g(c(t)) + d)c(t)$
that will result in three cross-points (and three equilibria, one at $c(0) = 0$) of
$(g(c(t)) + d)c(t)$ with Equation (3.3). Explain the meaning of a "demographic
trap" in terms of initial conditions $c(0)$ being inside and outside of the trap.
For both (i) and (ii), does the size of the trap, and highest growth possible, in-
crease or decrease when $p$ increases (higher technology) and $p$ decreases (lower
technology)? Explain the meaning of your results. Hint: Notice that $p$ only
impacts Equation (3.3) so just consider changes in shape to Equation (3.3) due
to changes in $p$ for your chosen $s(c(t))$ and $(g(c(t)) + d)c(t)$ functions above,
and the impact on the cross-points (equilibria) (i.e., the size of the trap and
ultimate level of growth–what we called $c^E$ in the chapter).

**Problem 3.28 (Sensitivity Analysis for Poverty Traps):** Read Section 3.6.2.

(a) Derive Equation (3.9), and also Equation (3.10), but for $c^E$. Explain how these equations are used to make investment decisions.

(b) Consider Section 3.6.2 and the program `SensitivityPovertyTrap.m`. Repeat the sensitivity analysis, analytical and computational, for the case of considering changes in $s$, the savings rate. In terms of the analytical approach, to reduce $c^T$ would it be better to invest dollars in increasing the savings rate $s$ compared to decreasing $g$ or increasing $p$? What is your best investment to increase $c^E$? To answer these questions derive an equation like Equation (3.9), and also Equation (3.10), but for $c^T$ and $s$, and compare it to Equation (3.9), and Equation (3.10), to make the decision. Here, of course, you need parameter values to make an explicit decision. Use parameter values from Section 3.6.2 and pick the desired change in the poverty trap threshold, along with costs $c_p$, $c_g$, and $c_s$ (cost to improve savings), and for one case of values of these costs make your investment recommendation.

(c) This part reconsiders Problem 3.26 and further analyzes the production function there, but from a sensitivity analysis perspective. Does $c^\epsilon$ increase or decrease when (i) $p$ increases, and (ii) $p$ decreases off some nominal value that you choose? Use sensitivity analysis to prove your statement mathematically for small perturbations. Explain the meaning of your results in terms of high and low technology. Next, solve the problem computationally by changing the $p$ parameter, and using Matlab to recompute the roots, and study whether they went up or down via the computational sensitivity analysis approach. Next, compute the sensitivity functions for $c^\epsilon$, $c^T$, and $c^E$ using the central difference formula for all $p$ on a discrete grid of your choice and plot the sensitivity functions versus $p$ on that grid; explain the results in terms of identifying where incremental (small) improvements in technology will have the most impact on the well-being of people. For this, you are going to have to consider what discrete grid (including end points) to use. Will you choice of grid provide values for $c^\epsilon$, $c^T$, and $c^E$ in every case of $p$ on your grid?

**Problem 3.29 (Optimization Analysis for Poverty Traps):** Read Section 3.6.3. Consider Equation (3.8), and assume that all parameters are fixed, except $p$ and $g$. Let $c^E(p, g)$ denote the dependence on $p$ and $g$. For other parameter values, use the ones in Section 3.6.3. Use the same methodology as in Section 3.6.3 to study the allocation of investments to technology quality and growth reduction to increase $c^E(p, g)$. You will modify

<p align="center"><code>OptimizationDevInvestAlloc.m</code></p>

to solve this problem; in all cases, provide plots, and explain them, to provide solutions. You will need to define your own $c_p$ and $c_g$. Also, you may need to consider a different range of values of $p$ and $g$ than is considered in Section 3.6.3.

(a) Provide a plot like the one in Figure 3.7, but for the case of $c^E(p, g)$. For this, you will need to pick a desired value of $c^E(p, g)$ (the white line). Explain all features of the plot.

(b) In Section 3.6.3, replace $c^T(p, g)$ with $c^E(p, g)$. Provide a plot like the one in Figure 3.8, but for the case of $c^E(p, g)$. For this, you will need to define your own $c^{tot}$ that will result in the white line. Explain all features of the plot. What is the optimal solution for $p$ and $g$? Explain why in terms of the plot.

(c) In Equation (3.11), replace $c^T(p, g)$ with $c^E(p, g)$, and $c_d^T$ with $c_d^E$. Pick an appropriate value of $c_d^E$. Provide a plot like the one in Figure 3.9, but for the case of $c^E(p, g)$. Explain all features of the plot. What is the optimal solution for $p$ and $g$? Explain why in terms of the plot.

**Problem 3.30 (Technology Diffusion and Development: Equilibria and Dynamics):** Read Section 3.6.4. Get the code `PovertTrapHWprobPlotter.m` from the web site as it can be useful for this problem depending on how you approach it. For Equation (3.13) with Equation (3.5) and all the parameters from Section 3.6.4, here you will analyze the equilibria of Equation (3.13). First, to find the equilibria, let $\frac{dc(t)}{dt} = 0$ and $\frac{dN(t)}{dt} = 0$ and solve the right side of Equation (3.13) for $c$ values paired with $N$ values that correspond to equilibria. Equilibria for this two-dimensional ordinary differential equation correspond to two-vectors $[c, N]^\top$ where $\top$ denotes transpose and it must be that $c \geq 0$ and $N \geq 0$ to be a valid equilibrium. There are three equilibria, two that are stable. The third one is a "saddle point," which is unstable. Give the explicit numerical values of the equilibrium vectors and explain their correspondence to Figure 3.11. Do research on what a saddle point equilibrium is, then sketch, by hand, the behavior of the trajectories in the vicinity of it; pay particular attention to what happens for different $c(0)$ when $N = K$. If you prefer, you can modify the Matlab program

$$\texttt{PovertyTrapTechDiffusionVFPP.m}$$

that was used to generate Figure 3.11 rather than using a hand made sketch.

**Problem 3.31 (Feedback Control for Sustainable Development):** This problem builds on Section 1.6.7 and Problem 1.35, along with Section 2.4.5 and Problem 2.38. Read Section 3.6.6, and for the problems below you will use

$$\texttt{EnvironmentalJusticeTOC.m}$$

(a) Using all the parameters from Section 3.6.6, change $N$ to $N = 300$ and rerun the simulation. Produce the plot like Figure 3.18. Compare to the case in Figure 3.18 for $N = 200$ and the case for $N = 400$ in Figure 3.19. What is different for the plot you generated compared to these two cases?

(b) Let $N = 200$ and $\beta = 0.000015$, run the simulation, and produce the plot like Figure 3.18. Compare to that case. What is different?

**Problem 3.32 (The Dynamics of Democracy, Development, and Cultural Values):**

(a) Read (Spaiser et al., 2014), "The Dynamics of Democracy, Development and Cultural Values." Summarize the main points of the paper.

(b) Use Matlab/Simulink to create the phase plane in Fig. 1b in (Spaiser et al., 2014).

(c) Repeat (b) but for a phase plane with $E$ (emancipative values) on the horizontal and $D$ (democracy level) on the vertical. Explain.

(d) Explain why the terms in each of the differential equations in Equations (2)–(11) in (Spaiser et al., 2014) make sense. To do this, consider both increases and decreases in each term and how it affects increases or decreases in the derivatives on the left-hand-side of the equations.

(e) What is the standard human development sequence? What do the authors propose it should be based on the results in their paper?

(f) Critique (Spaiser et al., 2014) by saying what is good and bad about it.

## 3.9 Annotated Bibliography

**Society, Technological Change, and Development:** The section on society, technological change, and development was based on the work of two sociologists (Rogers, 2003; Volti, 2006), two economists and a political scientist (Easterly, 2014; Acemoglu, 2009; Acemoglu and Robinson, 2012), and a computer scientist (Toyama, 2015). A relevant book is (Friedman, 2007), especially per the international competitive environment on technology. See also (Hickman, 1990) for a discussion of philosophy and historical issues on technology, and (Mokyr, 2002) on the historic origins of the knowledge economy.

**Development Economics and Other Approaches:** The books used to develop the sections on the perspectives of development economists were (Sachs, 2006; Easterly, 2007; Collier, 2008; Banerjee and Duflo, 2012). Sachs's book on sustainable development is (Sachs, 2014), and you could also see (Elliott, 2013; Blewitt, 2015). A later book by Easterly is (Easterly, 2014), which focuses on how so-called "experts" have done a poor job in helping development. For a critique of aid for Africa see (Moyo, 2010). An excellent book that has some similar features to (Banerjee and Duflo, 2012) is (Collins et al., 2009). Along those lines, a useful set of reports were produced by the World Bank under the

Voices of the Poor

program. Books that cover development include (Handelman, 2009; McMichael, 2012), and also the Oxfam book (Eade and Williams, 1995). Problems with state-led humanitarianism and development approaches are discussed in (Coyne, 2013) from an economics perspective. Agunga (Agunga, 1997) emphasizes the importance of communication in development, participation, and a systems-theoretic viewpoint. A Christian perspective is in (Corbett and Fikkert, 2012). See also, (Lupton, 2011). The role of volunteering in sustainable development is discussed in (Burns and et al., 2015). For a sociology perspective, see (Harper and Leicht, 2011). For a report on inequality in developing countries see (UNDP, 2013). For more information on the global economy, see (Rivoli, 2009). A historical perspective and explanation of root causes of prosperity, poverty, and underdevelopment is in (Acemoglu and Robinson, 2012); here, there is a heavy emphasis on the importance of institutions. For three other historical perspectives, see (Diamond, 1999; Landes, 1999; Rist, 2008). For a discussion on women's issues, see (Kristoff and WuDunn, 2010), and women's issues in development are covered in (Eade and Williams, 1995). For information on the debate about whether we can end poverty see (Economist, 2013; Chandy et al., 2013). For information on science, technology, and their connection to development see (Juma and Yee-Cheong, 2005; HDR, 2001; Watson et al., 2003; Palis and Serageldin, 2004). For a UN report on technology and development see (UNDR, 2001).

**Global Health and Education for Development:** The section on global health is based on the referenced WHO, UN, World Bank, OECD, and CDC sites. Also, (Skolnik, 2012) was used as the basis for Section 3.3.3. A book that gives the story of a medical doctor's work, Dr. Paul Farmer, in development is in (Kidder, 2009). The historical, and utilitarian/transformational perspectives, on education are based on (Maclure et al., 2012). The section on international education and development is based on (Harber, 2014). Two other sources that were used were (Freire, 1993; Ansell, 2005). For more information on TVET, see (UNESCO, 2013). The section on mathematics, science, and technology is based on (UNESCO-Brookings, 2013). The importance of education in development for girls and women is emphasized in (Kristoff and WuDunn, 2010). Education for sustainable development is discussed in (UNESCO, 2014).

**Social Business Approach to Development:** The social business approach considered here first covers (Prahalad, 2010). Next, the following two books were covered (especially focusing on the second) (Polak, 2009; Polak and Warwick, 2013). Criticisms of these approaches are discussed in the chapter, (Karnani, 2006), and in (Toyama, 2015). The above sources on social business were chosen since they had a heavier focus on technology, either in facilitating social business, as a product to be sold, or both. There are many books on social entrepreneurship that are not as technology-focused; two of particular note are (Borenstein, 2007; Yunus, 2010). See also (Martin and Zedillo, 2004). A range

of issues (e.g., organization descriptions, job descriptions, career trajectories, organizations, preparation, advice, etc.) in social entrepreneurship are covered in (Mehta, 2015). A recent report from the UN Development Programme (UNDP, 2014) provides an overview of the role of the private sector in development.

**Models and Analysis of Development:** The section on poverty traps is based on (Sachs et al., 2004; Sachs, 2006; Banerjee and Duflo, 2012; Acemoglu, 2009). Optimization theory and algorithms are covered in (Bertsekas, 1999). The theory of the diffusion of innovations is covered in (Rogers, 2003) and the ideas used here for diffusion of innovation models are from (Kijek and Kijek, 2010). For more analytical studies economic models, including the incorporation of technology, see (Acemoglu, 2009). The integration of poverty trap models based on capital (Sachs et al., 2004; Sachs, 2006; Banerjee and Duflo, 2012) with technology diffusion models (Kijek and Kijek, 2010) is partly based on (Solow, 1957). See also (Romer, 1990) and (Acemoglu, 2009). For ideas on management of the commons, see (Hardin and Baden, 1977; Ostrom, 1990; Kareva et al., 2013). The use of cooperative decision making for common pool management is discussed in (Meinhardt, 2002). Also relevant are "public goods games," including dynamical versions (Hauert et al., 2004), and those for the climate (Milinski et al., 2008; Tavoni et al., 2011; Jacquet et al., 2013). Some ideas on a systems view of development are given in (O'Neill et al., 2012b). A complex adaptive systems view of the impact of aid is given in (Ramalingam, 2013).

# Chapter 4

# Engineering for Sustainable Community Development

## Chapter Contents

*First, do no harm.*

*Hippocratic Corpus*

*The wearer knows best where the shoe pinches.*

*Plutarch*

*From the depth of need and despair, people can work together, can organize themselves to solve their own problems and fill their own needs with dignity and strength... We cannot seek achievement for ourselves and forget about progress and prosperity for our community... Our ambitions must be broad enough to include the aspirations and needs of others, for their sakes and for our own.*

*Cesar Chavez*

*If you want to build a ship, don't drum up the people to gather wood, divide the work, and give orders. Instead, teach them to yearn for the vast and endless sea.*

*Antoine De Saint-Exupery*

*I measure the progress of a community by the degree of progress which women have achieved.*

*B.R. Ambedkar*

*Education is the most powerful weapon which you can use to change the world.*

*Nelson Mandela*

*Never doubt that a small group of thoughtful, committed citizens can change the world; indeed, it's the only thing that ever has.*

*Margaret Mead*

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What features of humanitarian engineering make it a helping profession? Why are a good working alliance between a helper and client, and communication skills (e.g. listening and questioning), so crucial to effective helping? How does the helper assist the client with problem management and opportunity development?

What are the core challenges of community development? What role does relationship-building have in community development? Why is community participation in development projects important? What are the different ways in which engineers can participate? Why is it important to build the technological

capacity of a community for technology operation and maintenance? After a team is formed with the community, what are the principles of effective teamwork and project management?

What are the most effective ways to learn about a community? Research? Interviews? Focus groups? Surveys? How do you aggregate information gathered about a community? What technical assessments are needed for the technologies you have in mind for deployment?

How do you select a project from among the set of all possible projects that could be conducted? What are the relevant humanitarian technologies? How should I select one if there are multiple off-the-shelf solutions? How can I design a humanitarian technology with a participatory approach?

What are the principles of how to approach humanitarian STEM education? How should participatory development be used for STEM education? What are the features of technologies that are used for educational projects? How can a program on STEM education for sustainable development be assembled?

Why is it important to assess the outcomes from a humanitarian engineering project? What are possible unintended consequences and failures? What are some common approaches to quantitative and qualitative assessment? For successful projects, is there a way to scale up so that the benefits reach more people?

In humanitarian engineering fieldwork, why are the mandate to do no harm, and always seek community benefit, so important? Why should university programs align educational and community development objectives?

Using analytical approaches, can we explain how to develop a fully- or partially-automated approach to cooperative management of community technology (i.e., a shared technology)? How do technologies affect community dynamics and ultimately, sustainable community development?

This chapter, which has the theme of community development, will answer all these questions.

## 4.1   The Engineer as a Helper

From a global-historical perspective, engineers have often thought of engineering as a type of helping profession. Engineers help fix problems. They help develop technologies that greatly impact our lives by extending our capabilities. The technologies engineers develop reduce toil, improve health, and assist with education. The products of engineering have a strong and direct impact on human development (see Section 3.1). Yet, engineering is often thought of as working in the background as an *invisible* profession, and not to be a "direct contact" (Martin and Schinzinger, 2005) or "helping profession." In this section, it is explained how humanitarian engineering is a helping profession. Following that, two theories of helping for engineering are outlined.

### 4.1.1 Engineering as a Helping Profession

In Western culture, the "helping professions" typically include the following (Egan, 2014):

- Counselors,

- Psychologists/psychiatrists,

- Social workers, and

- Leaders/figureheads of religions.

There are other professions that directly focus on helping people, including the following:

- Health care professionals (doctors, nurses, and dentists),

- Teachers,

- Police officers,

- Consultants (e.g., for business),

- Lawyers,

- Managers/supervisors,

- Practitioners in some service industries, and others.

Engineering is typically considered to be different from these other professions (especially the top list) in the sense that it is not a "direct contact" profession (Passino, 2009) (i.e., engineers do not work face-to-face with clients to help them). However, there are counter-examples to this, such as the following:

- Rehabilitation engineering where, for instance, specially-tailored wheelchairs and prosthetics are designed for individuals with disabilities;

- Ergonomics and human factors to a certain extent, or other aspects of product design; and

- Sales and technical support (e.g., for computers) in some cases.

There are certainly a number of areas where engineers only *indirectly* help people. Examples include ones in electrical engineering for design of solid state devices, crank shaft design in mechanical engineering, chemical process control, etc. These tend to focus on technologies that are "buried" underneath a more visible (or touchable) portion of a technology (e.g., a phone). For such cases, the engineers creating such technologies are sometimes thought of as being "invisible helpers" and sometimes people generalize and call engineering an "invisible profession."

Humanitarian engineering challenges the notion that engineering is not a direct contact profession in many ways, ones that are discussed throughout this

chapter. It is natural that engineering would evolve over time to such a stance. As technology becomes more and more ubiquitous in our lives, and we depend more and more of it (consider it essential), we can naturally expect that the engineers who create, modify, and apply it to "get closer to the lives of the users of technology." This creates, or at least amplifies, the idea that "engineering is a helping profession." This may not be the case for *all* areas in engineering, but it most certainly is for several areas in the subfield of humanitarian engineering. This chapter will, in fact, show how the humanitarian engineer can be a different type of:

- Social worker, one who seeks to promote community change via participatory development of technological solutions, and a

- Teacher, one for building technological capacity in a community (e.g., for technology operation and mainenance), or international STEM education.

These are two examples where the humanitarian engineer is clearly a (direct-contact) helping professional.

### 4.1.2 Gerard Egan: The Skilled Helper

Gerard Egan is a Professor Emeritus of Organization Development and Psychology in the Quinlan School of Business at Loyola University, Chicago, IL, US. He is the author of 15 books. Here, his book "The Skilled Helper: A Problem-Management and Opportunity-Development Approach to Helping" (Egan, 2014), which outlines the elements of a general framework for a person ("helper") to help an individual ("client") is discussed, in the context of engineering. While the framework described in Egan's book is primarily intended for the traditional helping professions (all those mentioned in the last section), his framework is generally applicable to teaching many types of helpers how to help clients of all sorts. This section, along with Section 4.1.3, form the basis for the treatment of participatory community development in Section 4.2. Learning how to help an individual first makes sense, as if you work in a community you are helping many individuals, but often one person at a time.

**Elements of Successful Helping**

A client's "problem situation" describes their immediate living conditions (e.g., their household, community, and impact of social and physical environment) and challenges (e.g., generating income, getting an education, or accessing healthcare). The objectives of helping are to help the client solve or manage problems by improving their problem situation, sometimes by helping them identify resources and opportunities, and exploit their own potential.

Clients specify what they want to do about the problem situation, and may set goals related to having better outcomes as they define them; they should set goals to solve problems that are most important to them and that they are willing to work on. If the problem situation is very complicated, then it

may be best to work on a subproblem. The helper should assist in finding a problem that, if addressed, will lead to some improvement quickly as this will tend to engage the client and motivate them to take on more difficult issues. Small successes can give hope. Try to find a problem where the (immediate) benefits are greater than the costs (e.g., investments of time, money, and effort) so that the client is incentivized. Sometimes, there may be an exemplar in the community where the client lives and they may provide the client ideas on setting goals if they aspire to be like the exemplar.

The helper assists the client in stating goals in terms of outcomes, that are specific, substantive, prudent, realistic, have longevity, flexible, congruent with values, and that can be achieved in some time frame. "Second order" goals are ones that focus on changing the current system rather than only adjusting it, creating something new, making change that will endure rather than be prone to collapse, transforming rather than fixing, using new learning, and addressing causes rather than symptoms. Second order change is substantial change, "real" change, or "good" change. Sometimes, goals can be set early in the helping process, while other times goals may emerge later during the helping process.

Helpers should put the client in the "driver's seat" to achieve change.

Achievement of client-specified goals is primarily in the hands of the client, not the helper. The helper's goal is to help clients become better at helping themselves. The client should be put firmly in the "driver's seat." This empowers a client to be an agent of change themselves so that they can solve problems later on their own. Success of the helping process is defined by "life-enhancing outcomes for clients" (Egan, 2014). If there is a hero in the helping process, it is the client.

A client seeking life-enhancing outcomes must do so within the constraints of the *context* in which they live. Context can include their problem situation; past successful or failed attempts to change their problem situation and/or employ unused opportunities or resources; their personal history; their expectations, aspirations, and disappointments; their skills and strengths; their hopes and fears; their openness and readiness for change; their willingness to work for change; their reluctance or resistance to change; their ability and willingness to collaborate with a helper; their sense of right and wrong, ethics, and morality; their cultural beliefs, values, and behavioral norms; their existing relationships; their communication skills; obstacles to change; and external factors that support change.

The effective helper should have good interpersonal skills; seek to build trust with the client; seek to establish an agreement with the client on on the goals of the helping process; understand the client and her or his problem situation and identify causes; understand the general cultural, social, economic, and political context of the client; maintain a flexible stance in helping and effectively change helping as unexpected situations arise; be competent in helping create candidate solutions and persuasive with suggestions; can help monitor progress; sets up feedback methods to monitor progress in change and the helping process; can help instill hope and optimism; does not avoid the most difficult issues; and is committed to professional self-improvement.

"Helping is a two-person collaborative exercise in creativity" (Egan, 2014).

The client should be helped to nurture and use their creativity by encouraging them to generate ideas, to vary existing things to adapt them, and via collaborative brainstorming. Special attention should be paid to the client's views as they understand the problem situation and context the best. Clients should be encouraged to engage in divergent thinking, recognizing that there are, most often, many solutions to a specific problem. In brainstorming, judgment should be suspended and ideas should be used to generate new ideas, even "wild" ones. After a set of ideas are generated, down-selection can occur. This brainstorming can be useful at several stages of the helping process, including goal-setting and plan selection.

In different situations a client may want different things from a helper. For instance, in (Egan, 2014) the author says:

> ...clients who were mainly from the lower socioeconomic class wanted advice, signs of real interest in their problems, encouragement and reassurance, understanding, and the instillation of hope from their helpers.

The helper can have a significant challenge in matching the approach taken to client views of what is useful. For example, the two-way feedback between a helper and a client in dialog drives the helping process. Monitoring the quality of the dialog, by the helper and client, and adjusting to improve the dialog is useful. One approach to improve dialog is to have the client and/or helper fill out a brief assessment periodically.

### The Helper-Client Relationship is a Working Alliance

Some view the helper-client relationship as a "working alliance" that is based on client-set goals and tasks to address the problem situation and develop opportunities. Working alliances emerge from dialog with a client in a helping process. A good working alliance can cope with changing client needs and desires, different and changing views of the relationship, ups and downs, and client negativity. In the alliance, the helper should help the client both understand, and move into, a role of a committed and proactive partner. Collaboration in the alliance should result in setting goals. In a good alliance, the client's point of view and preferences must be kept center stage. The alliance should have a foundation of "flexibility, honesty, respect, trustworthiness, confidence, warmth, interest, and openness" (Egan, 2014). Clients appreciate helper's "self-presentation and body language, nonverbal gestures, emotional support and care, honesty, validation, guidance, challenging, helper's education, helper's appreciation of client self-responsibility" (Egan, 2014). A helper should use their natural style with a client, make encouraging and positive statements, smile, and be friendly. The helper should establish rapport with the client. There must be flexibility in creating a relationship as every client is different.

In a working relationship with a client, it is important to show respect, to do no harm, and to not rush to judgment about the client and their problem situation. Also, the helper should be competent, committed, genuine (e.g., not

being a phony by over-emphasizing their professional role), show that they are "for" the client, down-to-earth and non-sentimental (e.g., talk eye-to-eye at their level, not down to them with condescension), assume the good will of the client, and always focus on the client's agenda.

A key way to show respect is via empathy, that is, by stepping outside oneself and taking on the client's perspective. Another way is to show an appreciation of diversity and multiculturalism and keep a keen focus on a person's humanity and dignity. For instance, compared to the individualistic US, other cultures value relatedness more and this may drive a client's view of the helping process and relationship. If you are working across socio-economic lines (e.g., with a client in poverty) you should be sure to understand what that poverty means, rely on the client to teach you about it and their problem situation, and in the process fully respect the client. "If you are dealing with a client with some disability, do not feel sorry for him or her, but try to see the world from his or her perspective" (Egan, 2014). Always remember that you are dealing with individuals, not cultures or countries. To work in a cross-cultural working alliance you must understand your own culture and its biases, and how you differ from your client. You need to understand values, beliefs, and viewpoints of clients. You have to be aware of how (Egan, 2014):

> ...sociopolitical influences such as poverty, oppression, stereotyping, stigmatization, discrimination, prejudice, and marginalization might have affected groups and individuals with whom you are working no matter what their culture might be. Culture is one among many targets of such abuse. Any sort of diversity–such as age, education, and disability–can become targets of these negative behaviors.

You should get to know the basics of the family structure and gender roles of clients, keeping in mind that there is great heterogeneity on these within any culture. Try to understand how the culture you are working with views help-seeking and getting help. Be sensitive to varying interaction styles and nonverbal communications. "Work with your clients the way they are, but don't feel the need to apologize for who you are. Keep it simple" (Egan, 2014).

In terms of empowerment and self-responsibility, it should be assumed that clients can bring about change if they choose to do so. Clients should be invited to "own" their problems and gain a sense of responsibility to address them. Clients should not be viewed as victims, and you should not be deceived by appearances and assume someone is not capable or is fragile. Helpers can view themselves as consultants, or coaches. They should help clients choose solvable problems, yet problems that if solved would have a significant impact on their life. Helpers should help clients understand the "problem maintenance structure" (Egan, 2014), that is the things that keep problems from being solved, and thereby learn about it themselves. Helpers should view the helping process as a learning process by both the client and helper. They should help the client develop a bias toward action to achieve life-enhancing outcomes.

**Communication Skills**

Communication skills are of fundamental importance in helping, and in particular:

- Paying close attention to a client ("empathetic presence," that is a close attention, synergistically focused on what their perspective is so that if for some topic that arises their perspective changes, you have some understanding of how they are thinking),

- Listening (see below, "active listening"),

- Understanding what a client is thinking and saying,

- Responding based on good understanding,

- Helping a client fully explore concerns and focus, and

- "Helping clients challenge themselves to develop new perspectives on their problem situations and unused opportunities" (Egan, 2014).

*Good quality listening forms the basis for good helping.*

The helper should take turns with the client in dialog: no monologues. The helper should "connect" to the client and there should be a sense that the helper-client pair is co-creating outcomes; however, of course, the client is always kept in the driver's seat.

Helper understanding is based on "active listening" (empathetic and focused listening, being "tuned in" both psychologically and physically). In "active technical listening," the engineer must simultaneously listen in order to:

- Learn about the current role of technologies in their client's life (if any), including the utility of the technology, its patterns of use, and effectiveness.

- Learn about technology deficits, that is poor functioning that does not then result in the person's needs being met or assets exploited to help with problem management.

- Learn about the problem management situation as it relates to context and technical constraints for design or application of a technology.

These are elements of "active technical listening," where the engineer, without distraction, listens for opportunities to help via technology. Active technical listening is difficult, as it requires *both* active listening and significant knowledge of existing relevant technologies and technological feasibility of potential solutions. Active technical listening is time consuming, happens in real-time during dialog with a client, and if done well, can help move the dialog useful ways to help the client.

Poor listening includes cases where the helper (i) is not engaged with the client, (ii) employs partial listening where the helper is "skimming the surface" and only picks up pieces of what is said but maybe not the essential message,

(iii) gets the words but is not really present/engaged, and (iv) when the helper is "rehearsing" a response while the client is talking.

On the other hand, "empathetic listening" leads to empathetic understanding and responses. Empathetic listening helps the helper avoid responding improperly and misleading the client. The helper needs to focus on the client, and organize in their mind what is being said about: (i) client experiences; (ii) client points of view and values; (iii) client's intentions, proposals, decisions, and plans; and (iv) client strengths, opportunities, and resources. Cutting off the client when they are speaking must be done only after careful consideration of the implications of doing so. The helper must not only listen to the client, but also to themselves, the relationship with the client, the helper-client dialog, the two-way feedback, and the decisions made and actions taken.

The helper must integrate all elements of the client's narrative, then thoughtfully search for understanding of the client and problem situation, set in context. The helper may probe for clarity (verbally or nonverbally, via statements, requests, or questions), and verbally summarize issues being discussed to check with the client if proper understanding was gained. Also, summaries can provide focus and direction to the helping process, and may be more effective if the client can articulate a summary. Overall, the helper signals a desire to understand the client and their problem situation. The helper should try to create effective questions, not too many questions, and open-ended questions. Such probes/questions can help engage the client, and can help them clarify (make concrete) issues. Probes can be used to fill in missing pieces of the picture, and can be used to invite clients to challenge themselves to act. Skills in how to respond involve being perceptive, having competence ("know how"), being accurate, being assertive, and considering all issues (client, and problem situation, and context). If the helper responds incorrectly, the client should be encouraged to address this, as it will increase understanding, may provoke more questions and discussion, and can lead to a better response later. The helper should take time to think after hearing the whole client narrative and try to keep responses short (not a long monologue). In the dialog with the client, at times, it is appropriate to invite a client to challenge themselves (client self-challenge). The client may challenge themselves to exploit their unused strengths and resources (internal and external), to apply these to opportunities, to take action to achieve life-enhancing outcomes. Client self-challenge should help avoid client reluctance and resistance to change.

Helping is finding a way to assist the client to move from the current problem situation to a better situation.

### Problem-Management and Opportunity-Development

Egan uses a "standard problem management framework," to specify questions that the client should ask themselves in order to find life-enhancing outcomes (quoted from p. 22 of (Egan, 2014), except the bold font there):

1. *What's going on?* "What are the problems, issues, concerns, or undeveloped opportunities I should be working on?" This involves helping clients spell out his or her *current picture*.

2. *What does a better future look like?* "What do I want my life to look like? What changes would help manage my problem situation and develop unused opportunities? What goals do I need to pursue to manage my problem situation?" This involves helping clients paint their *preferred picture.*

3. *How do I get there?* "What do I need to do to make the preferred picture a reality? What plan will get me where I want to go? What actions will get me started on the right path?" The plan outlines the actions clients need to take to create a better future. This is the *way forward.*

4. *How do I make it all happen?* "How do I turn planning and goal setting into the kind of action that leads to the solutions, results, outcomes, or accomplishments that have the impact I'm looking for? How do I get going and persevere until I manage my problems and develop my unused opportunities?"... ...This is the *ongoing challenge of implementation.*

This framework may need adjustments for a specific culture.

For item 1., the helper works with the client to get a clear understanding of the client, their problem situation, and context. Sometimes, this may leak throughout the whole helping process. For item 2., the client may consider many possibilities for life-enhancing outcomes, and must determine what they really want and need, and what solutions are best for them, perhaps with some inputs from the helper. The client must determine whether to commit or not, and what they are willing to pay (in money, time, or effort), to get a life-enhancing outcome. For item 3., with the helper, the range of possible strategies/plans and actions to achieve goals must be considered (e.g., via creativity, divergent thinking, and brainstorming), and the best one must be chosen (e.g., a realistic one that fits within resource constraints and fits their values). Sometimes, it can be useful to create a "balance sheet" to evaluate the benefits and costs of choosing a strategy, and their acceptability or unacceptability. In some cases, the helper may need to assist the client in understanding what new information they need (i.e., learning) in order to succeed. Strategies chosen cannot be based on "wishful thinking" (with respect to their impacts), a "play it safe" approach, or to simply avoid the worse outcome. Strategies to achieve goals should be chosen to balance risks against the probability of success.

For item 4., strategies must be clearly connected to actions: the set of actions and their sequence must be determined, along with contingency plans and actions for when a plan is implemented. Plans and action sequences help provide client discipline, help avoid the client getting overwhelmed, may lead to better plans, provide the opportunity to evaluate how realistic and adequate goals are, make clients aware of what resources are needed to achieve a goal, and uncover unexpected obstacles. Implementing a plan requires client responsibility and discipline, good commitment, little procrastination, avoidance of learned helplessness, self-efficacy, organizational skills, social support, good outcome expectations, self-reward, and self-monitoring. Implementation requires strategy (a practical plan to achieve an objective), tactics (ability to adapt the plan to

the situation at hand, including the ability to change the plan as needed when unexpected things happen), and logistics (being able to get the resources for plan implementation in a timely manner as the plan is executed). Overall, the process must be flexible since when clients engage in each stage and task they do so differently and results occur in a nondeterministic fashion. That is, there can be significant uncertainty in the process of achieving a life-enhancing outcome, that requires later readjustments (e.g., changes in the plan or goals). The helper must assist the client in tapping into their own resilience, their ability to adapt to the current situation and succeed in spite of obstacles and uncertain results of actions taken.

During this dynamic process, the helper must use active, empathetic, and focused listening to create a "model" (most often, a mental representation, or "mental model") of the client, problem situation, and context. The helper does this by attending to what is said to the client; how they respond; an assessment of the problem situation and context; what plans the client has; what actions they take; and how the client, problem situation, and context change as actions are taken. Basically, the helper's model of the client, problem situation, and context should include every aspect that touches the helping process.

Using the model, the helper seeks to give inputs to the client on how to change the problem situation so that life-enhancing outcomes are achieved. For example, the helper may suggest selecting a different plan (e.g., if the current one is not working), different actions, a change in goals, or that the client gain a better understanding of something. These suggestions may arise due to implementation of a plan that fails and requires contingencies. Each helper may have their own approach to make suggestions to the client based on the model (e.g., different approach to design). Also, different cases may require different approaches. For example, different helpers may have different styles with respect to suggestions on a spectrum from "micromanaging" to "hands-off," and this should be adapted by the helper to fit the client and case considered. Suggestions to the client on how to move from the current picture to the preferred picture should be done in a spirit of the working alliance, be collaborative, and always keep the client firmly in the driver's seat.

The helper should be transparent: there are no secrets about what the helper is doing or how it is being done. To be a full partner, the client must know what the helper is doing, how they are going about it, and what their goals are. In some situations, it may not be good to provide a detailed "grand plan" to the client, but a sketch of the helper approach may be useful to orient the client and make them feel that there will be no surprises. Overall, it is likely best to share everything, but to do so at the detailed level only at appropriate times throughout the process, not up front.

**The Key Role of Education**

If the client is in the driver's seat, a key activity for the humanitarian engineer is to educate the driver. Indeed, this can dominate the whole interaction. The engineer tries to, via active technical listening and exploitation of their store

of engineering knowledge, work with the client in a close alliance to develop a technological solution. The humanitarian engineer should be fully prepared to teach. This requires the following:

- Having more than the relevant technical knowledge;

- Skills in organizing information;

- An ability to provide simple explanations that cut through the jargon;

- Creating simple demonstrations of ideas; and

- Recognizing what the client knows and does not know (understanding "where the listener is at" so that you do not teach "over their head").

Some typical topics a humanitarian engineer may teach a client include:

- How to pick or create a good technological solution (with an understanding of how it may impact their life);

- How to operate a technology properly so that it is most helpful; and

- How to maintain a technology.

An engineer essentially helps the client help themselves with a technology. Of course, the engineer may be in the driver's seat in *designing* (creating) some types of technologies that are very sophisticated; still, the client is in the driver's seat in all other ways.

### Deciding to Start or End Helping

Helping is expensive in terms of time, money, and effort. It is important to help the client set priorities so that they get the most out of the helping process, that is, life-enhancing outcomes that have the most value. Helpers need to consider whether their helping approach has value. Clients need to work on the right things, ones that have value. Both the helper and client should try not to waste time. Both should ask whether helping is working in this case, and whether it is worth it. The helper should help the client create value in the helping process, and of course, seek to create value themselves.

In some situations, the helper should do an initial screening of the overall situation to decide whether to start the helping process in the first place (e.g., via an assessment trip as described in Section 4.11.3). Some cases where a helper may decide against helping include:

Deciding whether to start or terminate the helping process is complicated.

- A situation where the client appears to be already solving problems on their own (you would not want to help as this could usurp the client's self-efficacy (agency) and partly destroy their sense of accomplishment of solving problems on their own);

- A client who has a history of not engaging in the helping process by expecting to have everything done for them by the helper;

- A client with only minor problems;

- A client whose commitment is low and is not willing to work or use their resources to achieve the agreed-upon life-enhancing outcome goal (e.g., if they have other competing agendas from family or job or demands on their time); and

- A client who simply does not want help.

If the case passes the initial screening by the helper and the helping process is started, yet during the helping process the helper recognizes that situations like these arise, the helper is going to have to consider terminating the helping process. Of course, the helper has to be very thoughtful about such a decision, and if the helper is to terminate the process, the client must be informed and told the reasons why. Of course, informing a client of termination, may cause them to re-evaluate their priorities, and actually positively change their behavior in a way that may result in restarting the helping process.

**Helping a Client as a Feedback Control Process**

Feedback control is embedded in Egan's general framework for how a helper should assist a client in solving problems. There are many feedback loops in the helping process. Above, the two-way feedback between the helper and client was mentioned. Each individual senses what the other is saying or doing and reacts: the two people are closely coupled via feedback. When the client takes actions according to some plan to meet an objective, the results of these actions are monitored by the client (and perhaps the helper) and the client may resort to a contingency plan if the current plan is not working. Also, the helper monitors all aspects of the helping process and based on what is happening may suggest changes in plans or goals.

In (Passino and Antsaklis, 1989) the authors use the 1986 3rd Edition of (Egan, 2014), in (Egan, 1986), to show how artificial intelligence (AI) planning systems can be viewed as feedback controllers, and as an example, on p. 28 explain one way that Egan's helping process an be viewed as a feedback control system. Using the ideas from (Passino and Antsaklis, 1989), a summary of Egan's helping process from (Egan, 2014) is shown in Figure 4.1. The bottom of the figure, below the horizontal dotted line, shows the client observing the problem situation and context via measured outputs, and taking actions in order to drive the measured outputs to values that correspond to meeting the goals that they set (shown as inputs on the left). The client is depicted as having a set of candidate plans (strategies), from which the client picks the best plan and then executes it by creating actions that change the problem situation. The uncertainty that enters the problem situation and context can result in actions not meeting expectations. Plan execution monitoring and situation assessment determines what is really happening at the current time. Information from these processes informs the process of forming a set of plans, picking the best one, and executing it. While the client is acting to move the problem

Helping a client is a special type of feedback control process.

situation into a better state, the helper is observing all aspects of the process and forming (adjusting) a "helper model." As this model is updated, it is given to a process where the helper generates guidance in the form of suggestions for adding/removing candidate plans, how to pick the best plan, how to execute a plan, and how to set or adjust goals.
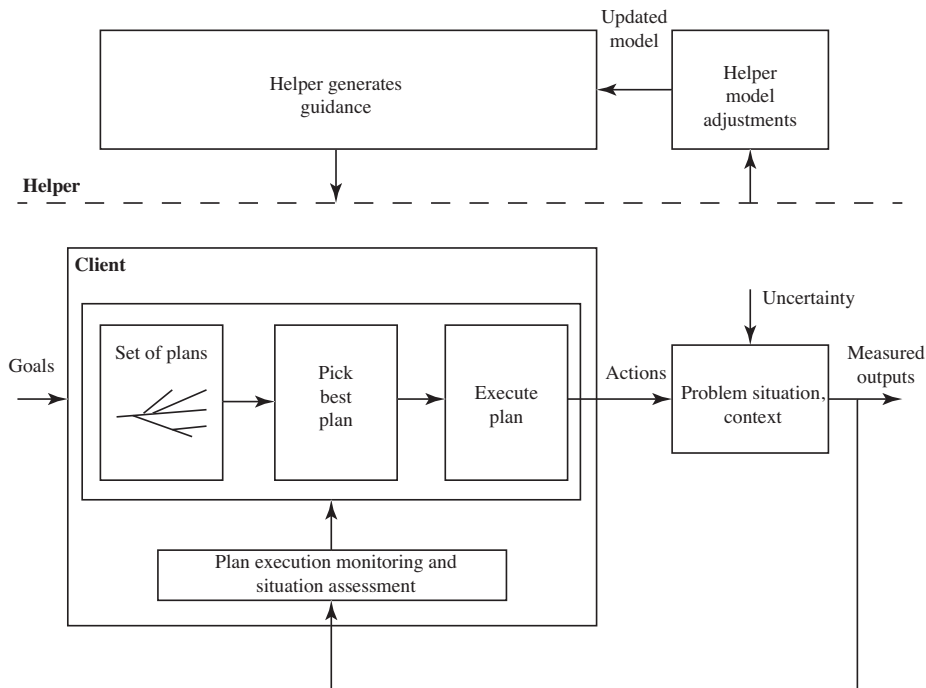


Figure 4.1: Helping a client as a feedback control process, a modification of Fig. 5 on p. 27 of (Passino and Antsaklis, 1989).

Many more details can be added to Figure 4.1 from the last section; as is, it only summarizes the helping process. Also, other diagrams like this are possible. For instance, someone who does not need help will subsume the layer above the dotted line, that is, they can help themselves. Indeed, clients will often achieve at least some of the functions of the upper level, but still need help. To depict that situation, another layer would be added on top of the upper layer showing a helper helping a client help themselves.

Figure 4.1 contains several well-developed ideas from feedback control theory. Most apparent is that the helping process is a general type of (adaptive) "model predictive controller (MPC)" (Garcia et al., 1989; Camacho and Alba, 2007; Rawlings and Mayne, 2009). The use of the auto-adjustment of the helper model, and its use to adjust what the client is doing, are ideas from "indirect adaptive control" (see, e.g., (Ioannou and Sun, 1996)); these ideas use the "certainty equivalence principle" which in this case says that the helper should go

ahead and trust the model and suggest changes to the client based on it, even though the model may not be accurate (i.e., they may not understand the client and their problem situation perfectly). If the helper and client are acting effectively, the process should converge to having goals met in spite of a somewhat inaccurate helper model.

### 4.1.3   Edgar Schein: Helping and Humble Inquiry

Edgar H. Schein is a professor emeritus from the MIT Sloan School of Management, and the author of a wide array of books. This section is based primarily on (Schein, 2011), but also has some material from (Schein, 2013) on humble inquiry, and makes connections to the treatment of helping in (Egan, 2014) that is in Section 4.1.2. Schein gives talks on (Schein, 2011) that are the subject of Problem 4.3, and also Problem 4.4. This section, along with Section 4.1.2, form the basis for the treatments of cooperation and teamwork in Section 4.3, and participatory community development in Section 4.2.

**Economics and Roles**

There is help that is actually helpful (such situations are described throughout this chapter), and other types of help that is not helpful (e.g., situations described in Section 4.2.12 below, and also Section 4.9). Help can be given to a single client such as a member of community, or a group of clients such as a community. Help can be broken into three categories. There is "formal help," such as when an engineer serves as a consultant to an organization, or we get help from a medical doctor, "semi-formal help" as when we get help from a computer expert with our computer, and "informal help" which is a process that "underlies cooperation, collaboration, and many forms of altruistic behavior" (p. 7, (Schein, 2011)).

Schein says that in any culture "communication between two parties is a reciprocal process that must be, or at least seem to be, fair and equitable," and that relationships are largely "based on scripted roles" (p. 11, (Schein, 2011)) that we play in certain situations. Each person often "claims value" (or, what is sometimes called "face" or that you may call "status") in a relationship to a single person, or with respect to a group of persons. Reciprocal interactions dictate that other persons validate that claim, or ascribe value to the other person. The helping process involves how the helper gives value to the client, and the client to the helper. Both these depend on how much *trust* there is between the helper and client, in both directions. Value we give to ourselves and others is typically communicated via social behavior. When in a new culture, it can be difficult to know how to communicate value in the local language and traditions of how we acknowledge another's value. As an example, in a paternalistic approach, the helper may convey that "they know what is best, just listen and do what I say" whereas the client my be made to feel like a child, and reject such an approach as being offensive.

Clients can be below helpers in status, but this can be fixed.

The New Oxford American Dictionary defines "trust" as a "firm belief in the reliability, truth, ability, or strength of someone or something." Here, it means that if we decide to reveal "thoughts, feelings, or intentions, the other person will not belittle us, make us look bad, or take advantage of what we have said in confidence" (p. 18, (Schein, 2011)). The "depth" of a relationship is the value we claim in what we reveal to others, or in a close relationship, the level of vulnerability which is the risk we take in opening up to another person (Brown, 2012).

**Helper/Client Traps**

In a helper-client relationship there are dynamics that result in inequalities or equalities, and uncertainties about assumed roles. Schein uses the term "one downness" of needing help by the client (p. 31, (Schein, 2011)) which creates a type of vulnerability in them (Brown, 2012). He says that "helping situations are intrinsically unbalanced and role ambiguous," and says that if you ask for help, you put your self one down relative to the helper. The temporary loss of value (face, or status), makes it difficult to know what to do next and may make it difficult to do anything effective. On the other hand, if you take on the role of the helper by being asked for help, you temporarily have "one upness" (gain status, value, face) and in a sense the client (or persons asking) confers power to you. This creates an unbalanced relationship, where the helper is expected to act, and it may be that the client becomes passive. This creates a difficult situation. How should the helper react? Take a chance that you can help immediately? Ignore the person?

Regardless, at the start of the helper-client relationship there is a type of imbalance, an inequality, with the helper one up (more powerful), and the client one down (more vulnerable). This imbalance needs to be fixed in some way, but it is often unclear how. In some informal helping situations, help may be given, and acknowledged, for instance, with gratitude by the client. Approaches to reducing the inequality depend on the helper, client, and situation. It may not clear what each expects of the other, and this can create anxiety or tension (Schein, 2011), which can raise emotions.

"Traps" are situations in the helping process that cause difficulties, and Schein identifies the following traps for the client (Schein, 2011):

Traps are situations where individuals can get stuck, and do unproductive things.

- There is often mistrust initially, which can result in the client trying determine whether the helper will indeed help (a type of " client trap"). The client may test, in some small way, if the helper can be trusted, for example, by providing some "hypothetical problem." There is a corresponding trap for the helper where they may move too fast to a solution, or they may provide a solution for the wrong problem (as the client has not had time to articulate the real problem), so that they may not learn from the client what the real issue is.

- A client may feel relieved to have shared a problem with a potential helper, and this may make the client feel dependent and subordinate to the helper;

however, this can be a problem (trap) if solving the problem requires work on the part of the client, which invariably it does, sooner or later. If dependency is promoted, it may be difficult to get the client involved at any stage of the process (e.g., operation and maintenance of a technology). Dependence can be acceptable in a minimum number of situations (e.g., children or disabled persons), but generally a goal of the helping process is to (gradually) reduce dependency (or avoid it altogether). The rate of reduction may depend on the frequency and duration of contacts between the helper and client(s).

- Some clients are not looking for help on a problem, just attention, reassurance, or validation and this is a type of trap. A client may have identified their own problem, and solved it, but they want validation or confirmation that they did it correctly, positive feedback, or perhaps even praise.

- Some clients may even look for opportunities to make the helper appear to be incompetent. This may especially happen if the helper tries to quickly solve some problem, without having enough information; in such a situation the client may use the opportunity to equilibrate the relationship by belittling the helper, that is by pulling the helper down, rather than building the client up. A looming trap for the helper in such a situation is to be defensive or argue with the client.

- Sometimes the client will stereotype ("all helpers like you say that"), have unrealistic expectations ("a helper like you can solve *all* our problems"), or "transfer perceptions" to the helper (the client may transfer positive or negative feelings, from deep and unconscious feelings about other people, like a parent).

There are a number of traps for the helper, a few of which were mentioned above, which are behavioral or emotional reactions that result from the helper feeling one up, that they have some wise advice that the client wants (Schein, 2011):

- The helper may give out advice too quickly, assuming they have quickly and accurately assessed the problem situation, and this pushes the client down even more than they are initially when it could be that the client has only "floated" a candidate problem, not the real issue to be addressed.

- If the helper falls into the trap of thinking they know the real problem, which is not actually the one that needs solving, then the helper may try to persuade the client that their advice or recommendations are most likely correct and so the helper needs to explain in detail why it is true. But, explaining something forcefully, that is irrelevant, is a recipe for frustration by both the helper and client. By working the wrong problem, no relationship-building is taking place and indeed the relationship can be hurt during the process.

- If the helper accepts a problem as valid too early, this validates the helper's position of being one up. Also, reinforcing dependency very early ("oh, I can take care of this, just sit back and relax") can make it difficult to get active client involvement later.

- Sometimes it is not appropriate for the helper to offer support as this may promote a client's subordinate status. A quick offer of support can put a helper in a strong power/expert role, when this may not be appropriate, especially early in the relationship when the problem may not even be well-understood.

- Some may resist taking on a helper's role; it can be challenging for the helper to be objective, yet involved, so that as help is really needed, a helper-client relationship can be constructed. When the helper takes on their role, listening to the client is very important, and the helper must give up their own guesses of what the problem might be. This is a useful way to equilibrate the helper-client relationship. *The client is given value or status by having them carefully describe the problem situation. It makes their viewpoint important in the helper-client relationship.*

- Some clients stereotype people who try to help, and color their views based on past "helpers." Sometimes a client may stimulate dislike or disgust in the helper; the helper needs to recognize such issues and may not want to enter into a helper-client relationship with such a person.

Due to the initial asymmetry in the helper-client relationship that results from the client asking for help and the helper offering help, the helper should seek to equilibrate the relationship; one approach to achieving an equilibrium is for the helper to listen, and thereby give active attention, and importance to, the client's understanding of their own problem.

**What is Not Known at the Start**

Initially, roles are not known and must be determined as this will help restore the balance in the relationship of the helper being one up, and the client being one down. Indeed, there  are a number of things that a helper does not know when the helping process starts (Schein, 2011):

It is important to acknowledge what helpers and clients do not know when the process starts.

- The helper does not know if the client will be able to understand the information presented to them, or questions the helper plans to ask. These issues often can arise in the engineer helper; it is the task of the engineer to learn how to communicate technical ideas in a way that the client can understand, and how to ask questions so that they are clear to the client. Such questions often help set the design constraints for a technology and are, therefore, crucial as they provide key parts to providing technical help.

- Next, the client may not have the knowledge or skill to follow recommendations for a solution. The helper will have to do some education in such

situations so that the client can engage in the helping process and help solve the problem. Sometimes, education can dominate the overall activities in solving a technical problem. Often, education is a good investment in time for the helper as it can help ensure that the client will be able to operate and maintain the technology.

- What is the client's situation, in context (e.g., relations to others, cultural constraints, and built/natural environment)? What is the relevance of these to the helping process?

- What are the client's experiences, and how do these change their "expectations, stereotypes, and fears?" (Schein, 2011). Does the client have very little hope, and therefore expectations, of the helping process? Do they stereotype helpers, or other members of the community? What are they afraid of? Due to these issues, the helper needs, right from the start, to help the client gain status, and try to get critical information about the client.

There are also a number of things that the client does not know at the start of the helping process (Schein, 2011):

- The client does not know if the helper has the knowledge, set of technical skills, and proper motivation to help. Also, the client does not know if they will be able to do what the helper asks of them.

- The client does not know, because they have not developed a client-helper relationship, what will happen if they ask this helper for help. Will they be ignored? Made fun of?

- Connected with the last point, the client does not know if they can trust the helper. Will the helper try to exert control over them? Will the helper try to sell them something? Exploit them in some way?

- What will this help cost the client in terms of time, money, effort, or emotionally and socially? Will the client have to reciprocate?

This shows that both the helper and client have areas of ignorance; the helper's role is to find ways to fill in these ignorance "holes" so that the helping process goes smoothly.

**Helper Role Choice**

There are three general roles that a helper can choose from (Schein, 2011) (quoted):

(1) An expert resource who provides information and services;

(2) A doctor who diagnoses and prescribes; and

(3) A process consultant who focuses on building an equitable relationship and clarifies what kind of help is needed.

Below, these three roles, that the engineer helper can take on at different times, will be referred to as the "expert-engineer," "doctor-engineer," and "process-consultant-expert" roles.

**The Expert-Engineer Role:** In the expert-engineer role, the engineer provides information or services, in a manner that is commonly thought of as a technical helper. It is common in humanitarian engineering that the expert-engineer may provide data sheets, other  technical details/drawings on why a technology will (or will not) serve the needs of a community, or perhaps a demonstration or prototype. The engineer-expert may also provide "services" by working with the community on assessing, installing, etc., a technology for an individual or community. The "expert-engineer" role is "based on a body of presumed knowledge and skill that can be applied to the client's problem to make the situation better" (p. 55, (Schein, 2011)); this can be knowledge from science, mathematics, and disciplinary-specific engineering knowledge/methodology and technology.

The helper must be careful to pick an appropriate role for themselves.

The likelihood that the expert-engineer will help depends on whether the client has identified the right problem, has clearly communicated it to the helper, the accuracy of the client in assessing whether the helper can solve the problem, and how well the client has thought through the consequences of doing what the helper will ask of them. Clearly, in many situations, for the expert engineer role, the client will not be able to perform some (or all) of these functions.

Schein says that persons who take on the expert role from the start, are less successful for more complex problems (p. 56, (Schein, 2011)). For engineering, "complexity" could be measured by the number of variables affecting the problem, dynamic and random variables that have a significant impact, functional complexity (difficulty of operating the technology), the diversity of human/social constraints, environmental impact, etc. Since technology interventions tend to be complex, sometimes too complex compared to what is needed, this implies that the expert-engineer likely should generally *not* start in this role for a helping process.

Starting in an expert-engineer role implies that the client will give away more power than what the "ask for help" resulted in. Staring in this role puts the engineer even higher, and makes the client even more dependent on their advice. In this role, the expert-engineer helper also will tend to give advice on what they know (their "tools of the trade," often engineering-disciplinary-specific, or set of pet approaches to fixing problems), which for every engineer is limited, and therefore the client becomes "vulnerable to being misled about what information or service would actually be helpful" (p. 56, (Schein, 2011)). Two engineers may give very different information or advice, if for no other reason, based on their experiences. A good fit, between an expert-engineer and client, is a specific time in the helping process where the engineer can assume the expert-engineer role, and it occurs only when the expert helper's information expertise (e.g., how to fix a water filtration problem) is obvious to the potential client. For all these reasons, the expert-engineer role should "rarely if ever be

used" (p. 57, (Schein, 2011)) near the beginning of the helping process. It may, however, be appropriate later in the helping process.

**The Doctor-Engineer Role:** In this role, the engineer diagnoses and prescribes solutions, and this role is viewed as a "extension and enlargement of the expert role" (p. 57, (Schein, 2011)). To some extent, it is analogous to how Sachs views the role for development economists relative to development (see Section 3.2.1). For this role, the client assumes that the helper will provide information and services, but also diagnosis and prescription (what should be done, exactly). The doctor-engineer role gives the engineer more power as the client relinquishes responsibility for diagnosis, and assumes then that "an outsider can come into the situation, identify problems, and remedy them" (p. 58, (Schein, 2011)). Yet, even in our personal lives we see how offensive advice can be, how expensive it can be, and how irrelevant to the current situation. A doctor-engineer can easily be seen as arrogant and irrelevant.

> The doctor-engineer role would never be chosen at eh very start.

Assuming that a doctor-engineer can come up with an accurate diagnosis is especially problematic. Diagnoses depend on getting information from the client, but also other people, historic information, and after mutual trust is developed (e.g., before a client will reveal potentially damaging information). If the diagnosis and prescription are developed quickly and without understanding the client (e.g., personality) and power/cultural aspects of the community that the client lives in, then the doctor-engineer is blind to the possibility that some technology solutions simply will not work. A client of a doctor-engineer may not provide good information to the doctor-engineer, and may not believe a diagnosis or utility of the prescription (e.g., that a specific technology is needed). The diagnosis is an intervention itself, and if it is not done in a sensitive manner, the client and/or community may be offended. It may not be know whether the client is able to make the recommended changes, and whether there is an increased level of client dependency that may ultimately adversely impact long term solution success.

Deciding to switch to the doctor-engineer role depends on whether there has been development of enough trust such that the engineer can move to the doctor-engineer role. This depends on whether the client senses a equilibration in the relationship, or the client is comfortable with the status differential. A key to this helping process is removing uncertainties so an effective helping relationship can be built (p. 61, (Schein, 2011)).

**The Process-Consultant-Engineer Role:** In this role, the engineer focuses on the communication process (e.g., tone of voice or body language) from the very start. The goal in this approach is to equilibrate status in order to build trust and help the engineer and client remove uncertainties about the helping relationship. For instance, it is good to clarify what kinds of help can be expected from the engineer, and what kinds of problems can be fixed. To do this, the process-consultant-engineer uses "humble inquiry" (see below) "in order to avoid the traps of being seduced by one's initial power position" (p. 62, (Schein,

2011)) and to convey interest in the client.

The process-consultant-engineer role assumes that clients must remain proactive since they (p. 62, (Schein, 2011)): (i) own the diagnostic and remedial initiative because they own the problems, (ii) are the only ones that know the many facets of the real complexity of their situation, and (iii) only they know what will work for them in the social/cultural context they live in. In some situations, the client may be able to help themselves; this can be more desirable than the engineer doing so as then the client is empowered so solve future problems. A key part of the helping process is the goal of teaching the client to identify problems and solve them on their own.

Virtually always, an engineer will *not* step into the expert-engineer or doctor-engineer roles at first. They will begin in the process-consultant-engineer role to avoid traps, help equilibrate status, get good information on what kind of help is needed, and what needs to be done. When trust is properly developed, it may be possible to step into the expert-engineer or doctor-engineer roles. Then, the engineer may switch between different roles as the helping relationship progresses.

## Humble Inquiry

New Oxford American dictionary says that "humble" is defined by

> having or showing a modest or low estimate of one's own importance

or

> (of an action or thought) offered with, or affected by, a modest estimate of one's own importance

and it defines "inquiry" as "an act of asking for information." So "humble inquiry" could be thought of as "asking for information while having a modest estimate of one's own importance." In (Schein, 2013), Schein provides his definition of "humble inquiry" as:

> Humble Inquiry is the fine art of drawing someone out, of asking questions to which you do not already know the answer, of building a relationship based on curiosity and interest in the other person.

Sometimes, Schein calls it "genuine inquiry" (p. 63, (Schein, 2011)), which could be thought of as being open and honest about what you do not know, and truly interested in the person's responses. He says that a key component of humble inquiry is that you assess your ignorance, and try to learn via observation and learning from the client. If you are working with a person from a different culture and language then the process is most often more difficult (Schein, 2013), and if you do not have sufficient language skills you will need a translator. Regardless, the cross-cultural helper must demonstrate good manners.

**Features of Humble Inquiry:** Humble inquiry is an approach to building the helper-client relationship. Humble inquiry is the heart of finding out what is needed for both the helper and client, and thereby is necessary for success in helping. Humble inquiry helps to equalize the relationship, even when the client is one down for having asked for help. Equilibration of the helping process is best facilitated by the helper giving the client something in "a supportive, giving, ego-enhancing way" (p. 66, (Schein, 2011)). The first thing to do in a helper-client relationship is humble inquiry. It could be that this inquiry is initially observation or listening in the first few minutes after meeting the client. You should not stereotype the situation the client seems to be in, even if everything seems to be the same as another case you have dealt with in a different location or context.

To begin the humble inquiry, you should start with some polite conversation, if appropriate, as discussed in Section 1.4.4. Humble inquiry questions may include:

1. "How are things?" or "How are things going for you?"

2. "How are things with your family?" or "How are things with your friends?"

3. If it is rainy season: "Does the rain create problems for you?" "Do you have enough clean drinking water during rainy season?"

4. If it is dry season: "Does the dry season create problems for you?" "Do you have enough clean drinking water during the dry season?"

The following questions, from (p. 68, (Schein, 2011)), may be interwoven with such questions:

1. "What do you have in mind?"

2. 'Tell me a bit more."

3. "When did this start?"

The dialogue that results from this humble inquiry process builds the client's status as in their role they know important things about how they can be helped. It shows that the helper is interested and emotionally committed to the problem situation and this helps build a helper-client relationship (even if if it is a temporary relationship). It provides critical information for helper so they can figure out what to do next. Without the information that the humble-inquiry-dialog provides, the helper may jump into an expert-engineer or doctor-engineer role too soon.

In the helper-client dialog, *asking the right (humble, gentle) questions* is very important, but *telling* the client is not important (Schein, 2013), and can have negative outcomes in some situations. Telling tends to put a person down, whether or not they already knew what they were told. If the client did not know what they were told, then either the helper is (i) communicating that the client should have known it, or (ii) emphasizing that the client does not know

something. In either case, this puts the client down. If the client already knows something that the helper tells them, it can be insulting to the client as it may appear that the helper does not really understand something about the problem situation.

Repeated humble inquiry can build trust between the helper and client: (i) the client helps the helper understand, and (ii) the helper shows interest in their situation. If the helper asks a good question, this can temporarily empower the client, but it may at the same time make the helper vulnerable as it can show that they do not know something that they should. Good questions from the helper can draw the client into the helper-client situation (relationship) and put the client in the "driver's seat" (imagery/analogy also used in (Egan, 2014)). This vulnerable opening by the helper makes it possible for the client to help the helper (slide into the driver's seat), or hurt the helper by mocking their ignorance, possibly to others. If the helper responds in a positive way, a piece of trust is gained and this forms the basis for a relationship. Via multiple positive interactions, the possibility for a solid helper-client relationship opens, as each person invests something and gets something in return (e.g., helper invests time/effort in asking genuine and relevant questions, and the client explains with honest open answers). Trust builds as the helper made themselves vulnerable in asking questions and the client paid attention and did not react inappropriately to these questions. Moreover, trust builds for the client as the helper showed interest in them and paid attention to what they said. It is often said (in different forms) "nothing happens except on the back of a relationship" (see (Homan, 2011), Section 4.2, and Section 4.2.5). Sometimes, the helper-client "relationship" term is replaced with "working alliance" as in (Egan, 2014) and Section 4.1.2.

There are four types of inquiry that Schein introduces to be components of humble inquiry. These are pure, diagnostic, confrontational, and process-oriented inquiry.

**Pure Inquiry:** The pure inquiry process builds the client's status and confidence so they are comfortable explaining their problems, tries to gather all needed information about the problem situation, and tries to involve the client in the diagnosis and action-planning process (i.e., get them firmly) in the driver's seat. Pure inquiry should start with silence on the part of the helper (p. 70, (Schein, 2011)), and only body language is used to convey a willingness to listen. The approach then tries to use questions that do not assume that there is a problem, and questions about the general, and work down to more specific, issues later. Start by just finding out generally what is going on. The client is subtly encouraged as they respond to questions to provide more information (e.g., via examples). This is a type of non-structured interview where there is generally no list of questions or issues to discuss. As the client's story slows to an end, they may ask for help; however, the helper should not make the mistake of giving a fast easy answer by becoming an "instant expert" (p. 71, (Schein, 2011)). The helper may feel the need for time to review what the client has said,

Often, the engineer-helper will start with pure inquiry, then possibly switch later to some diagnostic inquiry.

consider the built/natural environment aspects, or other client's views from the community, and may explain this to the client. Alternatively, the helper could steer the dialog to diagnostic inquiry, the next subject. The helper can have a sense if the client is ready for this next step by having a sense that the problem situation of the client is well-understood and sometimes, when in pure inquiry, the client initiates comments along the lines of diagnosis of problems.

**Diagnostic Inquiry:** In diagnostic inquiry, the helper tries to get the client to focus on elements of the client's story obtained via pure inquiry. These might focus on "why there is a certain problem?," "how did such a problem arise?," "what are the effects of the problem on the client?" The helper may focus on emotional reactions of the client to such basic issues (this could give good information on priorities for issues to be addressed), causes or motives (e.g., causes for poor access to clean water vs. motives of individuals in the community to help gain access to clean water), what actions were taken or considered in the past with respect to a problem discovered in pure inquiry. Virtually all problems identified by clients exist as part of the dynamics of a community of people along with its built and natural environment (e.g., see Section 4.2.2 and Section 4.12); hence there is a need for "systemic" questions (p. 74, (Schein, 2011)) that aim at untangling issues related to social structure of the community (family, friends, social network, etc.). The basic goal of systemic questions is to understand and respect the dynamic and uncertain complexities of context and their impact on the client(s).

**Confrontational Inquiry:** In confrontational inquiry, the helper interjects statements into the dialog with the client, that are the helper's ideas about the "process component" of the story (p. 75, (Schein, 2011)). Switching from primarily listening, the helper now makes suggestions on the nature of the problem, or its origins, and may also suggest solutions not considered by the client. Doing this, likely represents a switch to the expert-engineer or even doctor-engineer role; this switch must be done carefully and only when there is "enough trust and equity in the relationship" (p. 75, (Schein, 2011)) to achieve good communication from the helper to client. This switch to the other two roles my take a while, but sometimes may happen more quickly if trusting relationships are already established. Interjections can result in the helper gaining new information from the client that the client may have to cope with, and may lead the client into the helper's story, which may not be an accurate representation of what is happening. Indeed, confrontational inquiry may change all future interactions with the client.

**Process-Oriented Inquiry:** In process-oriented inquiry the helper tries to switch the focus of the dialog to "the here and now" (p. 77, (Schein, 2011)) helper-client interaction in order to make the client aware of the helping process that is going on in the immediate moment. The helper could ask: "What is happening between us right now?" "Do you like how our conversation is

proceeding?" "Is this approach to discussion working" (p. 77, (Schein, 2011)). Questions like this can help teach the helper how s/he is perceived by the client, and how much trust there is in the relationship.

**Constructive Opportunism and Maintaining Situational Propriety:** The pure inquiry approach is largely client-driven and results in a client-controlled flow of conversation. Sometimes, it is best to switch from this flow to allow for "constructive opportunism" where the helper interjects a question, more in the style of confrontational inquiry. This may make perfect sense so long as it is not done to the extent, at least near the beginning, that the helper dominates the conversation. Generally, especially on a first meeting, the engineer-helper should not interject ideas or solutions.

The helper's approach should *always* be to show client value, promote client status, or "give face" to the client. It is best if the helper knows "the client's areas of vulnerability and sensitivity, and either to avoid them or deal with them in a sympathetic manner" (p. 81, (Schein, 2011)). The helper should be confident in the level of trust and quality of relationship, along with there being an equilibration of status/value, before switching from

<div align="center">Pure or Process-Oriented Inquiry</div>

to either the

<div align="center">Diagnostic or Confrontational Inquiry</div>

Similarly, great care should be taken by the engineer-helper considering a switch from

<div align="center">The Process-Consultant-Engineer Role</div>

to either the

<div align="center">The Expert-Engineer Role or The Doctor-Engineer Role</div>

Overall, the humble inquiry process should keep the client in the driver's seat to (i) give them status and make them confident and active problem-solvers for their own problems, and (ii) provide good information that both the helper and client can use.

## 4.2 Participatory Community Development

"Community" is defined by the New Oxford American Dictionary as "a group of people living in the same place or having a particular characteristic in common" or "a feeling of fellowship with others, as a result of sharing common attitudes, interests, and goals." The extent to which each of these two definitions holds depends on the particular group of people. Almost no one lives completely isolated from any other human; hence, virtually all persons belong to some community, even if it includes only their family. Typically, though not always,

the word "community" here will be used to discuss a group of people who live, work, or congregate relatively close to each other (e.g., in a rural village or town, area in an urban slum, job site, orphanage, school, or university). Hence, we will consider "living communities," "work communities," and "educational communities." Note that the above definitions of community allow even some countries to be considered communities and that view is taken in a relatively small number of cases in this chapter (e.g., when discussing wide-area problems and structural injustice). Usually, two or more people are required to have a community; however, in the case where we do humanitarian engineering for only one person (e.g., designing a wheelchair specially suited for a disabled person), we will still consider it to be working with a community as improving the situation for one person typically has some impact on the community that person lives in.

We will continue with our use of the term "client" as a member of the community. If you adopt a perspective on development where your clients do not pay cash for humanitarian technologies, but work with you, you may prefer a term like "collaborator," "teammate," "member," "partner," "participant," "coworker," or "associate." If you adopt a business approach to development you may simply call the client a "customer" or "consumer." To emphasize certain aspects of creating humanitarian technology in a community, especially as it compares to conventional technology development, however, we will often use terms like "client," "collaborator," or "participant." Indeed, here, we have a heavy emphasis on "participatory development" so "participant" is a natural term.

The objective of community development is to increase the capabilities of members to act effectively and independently, increasing the number and utility of beneficial community assets, and making sure that the members own the process of change and the results of change so they are empowered. The treatment of community development here begins with an overview of social and physical aspects of a community, and is followed by aspects of how to promote participation by community members in development, with a treatment in the following order:

1. Social aspects of the community requiring attention (e.g., oppression), and perspectives on how to view a community (e.g., as a system) (Homan, 2011);

2. "Community capitals," human and physical assets and aspects of a community, focused on understanding how a community works (Flora et al., 2004; Flora and Flora, 2013); and

3. Features of "participatory development" where the community gets involved in many or all of the aspects of the development of their community (see, e.g., (Tufte and Mefalopulos, 2009; Mansuri and Rao, 2013)).

The first two of these give an idea of what is encountered when dealing with a community. In particular, the first two subsections of this section are mainly

based on parts of Mark S. Homan's book "Promoting Community Change: Making It Happen in the Real World" (Homan, 2011), whose audience is typically social workers in the US and globally. All quotes in these parts are from that book, and a few section headings. Homan is a social worker, and past professor, with many years of on-the-ground community development experience in many different areas.

## 4.2.1 The Challenges of Community Development

Homan challenges us to "look and see" what is happening in your community, and feels that this makes it difficult to ignore the call to try to work for change to promote social justice (Homan, 2011). He says that helping professions consider the following themes (Homan, 2011).

**Confronting Oppression**

Persistent social problems often involve oppression (e.g., the term "traditionally oppressed" is used by social workers in the US for some communities). Should we attend to oppression's "by-products" or work to reduce the "political, social, and economic structures that support it?" (Homan, 2011). By staying silent about oppression, do we support it? Homan recommends reading Paulo Friere's books "Pedagogy of the Oppressed" (Freire, 1993) and "Pedagogy of Hope." Homan defines oppression as the "systematic subjugation of people, their rights, opportunities, hopes, and beliefs to benefit the interests of others who have the power to maintain the current state of affairs." Oppression comes in many forms including systems that use racism to hold people down, or economic systems that exploit people. "Oppression is sustained when people are separated from one another and the recognition of their shared conditions and interests" (Homan, 2011). There is often some type of justification given for oppression that is used to keep oppression in place, avoid consideration of other options, and hence even the oppressed may not recognize themselves as oppressed or view the situation as so impossible to change that they do not even try. The oppressed may even resist challenges to prevailing conditions since they do not believe they can succeed in the face of change; they may have "bought into the notion that they are "less than"–less worthy, less able, less deserving. This can create guilt and self-hatred, leading to even greater submission and obedience to the oppressor" (Homan, 2011). People can become "co-conspirators" to their own oppression, and sometimes may act as oppressors themselves, which further weakens the oppressed. The oppressed may try to act like the oppressor to gain a feeling of power.

To confront oppression we must understand privilege. For instance, we need to understand our own unearned advantages and exemptions that make things easier for us, can sometimes make things harder for others, and that are deserved by all. If you try to act on behalf of the oppressed, the action is legitimate if the oppressed work with you in taking the action. "Oppression continues as we do

Development conditions can result from oppression now, or historically (e.g., colonialism and racism).

things for people rather than with them" (Homan, 2011) (a basic justification for participatory development).

### Empowerment

Promoting community change does not come through your leadership and others following, but by working in concert with others who are "acting powerfully" (are empowered). Acquired skills and social connections make people more capable. You should try to help partners believe in their own power, the power of the group, and give partners self-worth, confidence, and control so that feel they can participate with others to favorably change conditions that affect them. This is known as "empowerment." You cannot force people to be empowered, but you can affect the likelihood that they are empowered. Homan says that empowerment depends on:

Empowerment is a key goal.

1. Individual's interest and investment in the project, and a feeling by the individual that they are an important part of the project.

2. Individual's beliefs that there is a possibility for project success and good outcomes.

3. Identification, recognition, and development of people and group resources.

4. The existence of opportunities to take concrete action and make useful contributions.

5. Recognition of a the group's shared interests and shared risk taking.

Decision-making, opportunities, tasks, encouragement, belief in capabilities, and recognition of contributions, should be spread across and between participants. Group focus needs to be on overall progress and outcomes to reinforce common commitment and "shared risk taking" and finding opportunities to do things as a complete group to experience "united power." The group should reflect on what has been done and what has been learned.

### Resistance to Working for Change

There are a number of types of resistance to change: First, the "sunk cost effect" involves continuing to invest in something that is failing since it is too difficult to stop since there has been so much invested. Stopping the investment would imply that all past investments were wasted or a mistake. Second, "Perhaps the most profound source of resistance to change is simply what we tell ourselves" (Homan, 2011). While limitations must be acknowledged, so must assets and ways to use assets to break down limitations. Third, "Change can cause discomfort and provoke fear" (Homan, 2011). Resistance to change arises in these cases and is difficult to overcome. Fourth, "Change means that things aren't predictable anymore" (Homan, 2011).

Hesitation or trepidation about promoting change is natural, but Homan identifies the following steps to help (Homan, 2011):

1. *Confront the source of your concerns:* Consider how to organize your time, or assess and list your assets to reduce uncertainty in success.

2. *Develop support:* Work with others to share work, get encouragement, and benefit from group problem-solving. "Cultivate support" (Homan, 2011) and communicate with others who have succeeded in promoting change.

3. *Look at what you have that you can use:* There are skills, talents, social connections, passion, and energy. Homan says that if you take stock of what you have, it can be "pretty encouraging to realize that you already have a lot going for you" (Homan, 2011).

4. *Remind yourself of why the change is important:* Use the feelings you had about the need for change to continually motivate yourself, and remind yourself of the consequences of dropping the project (change often comes from setting ideas that things can be better and Homan supports being an idealist over the long term).

5. *Take advantage of training opportunities:* Get involved in workshops, classes, or other training to increase your own "sense of personal capability" (Homan, 2011).

6. *Identify a simple starting point:* Do not overwhelm yourself to the point of inaction; find a simple task and get started.

7. *Decide to act:* "Sort of doing things" gets you nowhere (Homan, 2011); decide to act and take clear tangible action.

8. *Reflect on your actions:* You and the group should think about actions you and the group took and try to learn from these to improve effectiveness of future actions.

### Root Causes vs. Symptoms

Should root causes be focused on, rather than treating the symptoms of root causes? Without removing root causes, community problems can persist over long periods of time in spite of effective treatment of symptoms. Homan provides a number of reasons why symptoms are addressed rather than root causes, here posed as questions (Homan, 2011):

1. Do we have the time to address root causes?

2. Are root causes too complex to even determine how to start addressing them?

3. Will it take too much work?

4. Will addressing symptoms help "smooth things over" rather than causing significant disruption by addressing root causes?

Humanitarian engineering can eliminate some root causes, via for instance, technologies for water purity, sanitation, food security, health, and education.

5. Are the people disturbed by addressing root causes more important than the immediate suffering of people?

6. Are the people who are suffering and having problems "worth the trouble"?

7. Is addressing root causes so significant of a project that it would cost too much?

8. Will the "major surgery" needed to address root causes kill or hurt the patients?

9. Does addressing only symptoms allow us to hide things we do not want to see?

10. Are we afraid that addressing root causes will result in chaos and a lack of control?

11. Is only addressing symptoms rather than root causes simply a bad habit?

12. "It is easier to shut up those who feel the problem than it is to challenge those in authority because those in need are less threatening and are appreciative of any help we can give them" (Homan, 2011)?

13. Do we address symptoms simply to satisfy our own need to feel that we are doing at least something?

Or, Homan says: "When we are up to our behinds in alligators, we forget that our original intention was to drain the swamp" (Homan, 2011).

**Relationships, Culture, and Diversity**

A theme in community development is "that everything happens through relationships that generate and use the investment of time as well as the varied perspectives and skills of many people" (Homan, 2011). Elements of relationships include communication, trust, and mutual interest, that can be more challenging in the presence of cultural differences (see Section 1.4); however, any differences can widen perspectives and skill sets.

Cultural competence is a key skill for promoting community change, and is basically the capacity to appropriately respond to different cultural environments and strengthen inter-cultural relationships. To begin a cross-cultural relationship, it is good to recognize that both sides will learn from such a relationship. You might both have different experiences, and different ways of seeing and relating to the world, but you must work toward a common interest. Working in the presence of cultural diversity demands that you confront the issue of racism that is rooted in ignorance and fear. To become culturally sensitive, it is important that you become "culturally aware" by learning "cultural knowledge" about someone's history, values, belief systems, and behavior. Knowing about cultural differences, but not assigning judgments of whether aspects of

cultural differences are better or worse (or right or wrong) indicates you have "cultural sensitivity." You should be aware that various difficulties can arise in cross-cultural relationships between individuals and groups; however, people of good will can work together based on their common interests and this will break down cultural barriers.

Even though cultural differences should be acknowledged, it is also important to acknowledge the diversity in any cultural group, and not assume that everyone in another cultural group is the same. In two interacting cultural groups, as may arise in development, it is important to know the history of the interactions and what the similarities and differences between the two groups are. When working with another cultural group it is important to understand their "customs, traditions, social networks, and values" (Homan, 2011), language (and slang), and their leadership styles, and who has the power. Moreover, you should understand your own strengths and limitations in this respect. What are your biases, fears, "assumptions, expectations, intentions, desire and capability to learn, and limitations of your own experiences" (Homan, 2011)? It is impossible to master it all, and you can "never fully understand another's experience and perspective" (Homan, 2011). But, you can learn. Some ways to learn include:

- Ask (it is respectful to ask, and many people are very happy to be asked),

- Find "resource people" who will teach you about the community,

- Acknowledge that you are there not to do things *for* the community but to work *with* them,

- Do not romantically stereotype a group or define them only in terms of their oppression,

- Encourage people to speak and then listen, and

- Acknowledge that everyone's experiences, including yours, shape your perceptions.

### 4.2.2 Theoretical Perspectives on Community Development

Homan says "a good promoter of change is well grounded in theory" (Homan, 2011). A number of theoretical frameworks have been developed through specific actions in communities, and these then constitute general approaches to community development.

**Systems Theory for Communities**

In this approach, you think of a community as having inputs (e.g., natural resources, built space, economic conditions), processing (e.g., by humans, buildings, and their many interactions), and outputs (e.g., products, group action,

and health). Due to the massive interconnectedness, one part of the system can affect even a distant piece of the system. Of course, the network of social interactions by humans in the community form an important basis, but this network's behavior is shaped by the natural and built environment. Due to the interconnectedness, the actions of people in a community can positively or negatively affect the well-being of the whole community, as can inputs from outside the community. Different communities interact via their inputs and outputs. Social systems theory perspective is treated in (Dale and Smith, 2013).

Dynamic systems theory approaches are used throughout this book, via an emphasis on feedback control of dynamical systems and distributed optimization. First, in Section 2.4 dynamic wealth distribution across a group of individuals is considered. This is followed by simulation of a democracy for voting on the wealth distribution policy, along with the dynamics of an environmental justice policy. Second, in Section 3.6 poverty traps, technology diffusion, and wealth distribution and democracy for breaking poverty traps for a group of people are considered, along with regulation of an environmental justice policy. In this chapter, in Section 4.12.1, modeling and computational analysis of cooperative management of community technology is studied. Also, in Section 4.12.2 a mathematical model of a community is developed, along with shared resource use, and a computational analysis is performed to study the effects of technologies on sustainable community development.

### Healthy and Close Communities

As Homan points out, the World Health Organization defines health as "the state of complete physical, mental, and social well being, and not merely the absence of disease and infirmity," and that healthy communities "tend to produce healthy people" (Homan, 2011). A healthy community sustains connections between its members and resources, and with outside resources and people. It recognizes resources and uses them to help members and the community grow. Resources include those of the natural and built environments, along with member skills and talents. An unhealthy community only sees limitations and bad connections among members and to resources. Healthy communities are inclusive in sharing benefits and decision-making, and celebrate diversity, and promote their "capital" which includes (see Section 4.2.3, also): the natural and built environments, financial or economic, human (the key resource), social, spiritual, cultural, and political. Information is a form of capital (communication, natural or electronic, including storage) as it, for instance, promotes relationships and community action. The main issue in community development is to recognize, grow, reinforce interactions between, and combine the various forms of capital, to create stronger communities and healthier members.

Social capital, is, however, of central importance to community development. Homan defines social capital as "the system of community norms and interrelationships that produce trust, collaborative action, and community consciousness" (Homan, 2011). Usually, social capital building is not the central goal, but it is built by addressing other issues and then may be useful for ad-

dressing other issues more effectively. "Community capacity," the ability of members to take effective actions to improve the functioning of the community, and social capital reinforce each other in positive ways (each increases the other). Social capital grows if it is used, but decreases if it is not. Strong social capital leads to collective action to solve common problems. Weak social capital implies mistrust, belief that the community's problems are those of someone else, feelings of powerlessness and exploitation, and lack of willingness to cooperate as members do not believe that others will cooperate. Some point out that the "economic class gap" is reinforced by a "social capital class gap:" lower-income communities tend to have less social capital, which then hurts the low-income community's development (Homan, 2011). Social capital is crucial as it affects everything about promoting community change and if you are not building social capital "you need to rethink the work you are doing" (Homan, 2011).

A close community is defined as the group of people you normally interact with and "draw identity and meaning from" (Homan, 2011); it is a subgroup in a community. Focusing on your close community has the benefit that it is easier to mobilize the group for action, and the benefit that improving the close community results in a positive impact on the larger community it is embedded in. However, working with your close community has the disadvantage of separating yourself from other communities and how they influence your close community, and also the disadvantage of solving local problems where solutions may be unraveled by outside forces.

**Power in a Community**

First, consider your own power to promote change in a community. Power is not dominance, it is just the ability to provoke a response, for example, to create action, collaborate, or educate. Normative or moral power can drive actions toward good ends and provide strength and commitment. "Everything happens through relationships" (Homan, 2011). Without relationships there is no power. With an established relationship, actions are as much about the relationship as they are about benefits to the individuals acting. "Power comes through connections and the ability to mobilize the resources, assets, and forces available through those connections" (Homan, 2011). Resources include relations with others taking action, financial resources, information, skills and talents, and influence. If you have more connections, you have a better ability to bring resources to bear on a problem and hence more power to promote change.

All these statements, however, must be considered in light of the power being held by various people in a community before change is promoted. Sometimes, there are highly conflictual relationships in a community, such as ones that have developed as the result of power differentials and control of resources by those who are powerful. Just because a community, taken together, has resources, this does not mean that all resources can be marshaled to help with community development. Powerful people may not be willing to help, may feel that it is not in their interest to have a community develop, and can take significant steps to

hinder or stop any progress. Powerful people can have strong effects on success or failure in a community.

**Organizing and Action**

Homan defines an organization as a group of people "acting together over time to produce a desired result" (Homan, 2011). Good organizations try to increase the amount of involvement of members. Change only happens via action, and action happens when people find the current situation unacceptable (they are not comfortable with it) or are excited about a new opportunity. Action requires some belief in a sufficiently probable success, some tangible course of action, and support by emotion (i.e., not just intellectual understanding). To create change, you need to arouse feelings in people and especially enthusiasm for taking action.

All actions to promote change in a community must take into account "values, norms, and rituals" of members. It is the cultural values that are used to determine what is important to the community, what people care about, or has meaning. Cultural norms set standards for what is acceptable and unacceptable behavior. Perceptions are affected by culture, as are relationships.

A community must be receptive to change for it to occur. Minor, incremental change may be easy to accept so long as it does not cost too much in money, time, and changes in behavior. Multiple small changes over time can result in a changed system. There can be many sources of resistance to change including, doubt, habit, or acceptance of the status quo (thinking things are fine as they are, or if change disrupts relationships outside the community).

**Principles of Community Building**

Homan says that three principles of community building are (Homan, 2011):

1. *Change and transformation:* There is more to transformation than creating things or transforming a landscape or enhancing efficiency. New products should enhance human dignity and raise human spirits. Transformation seeks to go beyond treating symptoms, to addressing root causes.

2. *Praxiology:* This considers action with personal and social consequences, and proceeds by an interactive process of reflection and action. Our actions begin with how we perceive the world and we get our knowledge by taking actions and reflecting on the results of those actions. We see people as "co-creators" in promoting change. Feasible change is determined by members' beliefs in themselves, the group, how the world works, and what they believe they want and can do. We value members' ideas and leadership. The view is that taking actions leads to better knowledge in the group, which in turn leads to better actions, and so on. Praxis thinks of bringing people together to act, plan, and learn. It requires people to believe in human dignity for themselves and others, and there is an emphasis on "mutual learning" rather than an expert taking actions on the uninformed.

3. *Appreciative inquiry:* In every community there are some things that are going well. It is important to focus on recognizing, valuing, and validating relationships and actions that promote community health as this will encourage us to shape a better future. In the appreciative inquiry approach, you produce what you pay attention to; you focus on the positive and its use as a basis for further community development. Or put another way, "just focus on the good things and good things will follow" (Homan, 2011). The principles of appreciative inquiry include:

- You both experience reality and create it;
- Rather than diagnosis preceding problem solving, it says we learn by inquiring and acting and therefore should start quickly;
- Envisioning a positive future as a guide to actions; and
- A focus on positive aspects rather than negative ones.

To find the positive things in a community, focus on "what gives it life," find what caused good things to happen such as what was happening in good times for the community, seek out imagination, passion, and boldness that provoked people to do extraordinary things, and collaborate with others to find good things. You should try to discover what works and do more of it. Groups within the community should be encouraged to dream together about what could be, and then determine what to do, based on what worked in the past.

### The Community Development Model

Homan says (italics are his) (Homan, 2011):

Community development *recognizes sources of wealth* (or community capital) that exist in the community, *helps those sources to grow*, and *links them with one another* to form a stronger, more capable community. Fundamental to this approach is the belief that *members of the community itself have the primary responsibility for decision making and action.*

The goal is to create self-reliant and self-sustaining communities. This involves community capacity building so it can act on its own behalf via the involvement of its own members. It involves shared responsibility of members and a group competence to act on that responsibility. It involves asset-building that helps members act and build a sense of community.

Community development usually proceeds along three dimensions: economic (e.g., jobs), physical (e.g., roads, parks, and buildings), and social infrastructure (e.g., network of relationships, better inter-member interactions, and cooperative problem solving). Finally, there is the element of ownership: a community must be able to assume ownership of a project before you undertake it.

Community development involves building on community assets, increasing skills of individuals, interconnecting people, connecting to existing resources,

creating or increasing community resources, the community taking ownership of direction, action, and resources, and the expectation that community members will do all work possible (this may require education on some subjects, and in as few cases as possible outside help). Homan says "Too often we train people for dependency, helplessness, and hopelessness. We train them to believe that they can't do things themselves. We usually do this in unthinking kindness– in the name of helping" (Homan, 2011). Community development also entails creating beneficial external relationships, promoting self-reliance and confidence, and self-sustenance. Often there are two simultaneous objectives: the pursuit of social justice for the community (e.g., to promote human dignity) and increasing community assets and healthy community functioning. Social action is often needed to achieve social justice and community development is often needed to fulfill the promise of social justice.

**Development vs. Service**

Development and service are different. Development focuses on strengths, and individual and community resources, that can be used to promote change; development focuses on community potential. Professionals often have a "service orientation" that starts with identification of problems and unmet needs, then provides services for these (creating passivity in the recipients), not expecting anything from the recipient. Homan says that services rarely change conditions and simply accommodate them, so they *perpetuate* need (Homan, 2011). Development requires contributions from community members and seeks to increase individual and community strengths to provide authentic self-sustaining change. Service is typically characterized by a power differential between the professional and the community member who is dependent on that professional. Sometimes, then, people slip into roles of "giver" and "receiver" or "expert authority" and "compliant needy person" (Homan, 2011). In the development approach, there is a more balanced power relationship, that is, there are "partnerships" between professionals and the community members.

## 4.2.3  Community Capital and Requirements

The way you approach a community is based on what you know about it (Homan, 2011). To characterize communities, the authors in (Flora et al., 2004; Flora and Flora, 2013) emphasize seven types of "community capital:"

1. *Natural capital:* These are resource assets, farm land, and features of the landscape.

2. *Cultural capital:* Festivals, work-ethic, and other aspects of culture (see Section 1.4).

3. *Human capital:* Peoples' skills and abilities, including the ability to get and use information.

4. *Social capital:* This represents the connections between people and orga-
nizations, and has two components: (i) "Bonding social capital" are close
ties that lay the foundation for community cohesion; and (ii) "Bridging
social capital" that involves weak ties that create and maintain bridges
between organizations and communities.

5. *Political capital:* This is the access to power and power brokers (e.g., those
who own and control resources).

6. *Financial capital:* This is the set of financial resources that can be invested
in the community (e.g., for projects or business development).

7. *Built capital:* This is local infrastructure, everything from houses and
buildings to streets, water, sanitation, and telecommunications.

Each community will have different capital, and mapping capital assets will help
you understand a community and impact the approach to community change.

Community capitals
identify basic
community features
and set the context
for technology
designs.

All aspects of a community, physical, human, and social define "context,"
and can impact the design of technology solutions, for example, by providing
constraints on a design or performance requirements (e.g., for the participatory
technology development process in Section 4.7). Next, the community require-
ments/capitals from (Homan, 2011) are outlined, also using ideas from (Flora
et al., 2004; Flora and Flora, 2013).

**General Features: Human, Physical, and Environmental**

First, it is important to understand the context of the community by researching
the country and/or city it resides in. Some features of these that can typically
be found easily (e.g., on the internet) are discussed in Chapter 1 and include
the status of the poverty and development, some cultural characteristics (e.g.,
religion, festivals, music, and values), information on weather patterns, and
geographical features to mention a few.

Gaining a fuller understanding of a community within a country requires
visits to the community, and an understanding of what to look for. To look,
it will typically make sense to walk around the community and talk to people
there. A sampling of features of a community you may want to look for include:

1. *Human/Social:* How many people live in the community? Is the popu-
lation going up or down? Population density? Age distribution? Mar-
ried/single? Diversity characteristics? Family characteristics (e.g., num-
ber of children)? Cultural characteristics? Educational backgrounds?
Typical length of time of membership in the community? Community
member interaction patterns? Do people live in the community and work
elsewhere? Do other people come to the community from outside to work?

2. *Physical:* How much landmass does the community reside in? Distinct
boundaries? Is there a meeting place or landmark? Are homes, buildings,
and transportation infrastructure in the community clean/dirty, old/new,
well-maintained or in need of repair?

3. *Environmental:* Natural resources? Mountains? Plenty of water, vegetation, or trees? Insects? Wild animals? What is the climate like? Temperature variations? Dry/rainy season?

## Environmental, Physical, and Economic

Requirements and capital in these areas include:

- Clean air and water, access to food, shelter, clothing, and healthcare?

- Recreation space, visually appealing space?

- Waste, drainage, and sanitation systems?

- Community projects built by community members (e.g., a park or monument)?

- Access to goods and services? Market? What is available and how much does it cost?

- Income levels? Regular work? Seasonal/day-labor? Women/minorities work?

- Occupations? Women/minorities?

- Barriers to opportunity? Women/minorities?

- Unused economic resources?

- Is bartering used?

- Who are the employers? Services? Industry? Growing or in decline?

- Does the money stay in the community or leave it? Do people make their money outside or in the community? Nonmembers make money in the community and take it elsewhere?

- Other external forces outside the community that affect its economic well-being?

## Human Development, Political, and Communication

Requirements and capital in these areas include:

- What knowledge/skills exist in the community? Which ones are needed?

- How are knowledge/skills developed? Apprenticeship? Formal/informal? Schools? Trade schools? Do these affect the economic situation?

- How are talents/skills recognized? Are some person's contributions ignored? Are "nonmarket" talents recognized (e.g., cultural aspects such as music and dance)?

- Do people offer their time, money, and skills to help in community efforts?

- Are people enthusiastic about helping the community or are they passive (see below) or pessimistic?

- What are people's connections to political power inside and outside the community?

- Do people feel they have the right and obligation to participate in political processes?

- How are community decisions made and about what? Formal/informal? Who do things really happen? Where is the power?

- Are there formal governmental structures? Who is the formal leadership and how did they get there? Are there informal leaders/decision-makers?

- How are community issues recognized by leaders? How are issues addressed?

- Who is given voice in the community and who is ignored?

- How do people learn about what is happening in the community?

- Is information technology being used? What kind? How expensive? Skills?

- Who do people listen to as an authority and how do they decide what is true?

- How are people educated? Schools? Other? Who controls the schools and curriculum?

- Is there some kind of media that is commonly used (e.g., radio)?

- Do people want to communicate with each other?

## Cultural, Spiritual, Social, and Emotional

Requirements and capital in these areas include:

- What role does music and dance play in the community?

- How is culture viewed? By different subgroups in a community? How does it influence the community? In economics, politics, and human development?

- What are expectations for roles of men, women, children, old, and young?

- Are there perceived threats to culture? Is traditional culture in place, or is it changing?

- Is cultural diversity within a community respected? Is there cultural conflict?

- How is culture transmitted in a community? To younger generations?

- Is spirituality valued? Discussed? Spiritual interests attended to?

- Does spirituality come in different forms in the community?

- Is a distinction between spirituality and religion made?

- Is there tolerance between religious groups, and with nonbelievers?

- What role does spirituality and religion play in community development?

- Do people want to, and have the ability to, work together?

- Do people feel safe and secure? Do people trust each other?

- Is there a sense of community identity and pride?

- Do people feel like they are a member of the community, and are cared for by others?

- Are people free to contribute to the community, along with their own goals?

- Are their groupings within the community? What is the network of relationships?

- Where do people have fun?

- How do people spend their time and money?

**Technology**

Requirements and capital for technology include:

- *Clean water:* Water filtration systems, chemical, solar, distribution, etc.

- *Sanitation:* Infrastructure, chemical treatment, etc.

- *Food/agriculture:* Fertilizers, irrigation, etc.

- *Energy:* Solar, wind, biomass, lighting, heating, cooking, etc.

- *Health/medical:* Telemedicine, diagnostic equipment, etc.

- *Education:* Instructional technologies (e.g., computers and tablets), STEM projects for hands-on learning

- *Shelter/infrastructure:* Houses, dams, buildings, bridges, etc.

- *Environment:* Pollution management and remediation

- *Information systems:* Cell phones, computers, internet, services support, market information, financial services, etc.

- *Education:* Computers and computer education, science/engineering experiments, etc.

### 4.2.4  Participatory Development: Introduction

There are many approaches and philosophies of development, such as the ones covered in Chapter 3. Here, there is an emphasis on having development practitioners, such as humanitarian engineers, collaborate with a community to promote community change. This is a "bottom-up" approach to development, sometimes called a "grass-roots" approach. It has many basic differences from approaches of some major aid organizations at times, some of which have been called "top-down" (the typical attitude at times seems to have been "let's just helicopter in a solution and drop it off"). The approach here can be complicated and slow, but there can be some significant advantages to a participatory approach to development.

#### Participatory Development: Background

Paulo Feire of Brazil developed early approaches to "participatory communication" where local people (including peasants) got involved in development processes and outcomes rather than just following an externally imposed approach and outcomes (Freire, 1993; Tufte and Mefalopulos, 2009). In this approach, "dialogic communication" (conversations with people, dialog) is used rather than "linear communication" (the unidirectional transfer of information, for instance from an outsider to a local). The emphasis is on group participation "in research, problem identification, decision-making, implementation, and evaluation of change" as it was later also emphasized in the "Rockefeller process" (Tufte and Mefalopulos, 2009). The "group" can include any "stakeholder," which could be anyone relevant to the development process, especially ordinary local people, but also a local government, school leaders, NGOs, state government, etc. Participatory development tends to be associated with grassroots and community-driven advancements in development. It empowers people, gives them voice, and thereby can help overcome some forms of oppression. Inviting someone to participate is respectful, promotes their dignity, and quest for freedom (Mansuri and Rao, 2013). There are many benefits to participation; however, how should participatory development be approached?

Some view participation as a "social movement" aimed at eliminating "unjust hierarchies of knowledge, power, and economic distribution" (if it is a grassroots movement it is called "organic" participation (Mansuri and Rao, 2013)) while in a "project-based perspective" (also called an "institutional perspective") participation is viewed as getting input and involvement by relevant stakeholders in setting goals, project design, implementation, and evaluation approaches to help make a project successful. Sometimes, a project-based perspective is called "induced participation," and is where participation is induced by a

Community participation is important for success of most project parts.

bureaucratically managed development intervention from the outside (Mansuri and Rao, 2013). Inducing participation is difficult, typically unpredictable, and possibly contentious. Some argue for a "sandwich" approach, via support from a central state and grassroots civic action (Mansuri and Rao, 2013), trying to incorporate the many positive features of organic development like initiative, enthusiasm, and self-motivation of people in a community. If a community has a history of social movements and organic participation, this can help with a participatory development approach. If they have a history of participatory development for one type of project, they may be more prepared to take on a different project. But, (Mansuri and Rao, 2013):

> The nature and extent of social and economic inequality and the composition and diversity of groups affect both induced and organic participation. Inequality and heterogeneity strongly affect the cultures and norms of cooperation that evolve within a community.

The participatory development process must be considered in the context of many current approaches to development. Consider (Tufte and Mefalopulos, 2009):

> It should be highlighted that within the current structure of the development aid system it is rather difficult to have a high degree of participation. The agenda of projects and programs is often set by a few individuals (for example, policy makers or technocrats) with very little input from other stakeholders, especially at the local level. Moreover, the rigid management procedures and the tight deadlines for planning and funding required for approving and implementing projects allows little flexibility needed for participatory processes.

Failure of many past development projects around the world has been attributed to a lack of participation (e.g., lack of understanding of key problems and local context, poor project design, and inadequate local stakeholder involvement in, for instance, maintenance). Context, in particular, is crucial; all local issues and problems are different and therefore require different approaches, or a concept for an approach like participatory development that *self-adapts* to local context. Yet, it is important to keep in mind that project success is not the only objective: social justice dictates that peoples' participation is a human right independent of anything else (Guijt, 2014). It is especially important in participatory development to promote involvement of the most marginalized people.

Participation gives people voice, adapts projects and goals to local context, and promotes ownership, commitment, and maintenance success.

### Stages of Participatory Development]

Project-based participation empowers people and communities to cope with their own challenges and set the direction of their own lives. It builds mutual trust among stakeholders (e.g., community and outsiders). Participation promotes ownership and community commitment, which helps with maintenance and longer-term impacts. Participation promotes competence and capacity.

Participation can facilitate the delivery of affordable and inclusive local services (e.g., education, health, transportation, agriculture, and water). It can give marginalized people voice and promote their involvement and provide opportunities for learning for all stakeholders. Project monitoring, critique, and evaluation are part of the participatory process. Also, it can impact local institutions that affect a community (e.g., local government).

The stages of a participatory development project process are (Tufte and Mefalopulos, 2009):

1. *Research:* The term "research" is used for the process of defining the development problem to be addressed in the community (e.g., lack of skills, polluted water, sanitation, or energy). It is called "participatory action research" by some and is discussed in some detail in Section 4.2.8. The process should identify problems, resources/assets, and goals, both near and long-term.

2. *Design:* This stage specifies the activities to be performed and participation is supposed to improve relevance, quality, and effectiveness of activities. See Section 4.6, and also Section 4.7.

3. *Implementation:* Actual activities are translated to implemented solutions, community capacity is built, and participation is designed to help with long-term maintenance.

4. *Monitoring and evaluation:* This is a group assessment, using measurements and indicators (quantitative and qualitative) for chosen aspects of the project. This process should be defined at the start of a project, proceed during the project, and for some length of time after implementation, in case adjustments need to be made. See Section 4.9.

All four of the above steps are based on free and open dialog between all stakeholders and such dialog should occur at *all* stages of the process; however, for some projects you may not need *full* participation of all stakeholders, but key decisions should be inclusive. To execute a participatory project requires a flexible project framework (e.g., in terms of scheduling) and participation in project management (e.g., not having an outsider running the project who is seen as a superior or "boss"). For more details on participatory project management, see Section 4.3.3.

> The stages of participatory development are broad, flexible, and dictated by a complex uncertain process.

### 4.2.5 Get to Know the People: Everything Happens on the Back of a Relationship

If "everything happens on the back of a relationship," project success depends critically on establishing good relationships with people in the community. There are certain basic guidelines on how to do this in the context of a helper-client working relationship.

**Basics of a Establishing a Relationship with a Community**

Up close, in person, you will generally find that clients (community members) are simply ordinary people who you will enjoy getting to know. With the right approach, like what you use to make a friend in your own culture, you will likely find it easy to build a relationship. Use humor. Smile. Be friendly. Ask and answer questions (see discussion in Chapter 1 on cultural differences and talking with people of different cultures). Cross-cultural conversion and learning is fun, if done properly. Talk to people "eye-to-eye" in a "down-to-earth" manner. Treat people with respect. Build trust. Listen. Listen. Listen. All people have equal dignity; treat them that way.

Of course, never be or sound condescending, for example by acting like a "know-it-all," even with respect to technology that you may know a lot about. Be humble. Do not look down on people for not having technical skills. Everyone has something to contribute, and there can be local brilliance. Clients are experts on context and constraints that are crucial in creating an effective technological solution.

Building relationships is a critical component of participatory development.

Recognize possible differentials in power between people, in a community, and between a community and visitors. For example, if you come from the developed world, how does the community view you? As rich, powerful, and technologically advanced? What does that imply about how you will be treated, or how they expect to be treated? Will these views promote trust? Do not patronize, defined as: "treat with an apparent kindness that betrays a feeling of superiority" (New Oxford American Dictionary). Do not judge people or their lifestyles by what you say to them, and to others about them (e.g., if someone is homeless do not assume they have no job, that it is their "fault" that they do not have a home, or make assumptions about how they spend their time each day). Do not use paternalism, defined as: "the policy or practice on the part of people in positions of authority of restricting the freedom and responsibilities of those subordinate to them in the subordinates' supposed best interest (New Oxford American Dictionary). Paternalism in development work often comes in the form of an outsider saying what is best for someone in a community, or the whole community.

**Basics of a Good Working Relationship**

Do not promote dependence, but work toward participation, cooperation, and community independence. You are not there to be the only one giving. You are there to work *with* people, not *for* people. Of course, the clients do not work for you; they work with you. Indeed, do not be shy or stand back and watch (e.g., because you do not know their language); jump right in and work together. Find a way to develop a good cooperative working relationship. Promote participation by setting an example, but do not over-involve yourself to the extent that you do everything while someone looks on. While you may want to learn about a client and their situation, keep in mind that they also likely want to learn about you. You are serving as an ambassador, even if it is to a

local neighborhood. Try to make a good and authentic impression. Of course, there may be language barriers, but in many types of work, conversation is not needed and the cooperative nature of work results in tangible non-verbal relationship building (e.g., identifying with each other how hot it is, or how tired you are). However, if at all possible, try to learn some of your clients' language, and do not be afraid or embarrassed to try to use it. It is respectful to try to use someone else's language, even if it is only a few words. You can say, sorry I am sure that my bad language skills may hurt your ears, but I would like to try. Often, community members are particularly happy to help teach you words from their language: it is sometimes nice for them to know something that you do not. If all else fails, do not hesitate to ask someone to translate if they are available; they are likely to appreciate that as it demonstrates that you care enough about the relationship to try hard to communicate.

Next, you should not give the impression that the work you are there to do (i.e., the "project") is more important than the people. This may be obvious, but it still needs to be said: engineers are often highly technically focused (sometimes to the point of being "nerdy," nonsocial, and introverted) and very task- and schedule-oriented (sometimes a characteristic of a culture). Certainly, do not view a community member's desire to sit and chat as being an indication of laziness; they may just want to build a relationship in the process, or even before working together. If you want to have an impact, go with their lead. Do not be afraid also to lead in a direction they are indicating (e.g., suggest a break in work to chat). Their actions and behaviors will show their priorities (as will yours) in trying to get a project done. Overall, though, you should be careful in what type of relationship you are developing, especially when the team has mixed gender (as it should). Generally, it should be a type of professional relationship with a "professional distance." In some instances, it is more like a professional-personal friendship mix. In special cases, a true friendship can be developed. Regardless, key features that are products of good relationships are open and good communications, trust, establishment of common interest, and solidarity. You should seek to build these. Keep in mind that "everything happens on the back of a relationship" so do not minimize its importance. Someone who takes the time to understand the nuances of the community, and fully engages the community, is likely to be liked by the community, and hence listened to and respected, and is more likely to be invited/welcomed back (Vandersteen et al., 2009).

An important feature of building relationships is that you learn about client needs and living conditions (especially if you live in the community for an extended period of time) and this can teach you about the context in which you will be designing technology and can ensure that the technological product is especially well-tailored to the community. This is a key reason for taking a participatory approach: so that the project adapts to local conditions. Yet, also, you should watch individuals under normal conditions at home, work, and play. Observe them when they are challenged and show needs. Observe them in every-day tasks to discover ways to help. Also, it is a good idea to simply take a walk around the community with one of its members and ask questions. Also,

working with someone can teach you a lot about them. Eating a meal together can teach you a lot as people in many cultures are used to conversation over a meal. If you are invited to a meal by someone in the community, accept. Relationship-building is also sometimes facilitated with a game (e.g., soccer).

### 4.2.6 Participation of Engineers

Engineers can and should be integral to the participatory development process when technological solutions are used. There are different levels of participation, ones that meet the constraints of engineers and the wishes of the community. There are several roles an engineer can take in participatory development, including being a student of the community, a teacher, a mentor, or a consultant. Of course, working side-by-side with the community in the many ways that are needed for a development project is desirable.

**Level and Type of of Engineering Participation**

We need to pay attention to the number of hours that an engineer, or engineers, need to be present in the community in order to make participatory development succeed. A relatively low number of hours/week or per year will degrade the quality of community engagement and the quality of participation, and can lead to problems that affect successful project completion and community technological education for capacity-building for operation and maintenance.

The following represent different types of engineering participation:

> The level and type of engineering participation can significantly impact project success.

1. *Engineers live in the community:* Having one or more engineers live in the community for an extended period of time can imply full participation provided the engineers really engage in community life, and can have a significant impact on project success. Living in a community is especially valuable at key stages of a project. For instance, in the needs/resources assessment stage it can be highly valuable to live in a community (e.g., for a month). In such a time period relationships can be built, context understood, and at least initial formulations of a problem to be addressed in a project can be achieved. Regardless of how long an engineer lives in a community it is important for them to also have local partner groups, like an NGO.

2. *Engineers visit the community and perhaps use electronic communications while not present:* In a number of cases, engineers only periodically visit a community. For instance, in some cases this may be for a week or two per year, or perhaps twice a year. In such cases, typically some engineering is done with the team in the community, and other work is done in an engineer's home country, perhaps involving others there. The periodic-visits approach will require some thought on how to best schedule the various parts of the project. Infrequent visits may help meet constraints for the outside engineer, but causes problems with building relationships, tailoring a project to a community, problematic scheduling of visits that

fit both the engineers' and the locals schedules (e.g., is it acceptable to visit during rainy season?), and can adversely affect chances of long term project success. Electronic communications (e.g., texting, phone calls, the internet), can in some instances help overcome these problems considering the prevalence of cell-phones in the world; however, in some cases such communications are impossible due to lack of access by community members to such communication modalities, for example, due to costs or infrastructure. Moreover, there is clear degradation of relationship-building and effectiveness of communication via electronic means compared to face-to-face conversation.

3. *Engineers work through an NGO or other organization:* A good NGO, or other group, can at times provide engineers with an understanding of a community and its needs/resources, especially if the NGO is co-located with the community and integrally involves locals. Engineers should not, however, have an over-reliance on an NGO to the extent that it creates a type of *barrier* between them and the community. Engineers must learn about people and challenges first hand. In working with an NGO, can you be sure that the NGO really understands how community needs and challenges can be met with *technological solutions*? The NGO may have no technical people. Will an NGO be able to communicate all the necessary contextual issues that lead to technology design constraints? How could they know that there are myriad issues that need to be incorporated in a good technology design? They may know about an issue, but not communicate it as they may assume you know about it or cannot imagine that it has relevance. Of course, working solely through an NGO also may have disadvantages with respect to (i) not capitalizing on the people-empowerment aspects of good participatory development, and (ii) not providing good synergistic *technical* education as discussed below that has many benefits. Finally, note that in the low-visit-frequency approach discussed above it is likely best, and often crucial, to have a good partner on the ground in or near the community, perhaps an NGO. Indeed, a reasonable model in some situations may be to primarily work in a technical support role for an NGO. This may be by serving as a consultant (e.g., for evaluations of technology choices that NGOs must sometimes make–such as for cookstoves and personal water filtration systems) as discussed in Section 4.6.5. Of course, a good model may be to have an engineer work at a co-located NGO.

**Time vs. Community Participation Level Tradeoffs**

For a participatory development project, there my be a fundamental tension between time spent by a visitor/engineer on a project and whether a fully participatory development process is achieved. Consider two examples:

1. Suppose a community already has the collective skills and willingness to participate (cooperate), with a clear and feasible need to be met, and clear

benefits for many individuals. This situation may need little outsider's investment in time to achieve participation, perhaps just some resources (e.g., materials) to get the project going, and perhaps some mentoring. This is close to an ideal case. The community is clearly in the "driver's seat."

2. Suppose that there is a fractured/conflictual community, or one that has never done anything together, so that an outsider may get no help in generating participation. Even with a significant time investment, the outsider may at best get one or just a few people to participate, and those persons may not be happy about that if the benefits of the project are shared with others (e.g., a water source for all). In this case, the community may have experienced problems with corruption, past failed attempts to work together, or significant internal socioeconomic inequalities may drive the problem. It may be that significant time investments are needed by the outsider to successfully promote fuller participation, or it may be that any level of participation is simply not possible no matter what happens.

One approach to avoid difficulties in promoting participation is to be very careful in project choice, to choose a simpler/feasible project, one where each person to participate will gain some clear benefit.

### The Engineer as a Student, Educator, Mentor, or Consultant of the Community

Community members are experts on their needs, resources, hopes, aspirations, context (social, cultural, economic, political, ecological), and the overall functioning of the community. It is your hope that community members will teach you about these topics as they all have important impacts on humanitarian engineering. You should not take the view that community members cannot contribute to your areas of expertise in the process: be open to client brilliance and suggestions in all cases. You may be an expert in science, mathematics, engineering, and technology (of at least one discipline). Community members can learn about all those topics from you. You should take the proper attitude toward teaching any community member who will listen about relevant science, mathematics, engineering, and technology. When you do so, you may be challenged not to use "technical jargon" that gets in the way of basic ideas and creates a distance between you and them that is not useful; however, in most cases, basic principles are easy to communicate: do not assume that since they do not have a degree or higher education that they are not smart enough to understand. You should certainly be prepared to explain any aspect of the technology, not just some "piece" that you are responsible for as people often understand the context. Also, keep in mind that there is a high value to educating community members about the technology development process. It helps make the relationship bi-directional, is strongly empowering for the community, and transfers ownership of the process and technology to the community (technical education builds community "technological capacity," an issue discussed

Promote multi-directional education between all participants.

Building community capacity to create technologies should be a goal of every project.

in Section 2.1.2). Also, it is the basis for educating clients and community on how to operate the developed technology and maintain it over the long-term. Note, however, as discussed below, the more technically complex a project is, the more likely it will fail (e.g., due to operational and maintenance problems, not to mention problems with reliability). Also, incentivization of a maintenance person (e.g., via cash payment or access to use of the technology) is a key issue as if someone in the community does not have the proper motivation, then the technology is unlikely to be maintained, and hence will typically fail relatively soon.

It is interesting to note that many professors of engineering are generally good at selecting technological solutions to problems, laying out the steps to create such technological solutions, and teaching people how to execute those steps (students or community members). Much of the engineering curriculum is about this, so professors understand the broad methodological approach and, typically, technology design in their disciplinary area. Experienced engineers as well as professors often know how to be mentors or consultants, and this is valuable not only for their students, but also to serve as a mentor for a community, or a consultant to the community (the role of mentorship in development is discussed in Chapter 10 of (Toyama, 2015)). The Bachelor of Science (BS) in engineering is a generalist degree, the Master of Science (MS) creates an expert in one area of one discipline, and the Doctor of Philosophy (PhD) is for depth and creating completely novel solutions. Clearly, each of these has a role in humanitarian engineering, as does the professor who educates persons to obtain these degrees. A professional humanitarian engineer, no matter what type of education they have, must become a teacher and mentor or "consultant," at least to a certain extent, in order to work effectively in the participatory development process with a community. This holds for a "living community" or an "educational community." Indeed, community capacity building is always an important part of participatory development. It is not good to take the view that a group of engineers is going to fly in and fix problems *for* a community. A collaborative perspective is much better.

Indeed, consistent with the view in this chapter, others view the approach to engineering for community development as one of capacity building via participatory and experiential education. This is the view taken in the

<div align="center">

MIT D-Lab, Creative Capacity Building

</div>

Moreover, it is the approach taken below in Section 4.8 on humanitarian STEM education, with more details at

<div align="center">

iSTEM: International Inclusive STEM Education

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This project is especially relevant to community capacity building for cases where STEM education is focused on humanitarian technologies that are needed in the region around the school.

### 4.2.7  Features of Participation

People define how they want, and can, participate in a development project. There are, however, various principles of participation, including who can and should participate, and the importance of team diversity, for reasons of social justice and doing good decision making by avoiding group think.

**Types of Participation**

In participation, an individual can participate in a number of different ways, and to varying degrees, including by contributing ideas, consultation input, cash, labor, materials, etc. In some projects, people are *required* to contribute some percentage of the overall project, or a percentage of the benefits they will personally receive, or they are not given access to project benefits, or the project simply does not proceed if the sum of the community's contributions is judged inadequate. Some different types of participation include (Tufte and Mefalopulos, 2009):

The level of participation by an individual may be driven by their own desires, or exclusion due to gender or other discrimination.

- *Passive participation:* An individual who is a passive participator may just be informed about a project that is happening or will happen, and may have little or no input to any aspect of a project.

- *Participation by consultation:* In this case, stakeholders answer questions (e.g., interviews, focus groups, or a survey) that are posed by outsiders, and may be consulted (e.g., via meetings) throughout the project. However, decision-making power is kept in the hands of outsiders who have no obligation to incorporate their inputs.

- *Participation by collaboration:* Groups of stakeholders participate in discussion and analysis of preset objectives set by the project from outsiders. This approach incorporates stakeholder's active involvement in decision-making about how to help the project succeed. This approach uses "horizontal communication" (communication between stakeholders), promotes building capacity, and may evolve into an independent local collaboration that does not use any outsider.

- *Empowerment participation:* In this case, local stakeholders are willing and able to initiate and execute a project. It can lead to joint decision-making by locals and outsiders, where everyone is viewed as an equal partner. Project ownership and control, however, lies in the hand of the local ("primary") stakeholders.

Specific methods or "tools" to approach participation (e.g., workshop-based methods, participatory rural appraisal, beneficiary assessment, systematic client consultation, social assessment, and gender analysis) are outlined in Appendix I, pp. 181-204, of (Bank, 1996).

Each stakeholder can view participation differently; hence, it is important for the development practitioner to consider the following questions (Tufte and Mefalopulos, 2009):

- What role does culture play in participation? Does it affect who participates?

- What does participation mean to each stakeholder? Participation in what form?

- Why is participation important, and to which stakeholders is it important?

- Which stakeholders should participate? Which ones will participate? What roles do people want in the participation process?

- When should there be participation?

- What are the participation constraints for each stakeholder?

- How can we evaluate the success of a participatory development process?

- Will participation help improve poverty-targeting (i.e., getting assistance to those that need it most)?

- Will participation increase demand for good governance by creating a more engaged citizenry?

Clearly, participation should not mean that only the elites in the community are involved. A properly representative group is required, in some cases everyone, even children (Guijt, 2014), as is discussed further next.

### Forming an Inclusive Group and Avoiding Group Think

The group of participants should always consist of a diversity of people (e.g., both genders and marginalized people), ones native to the community (as many as possible), degreed engineers (some perhaps from outside the community or from another country), perhaps persons from other disciplines (e.g., social work or other social sciences), perhaps local NGOs or government (see below), and other stakeholders. In forming the group, cultural issues should be kept in mind, the (mis)perceptions of members toward each other (e.g., based on the history of your country's interactions with their country), and differences in values (e.g., that members of the community may value establishing a relationship more than getting to work right away). You especially want to identify persons in the community inclined to do engineering and encourage their involvement in the group (e.g., persons who love technology and its use, are creative, or like to "tinker" and are good at it). The boundaries of what constitutes the group are broad: Anyone in the community involved in any way (e.g., in needs/resources assessment or design) will be considered to be part of the group (e.g., to achieve "community-based discovery" (IDEO, 2014)). In the remainder of this section, when the term "group" is used, it *always* includes members from the community; this is what makes the approach here participatory and human-group-centered.

In the social psychology of groups, there is a phenomenon called "group think" (Janis, 1982) that can occur. Group think is often thought of as arising

*Being inclusive with respect to gender and race can help avoid group think and improve outcomes.*

via a relatively small group, less than 10 people (e.g., a committee), but it can occur in a bigger group. If such a group is composed improperly it can:

1. Not have diversity and creative thinkers that also have authority.

2. It may not reach outside the group to properly consider any other opinions.

3. It may be given a problem where most or all of the group have a preconceived notion of what the conclusion to be reached is.

4. It may be that the group is charged with a narrow goal, for example, by a higher authority, and then set out to prove what they were asked to prove, not being internally critical by considering carefully other possibilities, and over-rating any evidence that they have, not matter how small it is, and using it to make the conclusion they were supposed to reach.

This problem must be guarded against by avoiding each of these issues so that group think does not "emerge" in the group. Group think can arise at any stage of participatory development. In assessing needs/resources, it may result in too narrow of a focus. In technology solutions it may result in a blindness to better solutions. In assessing outcomes, it may result in only focusing on good impacts, and not bad ones.

The group of participants must think carefully about how to avoid group think and accordingly develop strategies to address the issue. A key approach to avoid group think is to instill a sense of willingness to question the overall way of thinking of the group. Also, to avoid group think, the composition of the group must be carefully chosen. Some community members that the group may be tempted to exclude (e.g., women, minorities, or children) should be included and encouraged to speak up and become integrally involved. The success of the community depends on getting "all hands on deck;" it is disrespectful, and not in anyone's best interest to ignore the possibility of getting good inputs from someone solely based on discrimination.

More features of groups, teams, and teamwork are discussed in Section 4.3, where the focus is on how a group should function in order to succeed. That section assumes that the ideas above on formation of an inclusive group are used.

**Challenges of Participation**

The first challenge is to get people to participate. Promotion of increased participation can be difficult; however, if the project is truly important to an individual, it becomes more likely that their level of participation will increase. You can take a number of approaches to improve participation. First, you could simply go to a community and live there for a while, get to know people, and ask them about what they want to do or change. Then, you (or the locals) may help form a group that is keenly interested in the ideas, and then try to, through enthusiasm and persuasion (by the locals also), explain the benefits of project

completion, and thereby mobilize the community to action with a higher level of participation. An outsider, or insider, tries to be a "catalyst."

Being inclusive in involving participants can present problems. A particular challenge may be presented in some cultures of being socially inclusive by integrally involving marginalized individuals such as women, children, persons of very low socioeconomic class, those with other religions, or of other races (see (Bank, 1996) for more on the participation of women). Working within local power structures and hierarchies, and overcoming local prejudices, can be quite difficult. Sometimes leading by example can work. Other times, there can be significant resistance to being inclusive.

While there are many benefits to a participatory approach, there are also limitations and pitfalls (Tufte and Mefalopulos, 2009) including the following:

- Will a participatory method work in every context?

- Will it work for every development problem?

- Is it always the right time to use a participatory approach in a community?

- Will a facilitator, either from within the community or from outside, unduly influence stated preferences by the community?

- Will identified needs be shaped by perceptions of what can be delivered instead of expressing true needs (Mansuri and Rao, 2013)?

- Will a participation *requirement* result in a type of forced labor for low-income people, especially if they contribute more than more well-off members of the community (Mansuri and Rao, 2013)?

- It has been found that communities are not as effective at maintaining projects that are technically complex or new (Mansuri and Rao, 2013); they do better with modifications on past projects or on ones for which they had previous experience. How complex is too complex?

- Is it really feasible to involve a large number of people in a development process? What is the right number of people?

- Can the participatory strategy be "scaled up" so that it applies to other communities, cities, and even regions?

Community capacity affects project quality and maintenance. Technical support can be crucial, and it increases in importance with increasing project and technical complexity. Training and education of participants is important but challenging. Education can help participants know what type of project to choose, assist in project execution, and provide expertise needed for maintenance and repairs. Long-term maintainability will not be achieved if local individuals do not have the technical capacity to maintain the project; it is not likely that they will be able to recruit an outside expert to come do repairs. You should not assume that there is local capacity at the outset. That would be naive. You

will need to try to assess capacity, which can be very challenging, and build it where it is needed.

"Capture" is the act of an individual or group to gain undeserved control of, for instance, money, resources, or decision-making power. Does the participatory development approach reduce capture and corruption? Does "leakage" from a project result from resource capture by the powerful or elites? It appears that "the poor often benefit less from participatory processes than do the better off, because resource allocation processes typically reflect the preferences of elite groups" (Mansuri and Rao, 2013). Capture and corruption typically occur more often in highly unequal communities, with power held by only a few, in communities that are far from centers of power, that have low literacy, have low income, or have caste, race, or gender inequalities. A large injection of resources to a community participatory project can attract those better off and promote exclusion, capture, and corruption, and once funds run out, the project falls apart. A good practice is identified in (Mansuri and Rao, 2013):

> Only when projects explicitly link community-based organizations with markets, or provide skills training, do they tend to improve group cohesiveness and collective action beyond the life of the project.

Also, overall, evidence shows that in participatory development "local capture can overwhelm the benefits of local information" (Mansuri and Rao, 2013).

Finally, it is important not to have an unrealistic view of working with communities. Up close, things can be quite different from what you imagined. Consider the following quote from (Tufte and Mefalopulos, 2009):

> They are often taken for granted as homogeneous socio-economic and cultural entities–harmonious units where people share common lifestyles, interests and visions of life. In trying to emulate participation, it is important, however, not to conceal the power relations in a community, the differences in opinions, lifestyles, beliefs and the socio-economic distribution. A community can be full of tension, inequality and conflict, and practitioners need to be aware of the environment and treat the community as a sum of different groups rather than a homogeneous entity.

Clearly it can be quite challenging in some cases to work with a community to get something done. Your people-skills will matter!

## 4.2.8 Participatory Action Research: Learning and Acting

The community features (Section 4.2.1) and capitals (Section 4.2.3) define "what is there" and "what to look for" in a community and form the basis, or starting point, for assessing community assets and resources. Details of community assessment are in Section 4.4; here, a brief discussion is provided in the context of participatory action research (PAR), that was developed in the

PAR is respectful to a community.

1960s and 1970s by Colombian sociologist Orlando Fals Borda. PAR involves community members in helping understand the community and in taking actions to improve conditions. The basic idea is that members in the community understand it relatively well and know how to understand it better, and also can help direct how the information about the community is used. Those who are most affected by decisions should have a part in the decisions. Members should be active in all steps of the research process, from identifying issues to be addressed, to designing research questions and methodology, to collecting and analyzing data and disseminating findings. Traditional research tries to uncover knowledge or determine if something worked, and is approached typically by outside experts to provide the information outside the community. PAR is based on a member-cooperative activity of discovery of issues and the subsequent participation in addressing those issues. The information generated is primarily for use within the community. This PAR process empowers members of a community. It says that people are not "subjects" to be quantified with statistics; they are active agents for promoting understanding and change.

In the process below, the influence diagrams from Section 1.6.1 can be useful to visualize how identified issues, resources, and needs relate to each other, and for facilitating the community's discussions (e.g., via drawing on a white/chalk board). In fact, it may be useful to add a number between zero and one to each node that represents the community's view of what the priority of the need is, or for a node representing a resource, how important that resource is. To begin the explanation of PAR, overarching principles are discussed.

### Principles of PAR

The basic principles of PAR from (Homan, 2011) are:

- The research is supposed to deepen understanding, create theories on how to take action, and also produce actions.

- The actions taken create new and different relationships in the community and with outsiders.

- The people affected by local conditions take on a central role in choosing what to study, how to study it, and how to use gathered information.

- Gathered information is community wealth, owned by the community.

- It should build the power of the whole community.

- It is a collaborative process where participants learn from each other.

- It requires self- and group-critiques.

- It involves cycles of "reflection, planning, and action, observation, theory generation, new planning, action, and so on" (Homan, 2011).

- It "is based on hypothesis generation, hypothesis testing with valid and reliable techniques, critical analysis of findings, and distribution of information" (Homan, 2011) .

PAR's use of a scientific process for problem solving is empowering for participants.

### PAR Steps

For PAR to work, you need strong teamwork and collaboration skills from a core group that stays involved. PAR is used at two "levels:" to assess conditions, issues, and needs (assessment level) and focusing on a selected issue or condition, trying to understand it better, guiding action, and testing approaches (action level). The group from the community involved with PAR should be brought together and trained, and given a sense of excitement about the approach.

To start, you ask the following questions (Homan, 2011):

- What are we studying?

- What do we know about it, or need to know about what we are studying?

- What is our hypothesis?

- What assets or resources do we have that we can use?

- What specific actions will we take?

- How will we test if the actions we give the results we expected?

- How will we analyze what is happening and use it to change our later actions?

There are two phases to PAR, the assessment phase where the group finds information to determine which change to seek, and an action phase where the steps are repeated. That is, the group determines first how to focus the effort via an overall assessment (possibly considering many community conditions and issues) and then for the chosen focus from the assessment phase, in the action phase, the particular issue to be addressed is identified. In the action phase, the group determines what is known and unknown, taking into consideration appreciative inquiry (see Section 4.2.2) where assets and resources are identified. A specific goal is chosen with respect to how conditions are envisioned to change. A hypothesis is chosen, which is the group's statement about what action will result in what outcome: "if we do $X$, then $Y$ will happen." Homan says this occurs in both phases: in the assessment phase you specify an action that will produce what you want to know, whereas in the action phase you state the action that will produce the desired change (Homan, 2011).

Next, the group determines how to use assets and resources to implement the chosen action/strategy. After the strategy is implemented in a "test" (not a full deployment) the group specifies what "outcome" data is needed, how to

collect it, and how to analyze it; it is this data that is used to test if the chosen strategy will work effectively. Next, provided it was successful, the strategy is implemented and appropriate outcome data gathered. Then, the group determines if "$Y$" happened or something else, learns from this, and appropriately shares this with others.

Compared to traditional scientific research, PAR can have a lack of objectivity as it is passion that fuels participant's involvement to start (e.g., a powerful person in the group should not dominate). However, with good training (involved professionals must be good teachers), a focus on effectiveness, an understanding of how to use data, and collaborative critical analysis, the lack of objectivity can be avoided.

### 4.2.9 Participatory Monitoring, Evaluation, and Impact Analysis

Next, via participation, stakeholder satisfaction and possible project modifications need to be sought. The very approach to such monitoring and evaluation should involve stakeholder participation, should be agreed upon at the start of the project, and may involve quantitive methods (e.g., assessment of water contamination levels after a water filtration method is installed) or qualitative methods (e.g., written or oral comments from the stakeholders). Opinions of local end-users matter in determining if a project was successful. The assessment can include soliciting the group's opinions on the participatory development process itself and this can be useful for project continuation or if another project is to be conducted.

In (Bank, 2004), with respect to monitoring and evaluation, it says:

> Monitoring and evaluation (M&E) of development activities provides government officials, development managers, and civil society with better means for learning from past experience, improving service delivery, planning and allocating resources, and demonstrating results as part of accountability to key stakeholders.

First, performance indicators need to be defined in a participatory manner for all aspects of the development activity (e.g., inputs, outputs, strategy/process, and impacts) and gathered (e.g., via surveys, such as the ones identified in (Bank, 2004), or rapid appraisal methods also identified in (Bank, 2004)). These can be used to track progress, show results, and change the approach to make it more effective. Only key indicators, ones that are easy to measure, should be used.

In the participatory approach to monitoring and evaluation, four methods are highlighted:

1. *Stakeholder analysis:* Usually, assessment starts here and "it is used to develop an understanding of the power relationships, influence, and interests of the various people involved in an activity and to determine who should participate, and when" (Bank, 2004).

*Participative monitoring, evaluation, and impact analysis of a project are crucial to project success.*

2. *Participatory rural appraisal:* PRA uses a collaborative planning approach for developing and assessing appropriate interventions, and it involves urban and rural people, along with outsiders, and promotes shared learning via visual techniques so non-literates can participate.

3. *Beneficiary assessment:* This is the systematic consultation with project beneficiaries and other stakeholders to identify challenges, create initiatives, identify constraints to participation, and provide continual feedback for improvement.

4. *Participatory monitoring and evaluation:* This involves all participants cooperating to "identify problems, collect and analyze information, and generate recommendations" (Bank, 2004).

In (Bank, 2004), the issues of cost-benefit analysis (are costs worth outcomes and impacts?) and cost-effectiveness analysis (are monetary inputs worth non-monetary outputs such as empowerment) are discussed.

It is also important to do an impact analysis. What are the positive and negative impacts? On individuals? Households? Community? For this, the group must determine what impacts to study and how to study them. For instance, is income, health, or education to be impacted? Participation? These may be relatively easy to measure. What about empowerment? Group capacity to perform projects together? These may not be easy to measure. Quantitative methods for studying impacts include RCTs in Section 3.2.4 and Section 4.9.4, or the other assessment methods, including qualitative ones, in Section 4.9. Of course, design of a good monitoring and evaluation process is closely connected with impact analysis. For more details on impact analysis, see (Bank, 2004). Some of the benefits of performing an impact evaluation for a participatory development project include (Guijt, 2014):

1. To confirm if the impact that was sought was indeed realized.

2. To validate outcomes and agree on what lessons were learned, or what stakeholder recommendations can be made for the future to improve interventions.

3. Developing local leaders, capacity, and understanding to help improve future projects.

### 4.2.10 Participatory Development as a Dynamical Cooperative Feedback Control Process

A synthesis of the participatory development approach that will assist in understanding how all its pieces fit together is shown in Figure 4.2; this is designed to be analogous to Figure 4.1. In the community (box on the right), there are (stick) people, where the colors represent two things: heterogeneity/diversity, and level of participation. The ones colored blue are mostly passive with little involvement, due to their own choosing or due to them being marginalized. The

ones in red are active participants, but they may have different capacities (e.g., experience or skills). There are houses to indicate it is a living community, and the black boxes designate resources (e.g., water) and services if they exist (e.g., a school and healthcare clinic). Of course, this is only a cartoon; in a real community there can be many more people, houses, resources, and services. In any case, people interact with each other, infrastructure (e.g., houses), resources, and services to create a very complex and unpredictable community dynamical system. Indeed, external influences, including outsiders, weather, trade, etc. increase the level of randomness and hence it becomes extremely difficult, and likely impossible, to predict what will happen.
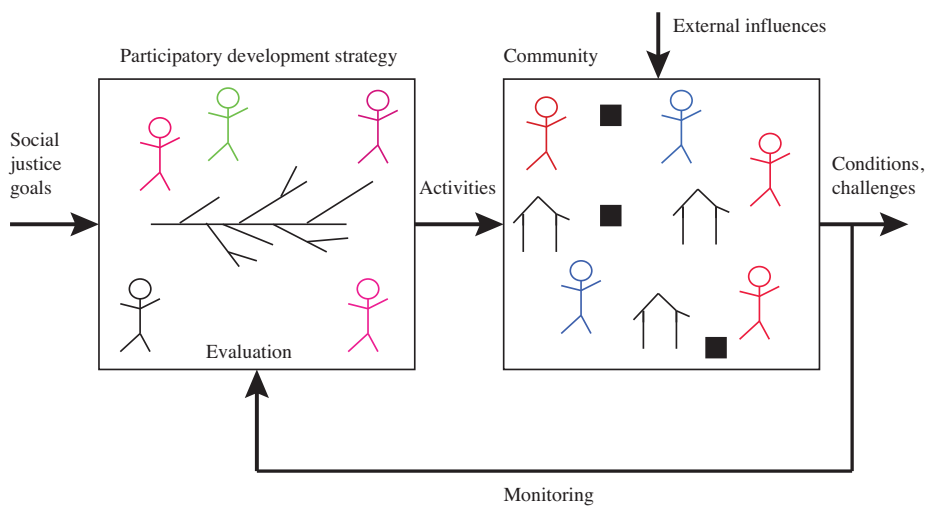


Figure 4.2: Participatory development as a dynamical cooperative feedback control process.

Via monitoring, community conditions and challenges are understood, and it is assumed that social justice goals are sought. The participatory development strategy shown in the box on the left of Figure 4.2 includes people from the community, colored red (the *same* ones as in the community box on the right). It includes a green-colored person representing an outsider such as one from an NGO or local government. It also includes, on the bottom left, a person designated with black who represents an engineer. This group of people must *cooperate* in order to complete a project by taking actions that affect the community. They may have their own resources to assist in the effort (e.g., money, supplies, and materials). The process, however, involves a few steps: (i) understanding conditions, identifying challenges, prioritizing needs; (ii) formulating an action plan that is flexible (e.g., by picking what the group feels is "best" to do at the current time); and (iii) executing the plan, but continually monitoring and evaluating, and appropriately dynamically readjusting, the plan and actions taken. The tree diagram in the middle of the box on the left rep-

resents two things: (i) that each person participating will have different ideas, plans, and objectives, including how they would deal with contingencies; and (ii) that the *group* will also have a notion (perhaps written down on a blueprint) of how to proceed, and this group plan must be some type of synthesis of the approaches of each participant. Indeed, if the approach is too biased toward one of the red persons, due to their power, via "capture" and corruption, they might steer the project so that it benefits them. The hope is that by interpolating between what everyone wants to do, and actually does, a fair result will emerge and there will be good outcomes for the whole community.

Recall that helping a client is best thought of as trying to teach someone how to drive a car (see Section 4.1). The challenge of helping a community is like trying to have a group of people all steer a sailboat on a windy day, each having their own rudder, including some who have never steered a sailboat (recall you move the tiller in the *opposite* direction you want to go), when wind directions and strength are continually changing, and each person frantically wants to go to a different location for safety. Such a challenge is also exasperated by dynamics: novice sailors often "overshoot" their intended direction due to ship dynamics. Clearly, helping a community is can be very challenging.

The participatory development strategy adds some features that helps it succeed. First, it adapts to the local context dynamically by monitoring and evaluation, *learning* by the participants (learning while doing), and an attitude of flexible readjustment of actions and plans. Also, typically, planning does not proceed too far into the future ("limited lookahead," a "limited time horizon" (Garcia et al., 1989; Camacho and Alba, 2007; Rawlings and Mayne, 2009)) as that can be a waste of time considering the uncertain and dynamic environment. In fact, the dynamical learning/planning process is embedded in group cooperation, which seeks positive outcomes and gives voice to all participating. Finally, note that this approach bears some relationship to praxiology discussed in Section 4.2.2. Also, there are clear relationships between the team of helpers/community case in Figure 4.2 and the single helper/client case in Figure 4.1.

This brief description gives you a way to think about the overall dynamical process of participatory development, and to be concrete, a number of details were omitted. These are covered in the above sections, and via some examples, below.

## 4.2.11 Examples: Common-Pool Resources, Education, and Health Services

"Common-pool" natural resources include, for instance, a forest, fish in a lake, shared land for agriculture, and water storage and use. Local participatory management of resources has proved to be a viable alternative to privatization or central state management, and involves shaping resource use distribution, and management. In this context, a key issue is "resource sustainability" (to avoid the tragedy of the commons discussed in Section 1.3.6) and when the "resource" is environment-based the term sustainable will be used since it is

environmental sustainability. When sustainability means long-term operation via maintenance of some other resource, the term maintenance will be used.

In the literature, the impact of inequality in a community on participatory common-pool management of fisheries and irrigation has been studied (Mansuri and Rao, 2013). In the case of irrigation, management is not as effective in unequal communities (e.g., with social and landholding inequalities). Community heterogeneity makes it more difficult for a group "to use social norms to enforce collective agreements and generally has a negative impact on cooperation" (Mansuri and Rao, 2013). There is, however, evidence for a $U$-shaped curve relating wealth inequality and quality of collective action management: when inequality is low or high, management is of high quality, but in the middle it is not as effective. It seems that the surprising case, high quality management for high inequality, arises since in that case it is as if there is private ownership by, for instance, elites, who execute effective management since it is in their best interest.

Establishing effective cooperation entails creating clear and accepted "rules of the game" and approaches to accountability, which may be difficult to establish in an unequal community. Another key element of a cooperation strategy is the equitable distribution of resources. Even though "the better-off tend to benefit more from common-pool natural resources," the "poor are far more dependent on such resources" and this heightens the importance of equitable distribution (Mansuri and Rao, 2013). "State intervention thus seems to determine the impact of participation on natural resource management, equity, and local livelihoods" (Mansuri and Rao, 2013).

Decentralization of running of schools is called "school-based management" (Mansuri and Rao, 2013). In this, decision-making is placed largely in the hands of a school or community. Usually, a school management committee is established that includes the principal, teachers, parents, local leaders, and other community members. Such a committee may have authority with respect to staffing and budgeting, but in some schools they may only be able to affect curriculum with little impact on staffing and resources. In still a weaker version, such a committee may only serve an advisory role. The risks of decentralization are standard: capture of resources and redirection to wealthier locations or plain corruption with theft of resources. The main objective of decentralization is to improve educational outcomes. Decentralization seems to improve school access; however, there is little evidence that there have been educational outcome improvements to date. In some cases, outcomes improved, and in others they did not.

There is a growing literature showing positive impacts of community engagement in health services, in particular for maternal and child health. Also, local governments have produced significant positive results, including economic impacts (Mansuri and Rao, 2013).

### 4.2.12 Participatory Development Outcomes and Lessons

Participation modestly improves community resource and infrastructure quality, but the people who gain the most are the most literate, least geographically isolated, and most connected to wealthy and powerful people (Mansuri and Rao, 2013). Locals' willingness to contribute to projects has been seen as evidence of their commitment, and as a way to ensure long-term maintenance, but there is little evidence this is true (Mansuri and Rao, 2013); however, co-financing (monetary contributions from people in the community to augment other contributions), which is viewed as essential by many, can exclude the lowest-income individuals in a community, and can make communities opt-out of a project as the requirements may be too stringent.

When it comes to community management of "common-pool resources" (e.g., a forest or water source) and "community engagement in the creation and maintenance of small-scale infrastructure" the following questions and issues arise (Mansuri and Rao, 2013):

- Is there evidence for better resource maintenance with community management? Clearly, individuals in a community must benefit from the resources they manage, but will this result in better maintenance or management?

- Is management inclusive and is there equity in distribution of benefits? Do wealth inequalities, ethnic differences, and experience affect maintenance of resources or infrastructure? Inequalities tend to degrade efficiency and equity of distribution, and at times there are important trade-offs between resource maintenance and equitable distribution. One approach to addressing inequalities in induced participation is to mandate inclusion of disadvantaged persons, women, and minorities, perhaps by using a quota system.

- Like in the management of common-pool resources, the impact of inequality of distribution of project benefits in a community on quality of maintenance has a $U$-shaped curve: (i) equal benefits implies effective maintenance; (ii) as inequality of benefits provided increases, the quality of maintenance first falls; and (iii) in the perfect inequality case the project is essentially privatized, no coordination is required, and maintenance quality is effective.

- Can local management conquer the specific problems that arise in the context of a community? Do the people have the capacity to manage a resource? Often such capacity must be built as part of the project, and often resources have to be provided for long-term maintenance and management or investments can be wasted and natural resources badly managed.

- Is there dependence of outcomes on the central state? It is crucial to have mechanisms for the central state to be held accountable for how they perform in the involvement.

- A number of studies (Mansuri and Rao, 2013) show that community engagement appears to improve quality and management of construction and infrastructure and this implies there are lower levels of corruption compared to provisioning by a government.

- Participation in health and education services "find modestly positive results overall" (Mansuri and Rao, 2013). In education, for community participation, "overall, studies report an increase in school access, an improvement in retention rates and attendance, and a reduction in grade repetition" (Mansuri and Rao, 2013).

- If a participatory project is not properly funded, it can create a burden for the community and degrades outcomes in the form of not meeting maintenance demands for infrastructure (e.g., a school), no personnel (e.g., teachers or healthcare workers since there is no salary for them), or supplies (e.g., medicines).

- Evidence suggests that participatory development has a limited impact on income poverty, but if a microfinance function is included, savings amounts and assets may improve.

- Induced participation seems not to build long-lasting cohesion in the community, and in the past many projects have excluded the lowest-income individuals, minorities, and women. Also, participatory development tends not to get subgroups in a community to be cohesive.

- Participatory development does, however, have the nice feature that communities express greater satisfaction with decisions when they have participated, even if they actually had no impact on the decision or when the outcomes are *inconsistent* with the preferences they voiced.

Spreading information around a community about the quality of services can improve outcomes.

Hence, the impact of participatory development has been mixed, and overall there is little evidence of poverty reduction (Mansuri and Rao, 2013). Income gains may decrease over time, stay in place for only subgroups (e.g., men), and not ones that have the lowest income. Also, in (Mansuri and Rao, 2013), the authors say that:

> Empowering civic groups may lead to good outcomes. But it is not clear that inducing civic empowerment is always superior to a pure market-based strategy or a strategy that strengthens the role of central bureaucrats.

Yet, in (Mansuri and Rao, 2013) the authors say:

> Well-designed participatory efforts can overcome the negative effects of wealth inequality and community heterogeneity to a large degree.

Evidence suggests that, overall, the impact of participatory development is mixed.

There are three key lessons from the evidence about outcomes for induced participatory development (Mansuri and Rao, 2013):

1. *Induced participatory development projects work best when supported by a responsive state:* The state needs to be responsive to community demands, and:

   > Parachuting funds into communities without any monitoring by a supportive state can result in the capture of decision making by elites who control the local cooperative infrastructure, leading to a high risk of corruption.

2. *Local and national context is extremely important:* What works in participatory development in one community may utterly fail in another community. Locals have the best information and understand context and that is one of the key reasons to involve them. It ensures flexibility of approach, sensitivity to local issues and constraints, and the participatory process ensures *adaptability* of the approach to the local setting.

3. *Community engagement is a process that has an unpredictable path:* Donor-driven participatory projects typically expect a well-timed deterministic path toward development with deadlines and measurable outcomes that are highly optimistic. Realities on the ground create a very different project path. Building infrastructure (e.g., dams, bridges, roads, schools, and clinics) has a more predictable path, but the human aspects are more unpredictable (e.g., political systems or other social change like modification of norms or culture). For these latter challenges a different approach is needed, "one that is flexible, long term, self-critical, and strongly infused with the spirit of learning by doing" (Mansuri and Rao, 2013). The unpredictable nature of the path of projects emphasizes the need for good approaches to monitoring, evaluation, and impact assessment (which is often ignored in projects). These will contribute to continual readjustment of aspects of the project, learning on the ground, and experimentation. New electronic communication methods (e.g., text messaging) may assist with some aspects of the process, like project monitoring.

There must be ways to get honest feedback from stakeholders as this will facilitate *learning while doing* which is very important on any development project. Of course, you also need patience! You need a high tolerance for failures, and to view failures as lessons in what you should do instead. Failure may be the only way to find the right path to what works.

While some think of participatory development, either organic or induced, as "bottom-up" development, and may have negative views of "top-down" development (e.g., run by technocrats in a distant large bureaucratic world institution), consider the following (Mansuri and Rao, 2013):

> The evidence is very limited on how top-down approaches compare with bottom-up approaches in delivering goods and services to communities

The problem is that studies compare participatory development to doing nothing, not to a top-down approach.

Finally, consider the comment (Mansuri and Rao, 2013):

> This report thus appears in the midst of a raging debate over the effectiveness of participatory development. Does it work? Does it increase accountability? Is it captured by elites? Does it increase voice and choice? Is it "empowering"? Is the money directed toward participatory development well spent?

No matter what you think will work, you have to be modest and humble in approaching a development challenge! There is no real development problem that is simple to solve, and no one recipe for doing so.

## 4.3 Teamwork and Project Management

"Cooperation" is "the process of working together to the same end" and "teamwork" is "the combined action of a group of people, especially when effective and efficient" (The New Oxford American Dictionary). Here, cooperation and teamwork are treated alongside each other, and this will show the obvious similarities between the two; however, it will also show some differences, some of which arise simply due to the different fields in which these subjects are studied. After the treatment of cooperation and teamwork, Section 4.3.3 discusses the key elements of project management that will help lead to successful project completion by the team. In this section, a "team" is the group of participants, and cooperation is considered within this group.

### 4.3.1 Cooperation

Cooperation has been studied for a wide range of animals, from bacteria to the insect societies (e.g., ants and honey bees). Here, we focus on human cooperation. Cooperation has been found in the following situations (Rand and Nowak, 2013):

1. *Family and relatives (kin):* Immediate family and relatives often cooperate with each other to a high degree.

2. *Direct reciprocity:* This is, basically, the notion of "you scratch my back and I will scratch yours." In repeated interactions between two people, they may provide mutual help to one another.

3. *Indirect reciprocity:* Suppose an individual helps another individual, perhaps more than once. Suppose that an observer watches the help each time they help. This results in the helper getting a "good reputation." In such a situation, it may be that the observer will directly help the helper, due to their good reputation, and the likelihood that they will end up helping the observer also.

4. *Spatial and multilevel:* Sometimes when people are spatially co-located they will help each other. Also, multilevel cooperation occurs if groups are better competitors with other groups when members in the group cooperate.

Of course, these clean divisions between different types of cooperation may not exist; there may be various combinations or mixtures that arise from the interactions of the above four cases. See Problem 4.11.

### 4.3.2 Teamwork

Teamwork rests on good cooperation, and a number of other features. Here, the basic elements of teamwork are defined, and elements of successful team functionalities are highlighted.

**Teamwork: An Overview**

Following (Maxwell, 2001), typically, a team is needed when a single person cannot achieve some task, or cannot achieve it within some time constraint, by themselves. When a team is formed to complete some task, team goals are defined, vision is established that guides and reinforces good performance, and hopefully shared values emerge as these help a team guide itself to success. Often, "roles" are specified (or emerge) for each member, hopefully ones that fit members' skills and interests. In spite of the role assumed by each member, it is often best to have multiple members who can effectively perform in roles they were not assigned to; this results in members effectively "covering" for each other at crucial difficult times that can have a big impact on team success. During the process of trying to reach the goal, challenges may become increasingly difficult; in this case, the need for effective team functioning also increases. Morale matters; it helps a team overcome "the bumps along the road" where a team is most challenged. Ineffectiveness of a team an arise from one or more members who are not functioning effectively in their role or interactions with others, or perhaps that some member(s) have bad attitudes. Team effectiveness is driven by (i) members who get things done fast and with high performance, (ii) inter-member dynamics where members can depend on each other at crucial times, (iii) members who are willing to make sacrifices to make the team function successfully, and (iv) team members automatically making adjustments in response to good information about where the team is at relative to its goals. Good teams have many effective interactions and communications between team members. Communications help cooperation and coordination emerge, and should catalyze actions. Members invest in making the team work by performing well in their role, helping others as appropriate, and staying aligned with goals, vision, and values. An effective team must have an good leader, someone who "makes the tough calls," shows that each member is important/valued, praises members regularly, and can jump in and help alongside a team member who indicates such a need (see Section 4.1 on helping).

**Teams and Goals**

Within a project, a crucial issue is how the "team" that does the work *cooperates* to achieve success. According to (Katzenbach and Smith, 1993) (p. 165):

> A team is a small number of people with complementary skills who are committed to a common purpose, set of performance goals, and approach for which they hold themselves mutually accountable.

For team management, you should think of the team as a single unit. Not just any group of people is a team, and not just any group performs "teamwork." According to (Katzenbach and Smith, 1993) (p. 164):

> Teamwork represents a set of values that encourage listening and responding constructively to views expressed by others, giving others the benefit of the doubt, providing support, and recognizing the interests and achievements of others.

Just because a group does some type of work, does not mean it is a team. Unlike a team, a "working group" shares information and perhaps other resources to help each other, but the focus is on individual goals, individual responsibility, and individual accountability. In teams there is both individual and "mutual accountability" (accountability of subgroups of the team members), and reliance on more than sharing information and other resources. Also, in a team the work products are the result of joint action by members. Teams cooperatively work together. This can result in performance (success) levels higher than the sum of individual results from a working group. "The essence of a team is common commitment" and "commitment requires a purpose in which team members can believe" (Katzenbach and Smith, 1993). In the context of humanitarian engineering this "purpose" comes from a goal of successfully helping people and working with participants (e.g., a community). Good teams will translate purpose into goals, and these can bring a group together to do something concrete with a community. Often, one of the biggest challenges in humanitarian engineering fieldwork (see Section 4.11) is working on a team and getting the team to function as a cohesive cooperative unit. In practice, conflict and frustrations due to "people problems" arise (e.g., abrasive or insensitive personalities), as does lack of commitment, lack of good work performance, delayed completion of work, and poor communications by individuals.

*Teams work cooperatively to achieve a common purpose.*

**Strategies for High Performance Teams**

To get good team performance, you want to build good team performance in the following ways (Katzenbach and Smith, 1993) (p. 166, quoted, except text in parentheses):

1. Establish urgency, demanding performance standards, and direction (the team must have a clear vision of the importance of the project to the community in terms of impacts on real people, these goals must be challenging, and there must be a clear path to execute project steps).

2. Select members for skill and *skill potential*, not personality (you want a type of matching of the set of team skills to what is needed for a project, or at least some team members who can quickly learn new skills and adapt to a new situation).

3. Pay particular attention to first meetings and actions (first impressions matter and initial organizational issues can motivate people).

4. Set some clear rules of behavior (e.g., attendance at meetings, everyone does what they agree to on time, and everyone works hard on real tasks).

5. Set and seize upon a few immediate performance-oriented tasks (you want some concrete early successes to motivate the team).

6. Challenge the group regularly with fresh facts and information (e.g., generated from outside by talking to people, or by the group itself via research).

7. Spend lots of time together (especially at start, and spend time to learn to be a team, but not all the time needs to be in-person–some of it can be via electronic communications, and place value on informal team activities).

8. Exploit the power of positive feedback, recognition, and reward (given to each other, and shared satisfaction of team performance is a valuable reward).

There needs to be a strong commitment by the  team to figure out how they will work together (who does what, how schedules are set and followed, what skills need to be developed, and how the group will make decisions). There should be a team leader. Everyone on the team should do roughly the same amount of work, and everyone must contribute in a concrete way. The team decides who does what, and when. The team holds itself accountable (for a discussion on accountability in humanitarian engineering projects, see Section 4.11.4) to project goals and to each other. There is shared accountability, shared commitment, and everyone must trust everyone else (e.g., to get their work done or to have responsive communications). Each person's success depends on everyone else's success. The success must be awarded in a way that rewards are shared by everyone.

> Teamwork processes can be designed to promote cooperation and team performance.

### Communications, Cooperation, and Participation Process

Patterns  of communication in teams have a significant impact on success, and in (Pentland, 2012) it was found that for the cases studied, the communication pattern was more important than even the combination of individual intelligence, personality, skill, and substance of discussions. In (Pentland, 2012), the author defines the team's "energy" to be the number and nature of communications between members, and for his cases, this energy is positively correlated with team success. He says that informal interactions between team members, outside formal meetings, have a big impact on team success. Clearly, communication delays (e.g., not responding quickly and thoughtfully to electronic

> Effective cooperation relies on good communications.

communications or delaying meetings) can have a significant negative effects on team performance and success. In terms of the inter-team communications over the project period, by a leader or any group member, the following ideas help lead to higher performance teams (Pentland, 2012):

1. People circulate frequently.

2. People engage people in short energetic conversation.

3. People engage everyone equally (democratic) and help make sure everyone can contribute.

4. People listen as much as they talk (or more).

5. People spread ideas around.

6. People connect team members to each other.

Also, he says that "exploration" by team members outside the group (e.g., by research or consulting someone), positively impacts team success and drives innovation. It also has clear connections to avoiding group think (see Section 4.2) and enriching team discussions and challenges.

Often, people do not put enough thought into the work *process* rather than specific tasks and goals. Teamwork is a specific type of work process, a cooperative one, that has a heavy dependence on inter-member communications and a flexible attitude where you learn to see how things get done better if you work together to achieve the common goal. Goals that especially need this approach are ones that are very challenging to meet, ones impossible for a single individual to meet. Yet, it must be kept in mind that *the process of participation is a goal* also; that is, teamwork involves community members and the process whereby that participation occurs, and everyone works together effectively, has significant value, sometimes as much or more than achieving specific technological goals.

As discussed in Section 4.2, an inclusive team is formed to complete the chosen participatory project. Principles of social justice dictate the importance of inclusion, but more pragmatically, inclusion helps avoid the pitfall of "group think" per the discussion in Section 4.2. A diversity of people leads to a diversity of experiences, opinions, and decision-making approaches. This enriches brainstorming, and helps improve performance in organizational and technical matters. Per organizational matters, there are important issues that arise in how a team should function in a cooperative fashion in order to successfully complete a project.

> Good community participation in the process of cooperative teamwork is an important goal.

### 4.3.3 Project Management

There are many approaches to project management, such as the logical framework approach (LFA) in (PCI, 1979). Here, a very general, and well-accepted, project management approach from (Project Management Institute, 2013) is

overviewed, but is slightly modified to emphasize participation. In Problem 4.12 the relations between the approach here from (Project Management Institute, 2013), and the LFA method (PCI, 1979), are identified and studied.

At an abstract level, project management often includes (quoted from (Project Management Institute, 2013)):

- Identifying requirements;

- Addressing the various needs, concerns, and expectations of the stakeholders as the project is planned and carried out;

- Setting and maintaining active communication with stakeholders; and

- Balancing the competing project constraints, which include, but are not limited to:

  - Scope,
  - Quality,
  - Schedule,
  - Budget,
  - Resources, and
  - Risks.

Project management can be thought of as five interacting and often overlapping "process groups" that are covered next, and all these are based on (Project Management Institute, 2013). Each and every one of these process groups is participatory in obvious ways, though a single project manager is typically needed to lead the project, but of course in some cases it would be best for a person from the community to take the lead and for an engineer to serve as a consultant or mentor.

Following a project, there may be another activity that is solely dedicated to the participatory assessment of the outcomes of a development project (or such assessment is considered an integral part of the project), a process discussed in Section 4.9. Also, there may be project components that require their own management component. In humanitarian engineering, it may be that the technology design/development process requires its own project management as a "subproject" of the larger development project management challenge discussed here. For example, for technology products, the standard ideas on managing technology product development are given in Section 4.7.11, for participatory technology development.

*Project management involves initiating, planning, executing, monitoring, controlling, and closing a project.*

### Initiating, Planning, and Executing Projects

The "initiating process group" involves defining a new project or new project phase. Initial scope is defined and initial financial resources are committed. All stakeholders are identified and the project manager is selected. Project objectives are defined and feasibility assessed. Stakeholder expectations are

aligned with project objectives, scope and objectives are explained, and it is explained to stakeholders how their participation will result in meeting their expectations. Deliverables and project duration are defined, and resources that will be needed are forecasted. Larger and more complex projects may be broken into "phases" and the Initiating process group repeated for each phase, but there would also be an assessment of whether to continue, delay, or discontinue the project.

The "planning process group" involves setting scope, refining objectives, defining course of action ("activities," their durations, and time sequence) to meet objectives, along with a schedule and plan for spending/costs (which may require cost estimation/prediction) that includes a budget. It also involves defining a project management plan, assessing resource needs for activities, and planning what quality is expected for the project and its deliverables. Planning must also be done for human resources, such as roles, responsibilities, required skills, and a plan for how to manage persons performing activities. A plan must be made for effective and efficient communications between all stakeholders, and for how interactions/involvement of stakeholders is to proceed (based on their needs, interest, and possible impact on project success). Planning, analysis, and re-planning, may be needed in an iterative feedback fashion, as described in Section 4.2.10. Inputs and involvement from all stakeholders is needed for planning. Some projects will have significant risks that must be identified, assessed (qualitatively and quantitatively), and considered in planning. Also, risk responses must be planned to find options to reduce threats to objectives; this may involve adding activities, resources to the budget, and modifications to the project management plan and schedule. A plan for procurement of resources may be needed, one that respects local supply chains.

The "executing process group" involves completing the work for the project, by forming a work team, and possibly developing the team (e.g., competencies and effective team member interactions). Work activities must be led and performed. The team must be managed by tracking members' performance, providing feedback, resolving issues, and possibly, as needed, coping with team changes. The goal is good team member behavior, management of conflict, and assessment/feedback to members on their performance. An important part of this is management of the communication process between team members, with stakeholders, and keeping everyone informed on aspects of the project. Execution involves coordinating people, resources, expectations, and performing activities per the management plan. Re-planning may be necessary, with changes in activity durations, resource availability, and unanticipated risks. Procurements will need to be made. Quality must be monitored and assured.

**Monitoring, Controlling, and Closing Projects**

The "monitoring and controlling process group" involves tracking, reviewing, and regulating progress and performance, and identifying and initiating plan changes as needed. Project performance is measured and analyzed at regular intervals, and events and conditions that cause deviations from the project

management plan are identified. Also, changes are controlled, and corrective/preventative actions are taken in anticipation of possible problems. Project activities are monitored and compared to the project management plan, as is project performance. Also, influence is sought over factors that could hinder change control. Project "health" is monitored, and attention is focused on key problems. Project work is monitored and controlled so that stakeholders understand the state of the project, steps being taken, budget, schedule, and scope (including forecasts of these). Change control is also involved, which includes project change requests, approving such changes, and considering such changes in the context of all project aspects including the project management plan. Also, project activities are monitored and, as needed, changes to the schedule are made; this allows for making changes to the plan to take corrective/preventative actions and minimize risk. Costs, and quality, are also monitored and taken into account in this process. Communications are monitored and adjusted as needed, as is stakeholder engagement. Risks are monitored, including new ones, and appropriate risk alleviation strategies used (see Section 4.4.5 for more information on risks). Procurements are monitored, and appropriate adjustments may need to be made to aspects of the project.

The "closing process group" involves finalizing activities to end a phase or project. When complete, this verifies a project is done. This may involve premature closure of a project. At the end, there may be a review, reports, recording of impacts, and documentation on lessons learned. Other assessments may also be done, such as for team members (see Section 4.11.4 for a discussion on individual assessments for university students). All aspects of the project are finalized.

## 4.4 Community Assessment: Learning About a Community

Community assessment can be viewed as occurring on the following three levels (Watkins et al., 2012):

1. *Strategic:* Pertaining to the relation between the community and the society it exists in. What does society need and what resources does it have? How does this relate to what a community needs or the resources it has? How does societal capacity impact community capacity?

2. *Tactical:* Pertaining to the community and perhaps related organizations. What are community needs, resources, and capacities?

3. *Operational:* Pertaining to projects/programs occurring within a community and constituent tasks to get results. In a community project what are the needs, resources, and capacities to get things done?

Assessments can guide decisions that are strategic (based on society needs), tactical (based on community needs to determine what project/program to take

on in the community), and operational (e.g., daily project decisions that align with the tactical and strategic levels). Assessment includes society, community, and development project aspects. It also includes assessing resources, capacity, and aspirations.

Simply put, community assessment is a set of ways to learn about a community. Another way to understand a community is the community capitals approach in Section 4.2.3. PAR, described in Section 4.2.8, is also a way to learn about a community. Participatory communication assessment (PCA) (Tufte and Mefalopulos, 2009), closely related to PAR in Section 4.2.8 and shown in Figure 4.3, is a way to learn about a community. At the top of the figure, a process of building relationships is given. Just below it, and the next step in the process, in a participatory manner the group seeks to identify a problem, considering causes and effects the next layer down. In this section, methods for assessing needs, resources, capacity, and aspirations of a community are provided. The output of this assessment process, the bottom of the funnel, is some conclusion about what the desired community change is. Typically, however, not everything desired can be done at once. Hence, following the community assessment sections, participatory methods for selecting a project are discussed in Section 4.5.

**Community assessment**

Setting the foundation: building trust, listening, understanding groups' perceptions and cultural norms

Exploring broader socio-economic issues, priorities, problems, needs, resources, capacity, aspirations, and opportunities

Investigating specific issues, causes and effects, best options and the communication environment

Defining desired change

**Project selection**

Figure 4.3: Participatory communication assessment viewed as a funnel. Diagram adapted from the one on p. 24 of (Tufte and Mefalopulos, 2009).

There are many approaches to assessment in general, and community as-

sessment in particular. An overview of methods is in (Eade and Williams, 1995). Some view assessment as focusing on the individual (personal needs), family, community, and/or society. Assessment of personal needs is different from groups' needs. A group's needs, resources, capacity, and aspirations are not generally simply the sum of the individual group member's needs, resources, capacity, and aspirations. Why? Communities typically have interactions between members and these dynamical interactions are complex, have a significant impact on how well a community functions, and depend on individual and shared needs and resources. Hence, social aspects and interactions/couplings give rise to needs to improve interactions, and different ways to use resources. Moreover, by cooperating (working together) a community can gain greater capacity compared to if individuals are completely independent of each other. Community capacity is an "emergent" property that arises from individual capacities and social/physical interactions. The goal of assessment is to untangle these complex dynamical community aspects to determine how to build community capacity for well-functioning and robust development.

## 4.4.1 Combining Needs, Resources, Capacity, and Aspirations Assessment

Community assessment provides information that forms the basis for decisions on community development. Proper assessment is crucial to ultimate success as you cannot make good decisions without good information.

To start, some relevant definitions are:

- *Needs:* The New Oxford American Dictionary defines the noun "need" as: "circumstances in which something is necessary, or that require some course of action." In development, a "need" is a *gap* between what is and what should be (e.g., a gap between current performance, results, or achievements and desired performance, results, or accomplishments) (Altschuld and Kumar, 2010; Watkins et al., 2012; Altschuld, 2015). To define a need, you need to know the current condition and the desired one (i.e., the goal). Examples of human needs, as defined by Maslow, were given at the start of Section 1.1. Examples of community "requirements" (types of needs, ones for good community functioning) are given in Section 4.2.3 and (Homan, 2011).

- *Resources:* The New Oxford American Dictionary defines "resource" as: "a stock or supply of money, materials, staff, and other assets that can be drawn on by a person or organization in order to function effectively." Examples of community resources, many of which are referred to as community "capital," are given in Section 4.2.3 and (Homan, 2011).

- *Capacity:* The New Oxford American Dictionary defines "capacity" as: "the ability or power to do, experience, or understand something." Hence, "community capacity" is created by the presence of resources, knowledge, and skills and it enables a community to do something (e.g., promote

change in a community by themselves, develop additional resources, and cope with challenges or "shocks" produced by economic or natural disasters). Technological capacity was defined and discussed in Section 2.1.2. Community technology capacity is the ability to work together to build more technological capacity for its members. This could happen in an informal setting, or in a formal classroom setting via STEM education. Building technological capacity is crucial to ensure proper design, operation, and maintenance of many technology solutions.

- *Aspirations:* The New Oxford American Dictionary defines "aspiration" as "a hope or ambition of achieving something." If people have such hope or ambition, they will be more likely to be willing to work to fulfill the aspiration (e.g., by participating in a development project). As an example, it may be that meeting some need, creating some resource, or creating some capacity, is an aspiration for an individual or community.

There are multiple perspectives you can take on development, based on what your assessment perspective is:

1. *Discrepancy perspective:* This focuses on needs assessment as differences between what is and what should be (e.g., as in (Altschuld and Kumar, 2010; Watkins et al., 2012; Altschuld, 2015)).

2. *Capacity perspective:* Essentially considers the differences between needs and resources, and whether the community can close the gaps (has the capacity to do so).

3. *Appreciative inquiry perspective:* Building on Section 4.2.2, this focuses on what works, and not just what does not work (often the needs assessment focus), and typically would highlight resources/assets also.

4. *Aspirations perspective:* Focuses on what people hope for, and have ambition to achieve.

> You should never focus only on assessing needs; you should also assess resources and assets that can be built on to enhance project success.

Here, simultaneous assessment to provide a basis for all four is advocated, along with the use of assessment for project monitoring and evaluation. Broadly speaking, a community with few resources typically has many needs. As a community develops, needs are addressed, resources are accumulated, capacity is built, and aspirations are achieved. At some point in its development, the community becomes self-sufficient by building capacity so that it addresses needs, creates resources, and meets aspirations on its own. It then has "community capacity" that is sufficient for independent and robust operation. Needs, resources, capacity, and aspirations assessment is part of a feedback process that leads incrementally to development (see Section 4.2.4 and Figure 1.2 on p. 31 of (Watkins et al., 2012)).

Do not start with preconceived notions of what needs, resources, capacity, and aspirations are (e.g., based on your experiences with a different community or where you live). To design an assessment strategy, you need to know what

decisions are to be informed by the assessment information that is produced. Community and individual needs are sometimes not known, are undeclared, or are considered unimportant by persons who could help meet those needs. In needs/resource assessment you seek to discover needs and identify resources. A community assessment should be completed using a participatory approach (e.g., using PAR), and such a participatory approach can help make participants invested in the change process.

You "do not define the community according to its unmet needs or its problems, or even worse, its symptoms of deeper problems" (Homan, 2011). Such a list is well-known to the community. It reduces the community to a set of problems and "confirms desperation." Homan says that agencies often produce such assessments and lists, but he says that such approaches may reflect a "service only" approach that "will produce few, if any, meaningful changes" (Homan, 2011). He says for a needs assessment there should be just as much work done to find resources and assets. He says if you only plan on assessing needs, do not even do it; however, if you need to discover issues for action via the community's capabilities, then the assessment may provide valuable information for promoting change. You should also be seeking to uncover assets and resources in the community. It may be that existing assets or resources can be used to meet needs and improve conditions, perhaps via a reallocation. An asset/resources assessment can result in the question of what can we do, or create, with what we have? Needs and resource assessments can proceed in the same way, and can use participatory action. It is good to focus your resource assessment on what you want to accomplish and the resources to support it, then question the community about the existence of those assets (this helps make the assessment more limited in scope and hence more manageable). Keep in mind that, as discussed in Section 4.2.3, there are many types of resources (capitals): natural resources, built environment, money, skills, talents, human qualities (e.g., passion), procedures/voting, information (e.g., libraries or electronic sources), cultural traditions, spiritual/religious activities, relationship networks, and dual-use resources.

### 4.4.2   The Community Assessment Process

The authors in (Altschuld and Kumar, 2010; Altschuld, 2015) break the overall assessment process into three parts, pre-assessment, assessment, and post-assessment (see also pp. 248-253 of (Watkins et al., 2012)). For instance, in pre-assessment, the following tasks are completed in a participatory manner:

- Define the objectives of the assessment process via a preliminary assessment (a small "pilot" assessment). You will not be able to assess everything. You need to narrow the focus (scope) so that the assessment process is manageable within the time and cost constraints you have. Usually, this results in a few clear assessment goals, for example, stated as "We want to know...". These are typically connected to some envisioned project goals; hence, you may want to review Section 4.5.

- Define what information you need, qualitative (words, written or verbal) and quantitive (numeric).

- Create a plan for managing the assessment process within the constraints you have. This may require ideas from project management as in Section 4.3.3.

The post-assessment process includes activities like synthesizing and analyzing gathered information.

The typical steps to the overall assessment process, that include pre- and post-assessment, include (Altschuld and Kumar, 2010; Homan, 2011; Watkins et al., 2012; Altschuld, 2015):

1. Form the team. See the discussion on PAR team formation in Section 4.2.8 (also see Table 2.2 on p. 54 of (Watkins et al., 2012)). Sometimes, it is necessary (or a good idea) to get a community leader's approval for the assessment, and perhaps their inputs or involvement, so long as they do not dominate and/or misdirect the assessment process.

2. Determining what data are needed, at what level, and via what sources. Focus on getting only what you need for project decisions.

3. Collect information (methods for this are below), perhaps by pilot tests of collection methods first. If possible, use multiple collection methods to gain different perspectives as this can enrich decision making.

4. Gather information on needs based on information on performance gaps. Repeat for resources, aspirations, and capacities, if desired.

5. Gather information on the prioritization of needs, resources, capacities, and/or aspirations.

6. Collect information on causal factors, root causes, and what is and is not working. Consider whether additional information is needed for the higher priority issues.

7. Perform technical assessments.

8. Synthesize, analyze, and visualize the information.

9. Identify criteria to base decisions on (e.g., cost, time, priorities, and outcomes).

10. Reflect on the assessment process and possibly modify, perhaps for the next time assessment is done.

Sometimes, it is desirable to collect information per gender, and there are special methods for assessment of gender-specific issues in the context of development (e.g., the "Gender Framework Analysis" on pp. 135-140 in (Eade and Williams, 1995)).

In developing an approach to community assessment you need to determine who you are going to talk to, how many people you will talk to, whether you are going to talk to them individually or in groups, will you send invitations, or have a public hearing or focus group, or will you mail out a questionnaire/survey? You should try to gather information from persons who may be later involved in deciding the course of action to address issues, and the ones who will be acting to promote community change. You need to carefully consider costs in money and time to perform the assessment, and plan the assessment process (e.g., using a Gannt chart). The community needs to decide how the assessment information is to be used, who it can be shared with, and who owns it. After you gather all your information, critically analyze it so that you get the best conclusions (e.g., try to understand the "intensity" associated with response, that is, strongly held vs. weakly held opinions). These issues, and others, are the subjects of the next section.

### 4.4.3   Gathering Information About a Community

There is a wide array of methods to perform assessment of a community. While it is wise to start with research (e.g., via the internet) to at least give a broad context for the assessment, other methods where the community is engaged in person are essential. Below, some of the key information-gathering methods are outlined, including interviews, focus groups, and surveys. Other methods, including strengths, weaknesses, opportunities, and threat (SWOT) analysis (see pp. 127-136 and the SWOT matrix in Figure 3A.1, p. 130), the Delphi approach, and task analysis for assessing processes are given in (Altschuld and Kumar, 2010; Watkins et al., 2012; Altschuld, 2015).

**Research**

It is probably best to start by reviewing existing documents relative to the community, for example, on the country or city the community is in. Of course, there may be relatively little information on the community itself that is available. Yet, there is likely some useful information that can be found via the UN or World Bank (see Chapter 1), the World Values Survey (see Section 1.4.5), or on the internet via a search engine. At least, you can come to understand aspects of poverty and development, along with historical, cultural, economic, and political context (at the strategic level). Sometimes, there may be a local expert on the community that can be consulted, or at least someone from the country's diaspora, before the assessment or perhaps to help interpret gathered information about a location.

**Interviews**

Interviews are used to collect information from a single person in a structured, semi-structured, or unstructured format (Watkins et al., 2012). Of course, multiple people can be interviewed and this can provide useful information for

finding a project that fits a visiting group. An interview is done orally, and *must be in the language of the interviewee.* This may require a translator. In some cases, it is crucial to have someone else from the community present at the interview (e.g., in a door-to-door approach), especially someone of the same socioeconomic class; such a person can give an interviewer credibility and help the interviewee trust the interviewer. A skilled interviewer will use the "active listening" techniques discussed in Section 4.1.2 and humble inquiry ideas in Section 4.1.3. An interview can allow for a focused discussion, follow-on questions, story-telling, and gaining an understanding of context. It may afford a type of privacy where the interviewee may provide more information than in, for instance, a focus group (see below), especially about aspirations. Interviews can, however, take a significant amount of time, not provide for a broad sampling of a community, may provide conflicting and difficult to analyze information, and can get "off track." Before interviewing someone, you should have a clear information-gathering goal. Also, you should carefully select who to interview, considering: (i) talking to "experts" or leaders, (ii) talking to some type of cross-section of the community, and (iii) being inclusive to the greatest extent possible (e.g., talking to women and minorities).

In a structured interview you will need a list of questions, placed in a specific order, and designed to meet your information-gathering goals. Adding structure to the interview will make it easier to aggregate information that is gathered from more than one interviewee. The questions could be along the lines of the ones discussed below when survey questions and responses are used, but often different in two ways: (i) questions are given orally in the language of the interviewee, and (ii) they may not be as detailed per requirements in rating various responses (e.g., with five levels of response) and may have no associated numeric response. In an unstructured interview, you should have an information-gathering goal, but your list of questions may be fluid and, depending on the situation, you may not ask some of them, or you may re-order them. For either the structured, semi-structured, or unstructured cases, you should consider including both "closed questions" (e.g., ones with a yes/no or pick one of $N$ options) or "open questions" (e.g., how would you solve this problem? or what are the needs and resources in your community? or what are your aspirations?). Many types of questions are possible, including ones like those given on a survey (see below). Sometimes, pictures or a technology demonstration may be useful (see below) to provoke inputs from an interviewee. Notes are taken by the interviewer, or an assistant, though in some cases, an audio/video recording might be possible if the interviewee allows it, but that may inhibit free and open responses so you should hesitate to take that approach. For more information on interviewing, see pp. 106-115 of (Watkins et al., 2012).

**Focus Groups**

"Focus groups" are a commonly used assessment approach and the ideas in this section are from (Watkins et al., 2012; Homan, 2011). Focus groups can be useful for gathering information, especially if the focus group is run according

to a systematic and structured format, and is centered on a clear and specific goal. Focus group size can vary, for example, between 5 and 15 people and the length of the focus group meeting can be 45 minutes to 3 hours. A focus group would normally convene at a convenient and neutral meeting place in the community. It should start by having everyone introduce themselves, unless everyone knows each other.

Focus groups should be composed of persons with a variety of perspectives on an issue, and inclusion of the marginalized should carefully be considered (e.g., if the group is to discuss something to do with what in the society is considered "women's work," like carrying water, then women must be present). Questions are provided by a "facilitator" (moderator) who asks a set of questions (e.g., ones along the lines discussed above for interviews and below for surveys, but tailored to the group and typically delivered verbally), tries to direct the discussion and keep it open, makes sure it is not dominated by one individual (e.g., by having a "round robin" approach to comments/ideas where everyone takes a turn speaking and these rules are set at the start), and guides it in a way that the goals of the meeting are met (e.g., by avoiding going off on tangents). Everyone should speak at least once. Disagreement and debate should be encouraged, but the facilitator should be neutral. It may be useful to guide the meeting via some visuals, such as an outline/responses summary listed on a chalkboard, flip-chart, or large piece of paper. Sometimes, pictures or a technology demonstration may be useful (see below). Many ideas and opinions can be shared in such a setting and sometimes even a single point-of-view on an issue emerges, though that is not required. Sometimes, ideas of one individual are built upon by others. Sometimes, the facilitator will suggest a "straw poll," an informal vote on a question that then can help the group understand where it is going, and may help to build consensus, or show how much views differ on an issue. Near the end, the facilitator should signal that the meeting is near complete, and should consider summarizing at least some of the findings from the group. Throughout the process, group members should be encouraged to ask questions, and give inputs.

Focus groups are used to, for instance:

- Collect information on the current state of affairs, or performance of a program.

- Collect information on the desired state of affairs, or estimated performance of an envisioned program.

- Combine these to identify needs, resources, capacity, and aspirations.

- Gather inputs on how to prioritize needs and use resources and capacity to achieve aspirations.

- Collect proposed solutions, sometimes via brainstorming, along with their advantages and disadvantages.

Often, someone takes notes during the meeting, but if people are comfortable with it, the focus group meeting could be audio/video recorded, but that may inhibit free and open responses.

Aside from the potential that one person dominates the discussion, there can be other problems with focus groups. They may take too long. Some people may not feel comfortable expressing their true opinions in front of others, or sharing information with everyone in the group. Some facilitators may not do a good job in maintaining focus of the group, synthesizing responses, and creating new appropriate questions that help meet the goals of the focus group. Synthesizing information and generating good questions in such a dynamic social situation requires good listening skills and good creative abilities. For more on focus group guidelines, see pp. 95-105 of (Watkins et al., 2012).

Sometimes, focus groups are used after a survey (see below) to validate its results, while other times the results from a focus group can be used to help construct a survey for a larger group.

### Interviews and Focus Groups With Demonstrations

In either interviews or focus groups, it may be possible to provide some ideas of candidate solutions based on the pre-assessment. Such ideas could be explained in several ways:

1. *Pictures:* Sometimes, black and white or color diagrams or photos can be provided, along with an explanation of candidate technologies.

2. *Physical hardware/software:* Sometimes, some candidate technologies (e.g., water filtration systems or solar lanterns) can be shown to people to provide ideas on how issues can be addressed.

Either of these approaches can be very effective in focusing conversations, and help to show tangible ways that issues could be addressed. Indeed, assessment information can be gathered on candidate solutions (e.g., desirability of features).

### Survey Construction

Surveys are a common method used to gather information for an assessment; here, the ideas on surveys from (Watkins et al., 2012; Homan, 2011) are discussed and expanded upon. Sometimes, interviews and focus groups are conducted in order to put together a good survey for a larger group of people and other times interviews and focus groups are conducted after a survey in order to understand its results. Surveys could be administered in person, over the phone, via computers and the internet, or post mail if any of those are available. Here, it is assumed that a paper-and-pencil survey is used; a number of the examples and approaches below will change if a computer-based survey is used (e.g., one of the free ones available on the internet or one where fees have to be paid for use).

A survey can be used to learn about needs, resources, capacity, knowledge, skills, interests, aspirations, concerns, opinions, priorities, etc. Of course, the survey must be in the language of the persons who fill out the survey. A significant potential problem with a written survey can arise if the percentage of people surveyed who are literate, can read and/or write, is low. Can assistance be provided for such people to get their survey information? Assessing the literacy level of a community in order to decide whether a survey will work can be a challenging task in itself; however, sometimes a community leader (e.g., a school teacher) will have a good idea of the literacy rate in a community. Of course, this literacy rate can depend on age, gender, race, etc. Illiterates may be the ones that need the most attention, but to hear from them you may need an interview or focus-group approach, or at least a survey administrator who is prepared to help an illiterate fill out the survey (but of course, then it becomes something like a structured interview).

Issues to consider for a survey include (Homan, 2011): (i) the population to be surveyed, (ii) sampling, that is, how many and who to ask (e.g., to get a cross-section), and a method to choose people at random (to remove bias), (iii) design of the survey "instrument" by picking questions to reflect really what you want to know, with mainly close-ended questions and perhaps a few open-ended ones to solicit opinions and provoke creative responses, (iv) longer surveys tend to discourage more people from responding so you should keep it short, (v) keeping questions accurate and clear (and perhaps pilot the survey questions before using them), (vi) conduct the survey in a way to solicit many open honest responses (e.g., by keeping it anonymous), and (vii) ask questions in a way that will ensure that data will give you the right information. You may want to start he survey with the most interesting questions, but you should keep put the questions in a logical order. Surveys generally should not ask what people *want* as they might then be misled to assume that they are going to get something and this may produce a false hope. Producing a well-designed survey and administering it are not simple. Here, some of the basic elements in survey design for a community are outlined.

### Question and Response Types

There are many types of surveys that can be constructed and you should take the view that a specialized survey, one that fits your goals, must be designed. The survey in Table 4.1 is one simple example, and one not intended to imply that every survey will be so short or focused. Many more questions are possible, of course. The type of questions, and the types of requests for responses, that you put in any community assessment survey must be chosen for each case and be directed toward a specific goal (e.g., improving food security or making a general needs/resources assessment). It is important to make the questions distinctly different from one another so the survey does not seem to be repetitive and hence a waste of time, and only include questions whose responses will really be helpful to a project. Survey response rate is generally inversely proportional to the length and complexity of the survey.

The types of questions that can be considered include the following:

- *Current and desired conditions:* It is typical to ask questions about current conditions and/or desired conditions, where conditions can be needs, resources, or capacity (e.g., the community capitals). For instance, Table 4.1 provides questions about current conditions, but you could also ask about how easy water should be to access, or if a somewhat bad taste of the water matters to individuals so long as it is clean.

- *Technology resources:* You may ask questions about a situation where there is no technology present (e.g., Table 4.1), or one where community members are asked to describe a level of satisfaction with a technology (e.g., a single centralized water pump). For example, if in the survey in Table 4.1 you replace "in our village" in the first two questions with "from our pump" you get a very simple survey about your pump technology, which can be viewed as a community capital. Of course, in a real survey you would likely have more questions, and different ones (e.g., asking how easy the pump is to operate, how frequently it breaks down, and how easy it is to maintain and repair).

- *Social justice:* Though sometimes sensitive questions, you may want to ask questions about social justice issues, including about person's opinions on whether their human rights are respected and supported (e.g., are they discriminated against and marginalized) or whether their capabilities are deprived (per Sen's capabilities approach in Section 2.3.2).

Each of the types of questions must be paired with an appropriate response type. Typically, this requires carefully considering how to word the question so it fits the requested response type (it is clear) and a choice of response type that facilitates aggregation and analysis of the results of the survey (e.g., taking averages). Responses to questions can use a wide range of approaches, including the following:

- Yes/no responses.

- Multiple choice questions.

- Mark-all-that-apply responses.

- Fill-in-the blank.

- Level of agreement, as seen in Table 4.1.

- Level of satisfaction, with responses extremely dissatisfied, dissatisfied, neutral, satisfied, and very satisfied.

- Magnitude of the frequency of occurrence of some event (e.g., technology failure), with responses of never, infrequent, once in a while, frequent, and very frequent.

- Features of some resource or asset in the community (e.g., how useful or accessible the asset is).

- Features of some vulnerability or risk.

- Skill/knowledge levels of individuals.

- Open-ended, fill-in-the blank or write-out-a-response, questions (e.g., on aspirations).

This is by no means an exhaustive list. It is only representative. The list of responses given are only possibilities; others may make sense. Though common, you do not have to use Lickert items (see below) for the questions. It may make sense to have yes/no or multiple choice responses (including options of "none of the above," "all of the above," and/or "other").

### Lickert Items and Scales: Discrete Responses

A "Lickert item" (named after Rensis Lickert, its originator) is a type of survey question. Some prototypical Lickert items that make up a brief survey are given by the example in Table 4.1 that is designed to gather information on only three issues in a village: water, food, and education. Notice that there is a "symmetry" to the responses, with a neutral response, and just as many responses above as below the neutral response. In picking the word-description associated with each numeric choice, 1, 2, 3, 4, and 5, there an attempt to make the difference in numeric values be the same as the difference in the meaning of the associated word descriptions: this is called "balance" in a survey response construction via a Lickert item.

A "Lickert scale" is simply a sum of the responses given to Lickert items. For instance, the Lickert scale for one individual, for one set of Lickert item responses, is the sum of those responses. For example, for Table 4.1 the three responses about water can be summed and the result is between three and 15. In this case, a value of three corresponds to the most dissatisfied individual, while a score of 15 would correspond to a very satisfied individual. Another Lickert scale, one for $N$ persons filling out the survey in Table 4.1 would be one that summed all the responses to the first question. This would give a rating of how satisfied the group of people are with ease of access of drinking water. Of course, assuming balance, means and standard deviations across individual and group responses can also be useful, as discussed below.

### Questions With Continuous Responses

Lickert items have discrete responses and a resulting discrete scale. Here, the survey example in Table 4.1 is redesigned to ask about satisfaction rather than agreement (simply to illustrate how the wording of the statements changes), and to allow for responses on a continuous range, and hence creation of a continuous scale. See Table 4.2. The advantages of the continuous response are: (i) not assuming, as in the Lickert item, that there is a type of equal spacing between

Table 4.1: Survey example using Lickert items.

| Village Survey (Example #1) | |
|---|---|
| Response options: *1=Strongly disagree, 2=Disagree, 3=Neutral, 4=Agree, 5=Strongly agree* | |
| **Statement** | **Response (mark one)** |
| 1. Drinking water is easy to access in our village | ①—②—③—④—⑤ |
| 2. Drinking water is clean in our village | ①—②—③—④—⑤ |
| 3. Water for non-drinking purposes is adequate in our village | ①—②—③—④—⑤ |
| 4. Food is readily available in our village | ①—②—③—④—⑤ |
| 5. Available food is nutritious | ①—②—③—④—⑤ |
| 6. Available food is inexpensive | ①—②—③—④—⑤ |
| 7. Teachers at the school are competent | ①—②—③—④—⑤ |
| 8. My children got/get a good education at the school | ①—②—③—④—⑤ |

discrete responses so that taking averages makes sense; and (ii) not unnecessarily restricting responses to one of a finite set.

For Table 4.2, any two end-point values can be used for the lower and upper limits on the range (e.g., 0-100). In some cases, it make make sense to put tick marks on the horizontal lines to guide the respondents as to where values are (e.g., the middle), but this may encourage respondents to place their marks only at the tick marks. The persons who gather and process the information will have to convert the positions of the marked "×" locations on each line into numeric, likely non-integer, values (adding tick marks may make the conversion easier). If you sum up all these numbers for a single respondent, then the resulting number on that scale (for the example Table 4.2, on $[0, 80]$) represents the satisfaction of the respondent for all eight issues. If you sum across all respondents for any single question, then you get the satisfaction level of that group for a single issue (e.g., if 50 people responded to statement 1, then the numeric value obtained will lie on the scale $[0, 500]$).

Table 4.2: Survey example using responses on a continuum.

| **Village Survey (Example #2)** | |
|---|---|
| Responses: Mark an "×" on the line between 0 and 10 indicating your level of satisfaction with the stated condition, with 0 representing complete dissatisfaction and 10 representing full satisfaction. | |
| **Statement** | **Response (×)** |
| 1. Ease of access to drinking water in our village | 0\|————————\|10 |
| 2. How clean drinking water is in our village | 0\|————————\|10 |
| 3. Adequate non-drinking water in our village | 0\|————————\|10 |
| 4. Readily available food in our village | 0\|————————\|10 |
| 5. Nutritious available food | 0\|————————\|10 |
| 6. Inexpensive available food | 0\|————————\|10 |
| 7. Competent teachers at the school | 0\|————————\|10 |
| 8. Good education for children at the school | 0\|————————\|10 |

### Non-Numeric Responses: Example Survey on Social Justice Issues

To give an example of a type of survey that is non-numeric, consider the survey on a few social justice issues in Table 4.3.

In constructing such a survey, you should not ask questions that your envisioned project can never address. Several of these questions can be quite relevant to an engineering project. For instance, the one on participation in community decision making will affect participatory development, and whether you will really be selecting a project that is addressing needs (e.g., if the women cannot participate in decision making, will your water project really address needs?). The questions on opportunities affects designed technologies for education, health, and promotion of economic development.

### Questions With Dual-Responses

In (Watkins et al., 2012) the authors describe a dual-response survey approach for identification of needs, one that seeks to identify current and desired conditions, and thereby identify the gap, which is the need. An example of a dual

Table 4.3: Survey example on social justice issues.

| Village Survey (Example #3) | |
|---|---|
| **Statement** | **Response (circle one)** |
| 1. I am... | Male     Female |
| 2. I am a minority in the community | Yes     No |
| 3. I can participate in community decision making | Never     Sometimes     Always |
| 4. I can influence community decisions | Never     Sometimes     Always |
| 5. I have the same educational opportunities as others | Never     Sometimes     Always |
| 6. I have the same healthcare opportunities as others | Never     Sometimes     Always |
| 7. I have the same economic opportunities as others | Never     Sometimes     Always |
| **Please describe any relevant issues:** | |
|  | |
|  | |
|  | |

response survey, one developed by modifying the one in Table 4.1 by focusing only on water, is shown in Table 4.4.

Table 4.4: Dual-response survey example for water.

| Dual-Response Village Water Survey (Example #4) | | |
|---|---|---|
| Response options; pick on on the left and one on the right: *1=Very poor, 2=Poor, 3=Neutral, 4=Good, 5=Very good* | | |
| **Current performance** | **Feature** | **Desired performance** |
| ①—②—③—④—⑤ | 1. Drinking water access in the village | ①—②—③—④—⑤ |
| ①—②—③—④—⑤ | 2. Drinking water is clean in the village | ①—②—③—④—⑤ |
| ①—②—③—④—⑤ | 3. Water for non-drinking is adequate | ①—②—③—④—⑤ |

Clearly, a problem with this survey example is that many individuals may mark "5" on the right; that is, clearly, they want the best for themselves. There are several solutions to this problem. First, the way the responses on the right-

hand-side are stated can be changed to say something like "Minimum acceptable performance" rather than "Desired performance." Second, sometimes a certain number of "points" are allocated to each set of survey questions for the right side, and the respondent is asked to *allocate* these across a set of questions. This results in a type of prioritization of desired performance, and this is discussed further below. Yet, even without a survey redesign of these two types, if people mark "5" for all the right-hand-side responses, the *difference* between what they mark on the right and left can be quite useful as it still represents a proportional deficit. Indeed, if the response on the right minus the response on the left is positive, then this indicates a gap, or need, with the magnitude of the difference quantifying the level of the need. It is possible that a response on the left is greater than on the right, indicating a surplus and in some cases this may then allow for a reallocation to other needs. If the response on the left is the same as on the right, this indicates no need, and current conditions are satisfactory. Is should be clear how to modify this survey to one that has continuous responses/scales as in Table 4.2.

The nice feature of the dual-response survey question is that the community member is the one that identifies directly the need (gap). Sometimes, they may not be able to really assess accurately the current condition, but they may be able to say what they want on the right-hand-side response, then correspondingly mark the left hand response to represent how deficient the current situation is. The opposite holds also. Clearly, three pieces of information are gathered from one dual-response question: current conditions, desired conditions, and the difference between the two, which is the need. The question and response types outlined above are candidates for a dual-response survey.

### Priorities/Importance: Discrete Responses

The interpretation of the meaning of "priority" is typically different than "importance." For priority, people typically think of priority *relative* to something else. For importance, a set of items can all be ranked as having an importance independent of other considerations; hence, importance is typically a type of absolute rather than relative concept. Priorities could come from the size of the gap identified above, with a larger gap corresponding to a higher priority. Another approach is to have explicit questions on priorities.

The simplest way to ask about priorities is to make a list of items and ask which is the highest priority one. Of course, you could ask them for their top set of choices, or their choices in order. For instance, to survey about priorities, consider a method to survey about the priorities of the items in Table 4.1 via the survey in Table 4.5. This approach forces an individual to produce relative priorities by ranking the options and if they consider two options equally important they are still forced to rank one over the other. Hence, there are not equal "distances" between the ranked options that are quantified in the priorities specified by the numbers; however, the numbers may be mistakenly thought to represent that. This creates some challenges in aggregating and analyzing the data from multiple respondents that are discussed below.

Table 4.5: Survey example about priorities, option #1.

| Village Priorities Survey (Example #5) | |
|---|---|
| Responses: Please fill in the blanks on the right side with numbers 1-6, with 1 indicating the lowest priority item, and 6 the highest. | |
| **Statement** | **Response** |
| 1. Improve drinking water access | |
| 2. Improve drinking water quality | |
| 3. Improve non-drinking water access | |
| 4. Improve food availability | |
| 5. Improve amount of nutritious food | |
| 6. Reduce cost of available food | |

Next, consider another approach to surveying about priorities via the example in Table 4.6 The constraint of picking only one high priority item, etc., forces the individual to set *relative* priorities. Of course, there are many other ways to do this. For instance, a certain number of points could be provided and the respondent asked to distribute this set of points across a set of items. This, however, can be a little complicated for a respondent as it requires the respondent to sum the number of points, typically several times, in coming up with a response. Notice that if you sum each item's response for every respondent then you get a Lickert-type scale for priority; however, this can be a flawed approach as the "distances" between ranked options is not in general uniform. This issue will be discussed below when we treat the case of aggregating data from priority surveys.

It is easy to modify the above survey to instead ask about the importance of each statement. To do this, change the response options and explanation to:

> Response options: *0=No importance, 1=Low importance, 2=Medium importance, 3=High importance.* **Pick three items to have scores of 0, and the remainder to be any value between 0 and 3.**

That last statement is added to add an element of relative ranking, and to avoid the situation where the respondents all simply say that everything is of high importance, which would not be very informative.

Table 4.6: Survey example about priorities, option #2.

| **Village Priorities Survey (Example #6)** | |
|---|---|
| Response options: *0=No priority, 1=Low priority, 2=Medium priority, 3=High priority.* **Pick at most one high priority item, two medium priority items, and three low priority items.** | |
| **Statement** | **Response** |
| 1. Improve drinking water access | ⓪—①—②—③ |
| 2. Improve drinking water quality | ⓪—①—②—③ |
| 3. Improve non-drinking water access | ⓪—①—②—③ |
| 4. Improve food availability | ⓪—①—②—③ |
| 5. Improve amount of nutritious food | ⓪—①—②—③ |
| 6. Reduce cost of available food | ⓪—①—②—③ |

**Priorities/Importance: Continuous Responses**

Table 4.7 shows an example where continuous responses are used for priorities. Notice that this approach solves the problem identified above where a person may respond with high priorities for everything: they are forced to order their responses lowest to highest. Also, they can do it on a continuous range so that you will be able to see the sizes of the gaps between priorities. The persons gathering the information will have to convert the number positions to numeric values on the scale.

## 4.4.4 Aggregating and Visualizing Community Information

The Lickert scale, that was used several times above, provides one way to aggregate (synthesize) information gathered via a survey for a community, either for individuals, or for groups of respondents. The design of interviews, focus groups, and surveys depends heavily on what information you are trying to gather and how that information will be aggregated and analyzed (e.g., via visualization). The Lickert scale provides just one way to aggregate information. Others are discussed next.

Table 4.7: Survey example about priorities, option #3.

| Village Priorities Survey (Example #7) | |
|---|---|
| Responses: Write the numbers of the statements on top the horizontal line between 0 and 10, with 10 indicating highest priority, and placed *in order* from lowest to highest priority. | |
| **Statement** | **Responses** |
| 1. Improve drinking water access | |
| 2. Improve drinking water quality | 0\|————————————\|10 |
| 3. Improve non-drinking water access | |
| 4. Improve food availability | |
| 5. Improve amount of nutritious food | |
| 6. Reduce cost of available food | |

### Qualitative Information: Verbal/Written Words

Verbal and/or written words, gestures, body language, facial expressions, etc., are often referred to as qualitative information. While such information can be very important for community assessment, it is fundamentally difficult to aggregate and analyze in a systematic manner as there are typically no associated numbers included that can be processed with mathematical or statistical methods. This does not mean, however, that it is not possible to aggregate and analyze qualitative information in ways that will render it useful.

In this section, the focus is on qualitative information in the form of verbal and/or written words. The approach to analysis of qualitative information depends on how it is gathered, including via the following:

- Verbal statements from respondent(s), with no audio/video recording.

- Verbal statements from respondent(s), with an audio or video recording.

- Note-taking during or after an interview or focus group, that is conducted via hand-written notes on paper.

- Note-taking during or after an interview or focus group, that is done via a computer.

The first two of the following methods seek to directly aggregate and analyze qualitative information, while the second two provide methods to convert qual-

itative information into quantitative information that can then be aggregated and analyzed using the methods of the next section:

1. *Extract common concepts and themes:* During or after the interview process, someone listening to everything may be able to identify common concepts and themes. Sometimes, such identification is easy, for example, when a straw poll is taken in a focus group and there is a high level of consensus. Typically, some aspects of the conversations are easy to highlight that are more difficult or impossible to understand with a quantitative approach (e.g., enthusiasm, passion, motivation, animation, and conviction). Often, it is possible to organize the information under the major concepts and themes, for example, with example representative statements (quotes) used from individuals to justify the validity of your claims of conclusions reached from aggregating information. Of course, this allows for subjective influences to arise (e.g., from your own biases), and this is one of the main reasons that quantitative information is preferred as it often may provide a detached and objective scientific assessment.

2. *Create a graphical representation:* Sometimes it can be useful to take key concepts and themes and create an influence diagram (see Section 1.6.1) that shows the interactions between them. Such pictorial representations are convenient for showing a group of people, and can facilitate discussions, modifications, and understanding.

3. *Word histograms and clouds:* If audio/video information is transcribed into text, then information is lost (e.g., tone of voice), but a simple computer program can count the number of occurrences of each word and a histogram showing the frequency of occurrence of the most common words can help uncover common concepts and themes. Another approach to processing such text files is via a "word cloud," such as the one shown in Figure 1.3. These approaches provide simple ways to convert qualitative information into quantitative information, or interpret qualitative information.

4. *Scoring for conversion to quantitive information:* Sometimes, qualitative information obtained from interviews and focus groups is "scored" by someone trained to do so in a consistent manner across subjects (e.g., in psychology). This provides a type of conversion from qualitative to quantitative information. Sometimes, such scoring processes are facilitated (or only possible) if an audio/video recording is conducted so that the scorer can rewind/replay to carefully study the responses in order to create scores. Of course, this can be a very time-consuming process.

As an example, a "phenomenographic approach" to qualitative assessment for humanitarian engineering is discussed in (Vandersteen et al., 2009). Another qualitative evaluation for humanitarian engineering for two case studies, Haiti and Benin, is in (Silliman, 2009).

**Quantitive/Numeric Information**

Aggregation of numeric information can occur for a single individual or a group of individuals. Here, we will discuss the group case as then it will be obvious how to handle the individual case if you need to do that. Of course, it may be that you want to aggregate some information for every individual case, then aggregate that resulting information across all individuals in the group. You will have to decide how to cope with a set of responses from an individual (e.g., via a survey), where all but a few responses are present. The case of such "missing" data can be handled by throwing out that respondent's responses altogether, or just the questions that were not responded to, but this biases the results of the survey. Or, in some cases, there can be a new category created for counting "no response" cases, then that can be used in the analysis. Other problems can include responses that were given, but not in the list of available responses, or responses where it is clear that they did not understand the instructions. Again, you will need to decide how to handle these cases. Assume that all these issues are resolved for the following discussion.

Suppose that there are $N$ respondents, and $M$ questions, and $x_i^j$, $i = 1, ..., N$, $j = 1, ..., M$, are the numeric responses on some question by the $i^{th}$ respondent for the $j^{th}$ question. While not exhaustive, some common approaches to aggregate information in a quantitive manner for various response types include:

1. *Discrete/continuous numeric:* Examples in Table 4.1 and Table 4.2.

   - Aggregation:
     (a) Mean of responses across all respondents, for each question: For $j = 1, ..., M$,
     $$\bar{x}^j = \frac{1}{N} \sum_{i=1}^{N} x_i^j$$
     (the sample mean for each question).
     (b) Standard deviation across all respondents, for each question, $\sigma^j$: For $j = 1, ..., M$,
     $$(\sigma^j)^2 = \frac{1}{N-1} \sum_{i=1}^{N} (x_i^j - \bar{x}^j)^2$$
     (the "corrected" sample standard deviation that produces an unbiased estimate). The variance is $(\sigma^j)^2$.
     (c) Other: Median, mode, range, quantiles.
   - Visualization: Two-dimensional "scatter plot," with horizontal labels being the questions $j = 1, ..., M$ and the vertical being the numeric responses $x_i^j$ for each $i$ (typically, a small "×" is plotted for each data point). Then, for each $j$, label $\bar{x}^j$ and $\pm\sigma^j$. Other options include a box plot, with/without outliers, and a quantile plot.

2. *Yes/no and multiple choice:* Examples in Table 4.3.

- Aggregation:
  - (a) Counts per choice: Number of responses of each type for each question.
  - (b) Relative counts: Divide number of responses of each type for each question by $N$.
  - (c) Fix a response, take counts only for that response (e.g., in Table 4.3 fix the response as "female" and find the number of females responding "Never" to question #3). There are many possibilities for this approach and such ways to "slice up the data" can be very useful to compare the responses of different subgroups (e.g., in Table 4.3 fix the response as "male" and find the number of males responding "Never" to question #3, then compare to the female case).
- Visualization: Histograms.

3. *Performance gaps:* Examples in Table 4.4, and the continuous response version of it.

  - Aggregation:
    - (a) Current performance, mean and standard deviation, and desired performance, mean and standard deviation. Find the difference in the means.
    - (b) Find gaps per response (desired minus current), find means and standard deviations of the gap sizes for each question.
  - Visualization: Scatter plot, similar to above, box plot, with/without outliers, and quantile plot.

4. *Priorities:* Examples in Table 4.5 (rank order), Table 4.6 (rank strategy), and Table 4.7 (continuous ranking).

  - Aggregation:
    - (a) Mean, for each response.
    - (b) Standard deviation, for each response.
    - (c) Other: Median, mode, range, quantiles.
    - (d) Count number of each response type for each question for the discrete responses.
  - Visualization: Scatter plot, as above, box plot, with/without outliers, and quantile plot. For the count case above, make a multi-histogram, with bars representing the numbers of each response type for each question, with question number plotted on the horizontal.

These ideas only include the most simple ones from statistics. For more advanced methods, see (Devore, 2004).

### 4.4.5    Engineers' Technical Assessment of a Community

In addition to the information gathered from/with a community, it is most often necessary to perform a technical assessment of the community as the focus is on the deployment of technology solutions. Such information helps provide information on the following, for example:

- Establish technical design constraints and trade-offs.

- Assess impacts on reliability and resilience.

- Estimate costs.

- Estimate time-to-completion.

- Uncover operational difficulties.

- Estimate maintenance costs.

- Determine availability of local materials for design and maintenance.

- Determine impact on the environment.

- Assess community capacity (e.g., for who to involve in the various parts of the project, including operation and maintenance).

- Determine social impact (e.g., beneficiaries and effects of participation).

Obtaining information on these issues is difficult at times, and requires engineering discipline- and application-specific approaches. Sometimes it is more important to "know what you do not know than to know what you know," and when to get help. For specific problems, you may find it necessary to consult non-engineering experts such as social workers, healthcare experts, education experts, business people, etc. in a multi-disciplinary approach

#### Assessments for Technology

Assessments for technology are discipline- and application-specific and can be quite involved. Next, a few ideas are provided in Table 4.8 for technical assessments simply to provide an idea of the type of information that is sought. For more information on technical assessments, especially for civil engineering applications, see (Amadei, 2014). A key part of many technology projects is a cost analysis.

#### Interactions, Root-Cause Analysis, and Dynamics

Any community is a very complex dynamical system that is difficult to analyze as an analysis must often must consider people, the built-environment, the natural environment, and the dynamical interactions between these. The issues that a project aims to address with a technological solution are found within this complexity. Here, methods are used to analyze interactions between entities

Table 4.8: Objectives, technology solutions, and examples of the types of technical assessments that are needed.

| Objective | Technologies | Assessment ideas |
|---|---|---|
| Clean water | Water filtration systems, chemical, solar, distribution, etc. | Contaminants types and concentrations, supply, access, needs |
| Sanitation | Infrastructure, chemical treatment, etc. | Total sanitation load, disposal options |
| Food, agriculture | Fertilizers, irrigation, etc. | Soil quality, climate, water supply |
| Energy | Solar, wind, biomass, lighting, heating, cooking, etc. | Solar irradiation, wind levels |
| Health/medical | Telemedicine, diagnostic equipment, etc. | Disease prevalence, communication infrastructure |
| Education | Instructional technologies (e.g., computers and tablets), STEM projects for hands-on learning | Age/learning objectives, needs of potential local employers |
| Shelter, infrastructure | Houses, dams, buildings, roads, bridges, etc. | Climate, water, topography |
| Environment | Pollution management and remediation | Local resource availability, contaminant levels |
| Information systems | Cell phones, computers, internet, services support, market information, financial services, etc. | Internet/cell network access/feasibility, local available information |

in a community (e.g., people to people or people to built/natural environment). Analysis of these interactions can, for instance, highlight how a designed technology is influenced by people, and what social impact it has. Alternatively, it may help identify causes of identified performance gaps, and the pattern of influences on them.

**Influence Diagrams for Interaction Analysis:** Influence diagrams were introduced in Section 1.6.1, and used for interaction analysis of wealth, health, and education as an example. They were also used in Section 2.4.1 to study ideas in social justice. Influence diagrams can easily be used to analyze interactions between entities, concepts, and functionalities in a community. For instance, you may want to define a number of different node types, ones for people, features of the built/natural environment, and the functionings of these. Then, when there is an interaction, a line can be drawn between two nodes (or a directed arc). The pattern of interconnections of the nodes will highlight chains of cascading influence, and feedback loops. In a stakeholder analysis, it may be that nodes simply represent stakeholders, and there is another node type for technologies, and then an arc from a technology to a stakeholder (perhaps with a positive strength label) would represent that the node it points to is a beneficiary to a certain level. A similar approach can be used to represent people that lose/pay for the presence of a technology without getting a benefit via an arc with a negative strength label. "Concept mapping" and "future wheels" are two examples of types of influence diagrams that can be used to understand a community and examples of these are provided in (Watkins et al., 2012). Other examples of influence-type diagrams are on pp. 245-249 of (Amadei, 2014).

**Fault Trees for Root-Cause Analysis:** While influence diagrams can provide for a type of cause-effect analysis and thereby used to discover root causes, a method explicitly designed for root-cause analysis is the fault tree method. Fault tree analysis is an engineering method used to identify root causes for faults in very complex systems (e.g., often used in analysis of nuclear power plants before deployment). The analysis procedure proceeds by drawing a "fault tree" that represents the interactions in a system, and how one failure leads to another (cascading failure). The approach applies to cases beyond failure analysis to ones where events occur and cause other events to occur. By drawing the tree, it forces the designer to go to the tips of the (inverted) tree to identify root causes (events). Also, it helps model, and thereby helps with understanding of, the possibly complex interactions between events.

Figure 4.4 shows an example of a fault tree for a hypothetical scenario. The labeling is made generic so that it applies not just to faults, as in the traditional engineering analysis, but also to causal events between events that are not necessarily failures, and shows how some events lead to others. The fault tree is a type of logic diagram, with discrete logic. At the bottom, there are four "root events" that are the root causes. The "OR" symbol, called an OR gate in logic design, has an output of "on" when either of its inputs are true

(on). The "AND" symbol, called an AND gate in logic design, has an output of "on" when both of its inputs are true (on). Hence, intermediate event 1 occurs when either root event 1 or root event 2 occurs. Intermediate event 2 occurs when both root event 3 and root event 4 occur. The top level event occurs when either intermediate event 1 or intermediate event 2 occurs.
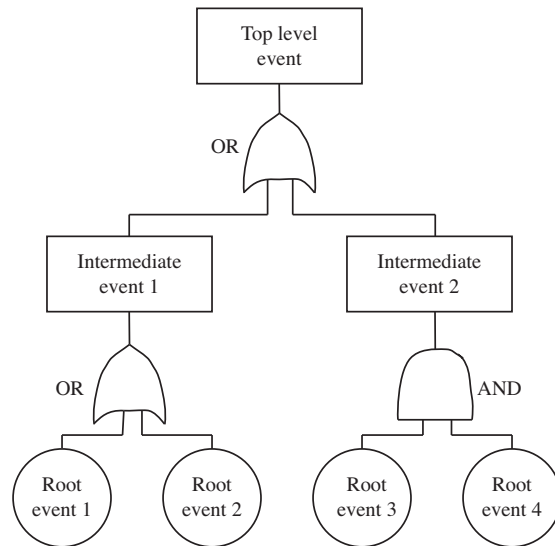


Figure 4.4: Example fault tree for root-cause analysis.

Constructing such a tree for a community can help identify root causes for performance gaps (needs). Such an identification can be very useful for the engineer as it will sharpen the focus of a technological solution on an issue that, if solved, will have broader positive impact on the community.

**Modeling and Simulation of Community Dynamics:** In Section 4.12.2 a community of people, and their economic, education, health, and environmental resource use patterns, are simulated. Simulations like that result in many benefits, including a systematic way to study complex dynamical interactions (e.g., multiple positive/negative feedback loops), effects of noise/uncertainty, and community resilience (robustness). Moreover, it is shown how an array of technologies affect community development (e.g., ones for healthcare or education). A properly developed simulation can be an invaluable tool for community assessment as it will allow you to ask a whole array of hypothetical "what if" questions, and get quantitative answers. These can be useful in understanding a community, and in helping to perform project selection, the subject of Section 4.12.2.

**Vulnerability, Risk, and Resilience**

For some types of issues a community faces it is important to assess vulnerability. For instance, if you are aiming at doing a water project, you may need to know how consistent the water supply is via rainfall, or via a river or groundwater. In an education project, is school funding uncertain? In an agricultural project, what is the probability of drought, or are people consistently able to get food (food security)? Connected to such issues is the problem of risk, that is the probability that something bad will happen. What is the probability of extreme weather? What is the probability that funding for the school will not materialize?

Risk analysis is a common topic in engineering where risks are identified, their impacts are considered, risks are prioritized, and risk management strategies are designed, implemented, and monitored (Amadei, 2014). Sometimes, a "Markov chain model" is used for risk analysis, where other times a fault tree approach, but with assigned event probabilities, is used. If a community has built up enough resources and assets, and other intangibles like skills and attitudes (see p. 297 of (Amadei, 2014)), then typically the community has the capacity to cope with significant problems and thereby gains a type of resilience where it can recover from shocks (e.g., economic or weather), assess itself, and autonomously take actions to develop. Issues such as these can be particularly important in civil engineering applications, but also others such as in agriculture, and a source for further study of these issues is (Amadei, 2014).

## 4.5 Project Selection

Project selection involves combining the following information and deciding what project to start:

- Project goals, specified in terms of outcomes, not technologies (e.g., specify improvement of health, not a specific water filtration technology, as the specific technology is chosen or designed *if* you decide to try to improve health by improving water quality).

- Information gathered from the community on needs, resources, capacity, aspirations, and priorities.

- Engineering technical assessment of the community.

- Level and type of participation by the community and engineering team.

- Project-related constraints (e.g., time, money, resources, and types and levels of team skills).

- Risks of project task failures.

Some of the information is qualitative (e.g., from interviews or focus groups) and other information is quantitive (e.g., mean response on a survey question

with a numeric response). Some individuals may have a tendency to ignore one or the other of these, but that is generally a mistake. Qualitative information can be crucial in, for instance, eliminating a project option (e.g., lack of community enthusiasm for participation). Ignoring quantitative methods for project selection generally removes rigor and science from the project selection process, and also ignores the important issue of whether the decision making in process selection is "robust" (to be defined and studied below). The ideas on project management discussed in Section 4.3.3 are relevant to picking a project that is manageable, and can be successfully completed within time and cost constraints.

## 4.5.1 Project Goals: Promoting Social Justice

There are many possible project goals, but here we focus on goals that can be achieved at least in part by technological solutions. These include ones that address root causes and basic issues like income, health, education, and capacity development. Here, we set such community development goals in the context of the treatment of social justice in Chapter 2.

There are so many possible humanitarian technology solutions that there is a need to be able to focus when discussing project goals. The first way to focus is, of course, based on the needs of the community you are working with. There are, however, other ways to focus, including via use of the principles of social justice. Social justice can be viewed as *the* goal for humanitarian engineering, so focusing directly on that ultimate goal is logical. For instance, there is a clear and common focus in social justice on human dignity and a focus on the "worst cases." Hence, you may gain some guidance from the principle to focus on the most significant needs, for instance, of the community you are working with. If you consider social justice perspectives, however, there are generally few statements on prioritizing what is most important; for instance, which human right or capability is the most important one to focus on? However, lack of direction on priorities, that comes from the complexity and interconnectedness of rights or capabilities, should not deter us from using social justice as a general goal. Indeed, the challenge of specifying priorities is simply solved by asking people and communities. This is integral to the participatory development approach, as is promoting social justice in a community by encouraging participation, developing capacity via education, empowerment, avoiding marginalization of people, and so on.

Focusing on aspects of social justice can provide an approach to focusing project work.

While the social justice perspectives in Chapter 2 provide many ideas for humanitarian engineering and technology, to be concrete, the basic issues of creating technologies for meeting human rights (e.g., as specified via the UN Universal Declaration on Human Rights that is discussed in Section 2.1.1) and extending human capability (Sen's approach in Section 2.3.2) are discussed here. All these are connected with community capacity building, which is closely related to the concept of the common good in social justice (see Section 2.2.2) and basic educational issues in the UN UDHR.

**Technologies for Fulfilling Human Rights**

There are many lists of human rights, from religious or secular (e.g., UN UHDR) perspectives. It makes sense to consider any human right, from what you consider to be an authoritative list, and align your work toward promoting such a right. Some examples, that have corresponding relevant technologies, are:

1. *Life and health:* Per the right to have a full long life, extending life via healthcare technologies or reduction of extreme toil (e.g., via transportation technologies that make water transportation easier) may be considered.

2. *Nutrition and water:* Per the right to basic nutrition, agricultural technologies and clean water filtration technologies make sense.

3. *Discrimination:* Direct impact may not be possible via technology, but indirectly, discrimination can be affected by empowering women and minorities and by reducing toil that is often expected of such groups (e.g., women having to collect water, and providing technologies to make clean water easily accessible, perhaps eliminating the need for carrying water).

4. *Inequality:* Working directly with a diverse group, especially for the development of technological capacity, is generally a good goal.

5. *Education:* Per the right to an education, learning in the participatory development process can be useful, as can humanitarian STEM education (Section 4.8), to help build the technological capacity of a community or country to promote general human development.

6. *Work:* Per the right to work, will a participatory social business, as discussed in Section 4.10.3, help create jobs in a community?

7. *Environmental justice:* Civil and environmental engineering have a whole host of technological approaches for, for instance, pollution remediation and management.

There other rights that can be addressed with technology, at least to some extent, some that might not be immediately obvious to an engineer. For instance, human trafficking/slave trade may be fought with the development of database and tracking methods to understand patterns and sources of the problem to assist in, for instance, trafficked child-rescue solutions (Chongsiriwatana, 2013). There may be ways to fight corruption with software technologies that promote openness, or detect fraud over the internet (Finke, 2013). These last two cases are examples of humanitarian technologies that present significant and important engineering challenges. See Section 4.6.6 for more discussion on these.

**Technologies for Extending Essential Human Capabilities**

Amartya Sen's approach to "capabilities" and quantification of poverty as "capability deprivation" in Section 2.3.2 provides an engineering-friendly view of basic social justice issues. Why? One way to define technology is as "a tool to extend human *capability*." The problem is that there are many human capabilities that could be considered. Here, we reconsider the list of "essential" capabilities, ones the authors in (Nussbaum and Glover, 1995) claim are needed to lead a good life, but reworded/condensed, and with associated relevant technologies for each of their 12 categories:

1. *Extended life:* See the last section.

2. *Health, nourishment, shelter:* Above, plus architectural technologies for affordable and sustainable housing.

3. *Avoid pain, have pleasure:* Healthcare technologies, and see below per technologies supporting leisure.

4. *Education, math and science training:* Humanitarian STEM education, see Section 4.8.

5. *Freedom of expression:* Internet and electronic technologies supporting communications (e.g., the cell/smart phone, computers, and internet access).

6. *Love, care, and attachment:* No clear direct technological approaches, beyond communication facilitation via electronic communications.

7. *Employment and political involvement:* See the last section, and technologies for open government for bi-directional communications between a government and the people. See Section 4.6.6.

8. *Concern and compassion:* No clear direct technological approaches, though the participatory development process can develop these, and solidarity.

9. *Environment:* See Section 4.7.9.

10. *Laugh, play, and recreation:* See Problem 4.29.

11. *Living one's own life:* No clear direct technological approaches, only indirect ones such as empowering individuals to do what they value.

12. *Property and freedom of association:* No clear direct technological approaches, aside from electronic communications (e.g., associating over the internet for political reasons).

Clearly, the technologies to address extending human capability are closely related to ones that help meet human rights.

**Human Rights That Cannot Be Promoted With Technologies**

It should be acknowledged that there are some human rights that have no obvious associated technological solution (e.g., the problem of being an orphan, and the right to have a parent, is certainly not going to be addressed with robotic parents). It seems that technologies cannot directly solve problems of discrimination in all its forms (e.g., gender inequality or racial or religious discrimination) though targeting under-represented groups for humanitarian technologies or education can be a good indirect approach (e.g., in the case of reducing the toil of water-carrying mentioned above). Also of concern are wrongful imprisonment, torture, various forms of persecution and oppression, freedom of face-to-face assembly and association, and others. In some cases, however, for these and other rights, technology may have an indirect impact via assisting with general development issues in a community or country (e.g., open electronic communications for public discourse). Of course, the negative side effects of technology should not be ignored, especially when technology is used in opposition to human rights (e.g., some cases in weapons and war) or even undermining to some extent human rights (e.g., when technology pollutes the environment or is only exploited by the rich for their benefit). Obviously, the humanitarian engineer does not want to develop technologies to promote *injustice*!

## 4.5.2   Multicriteria Decision Making

Multicriteria decision making is a way to combine numeric information quantified by a set of criteria and use it to make decisions. In some contexts and applications multicriteria decision making is called "multiattribute utility theory." The multicriteria decision making process can be viewed as shown in Figure 4.5. On the left, information is input to the decision making process, and on the right assessments of alternatives are provided. From these assessments, typically a ranking of the alternatives, one or more alternatives are chosen. A critical part of this process arises from the uncertainty that enters at the top. A good decision making strategy must take uncertainty into account in making a selection of alternatives. For example, often it would be unacceptable for the chosen alternative to change when only a small variation in the input information changes (e.g., some assessment that is not precise). The alternatives and choice are shown outside the box as in some cases it is the ranking of all alternatives that matters, and the best is chosen; however, in other cases the choice may include a subset of all possible alternatives (e.g., the top three alternatives).

In this section, the basic mathematical theory and computational approaches to multicriteria decision making are given. This will include explanations of criteria, priorities (or importance), aggregation of this information into preferences (assessments of each alternative), and choice. Moreover, there is a special emphasis on "sensitivity analysis" which will show how to analyze robustness of the decision making process, that is, how it can cope with uncertainty.

Later, the multicriteria decision making approach is applied to the following

Multicriteria decision making has many applications in humanitarian engineering.
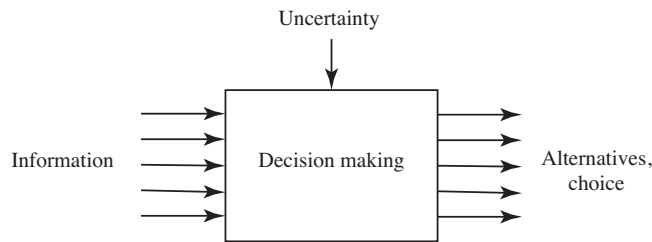
Figure 4.5: Inputs, uncertainty, and outputs of the multicriteria decision making process.

cases:

1. *Project selection:* The information that is gathered from the community, technical assessments, or other relevant information (e.g., estimates of time and cost) are used to form criteria. The criteria can be combined via priorities, the project alternatives can be ranked, and the ranking can be used to choose which project is the best one (or you may pick a few of the top-ranked projects to pursue). Section 4.5.3 applies the methods of this section to this case.

2. *Off-the-shelf humanitarian technology selection:* After a project is selected, sometimes it is possible to narrow down the set of solutions to off-the-self (existing) technologies, and then one of these must be chosen for implementation. "Features" of each of a candidate set of existing technologies are assessed, and using importance ratings for each feature, the quality of each technology alternative is quantified. Then, the top technology is recommended to either a client, community, or NGO. Section 4.6.5 applies the methods of this section to this case.

3. *Technology design concept selection:* In designing a new humanitarian technology there is a step in the creative process where different design concepts are evaluated, and one approach is chosen. Section 4.7.8 discusses the application of the methods of this section to this case.

These are not the only applications of multicriteria decision making in humanitarian engineering. Sometimes, the method can be used in needs/resources assessment to pick the highest priority need, in design to pick the best component, in planning to select the best plan, in scheduling to pick the best time sequence of tasks, etc. The multicriteria decision making approach is very general. The three application areas considered here are of sufficient complexity to illustrate the main points of multicriteria decision making and hence the reader will be able to apply the approach to other problems as they arise.

**Criteria, Assessments, and Uncertainty**

Suppose that the $i^{th}$ alternative of $n$ alternatives under consideration has $m$ criteria that are considered when evaluating the alternative. A "criterion" is a standard for judgment. Sometimes, criteria themselves can be thought of as being the result of the combination of a set of (sub)criteria, and so on (in a tree-like fashion). Here, this possibility is assumed to be dealt with by combining "subcriteria" into a single criterion. Let $f_{ij}$,

$$f_{ij} \in [0, 1]$$

represent for alternative $i$, $i = 1, ..., n$, a criterion $j$, $j = 1, ..., m$, that depends on various assessments. Here, $f_{ij} = 1$ corresponds to the best assessment, and $f_{ij} = 0$ to the poorest assessment. Moreover, increasing $f_{ij}$ from $f_{ij} = 0$ to $f_{ij} = 1$ corresponds to increasing the quality of assessment for any increase in $f_{ij}$ on the continuum $[0, 1]$.

In some situations, it can be difficult to choose the values of $n$ and $m$. First, choosing $n$ involves picking the number of alternatives and involves considering gathered information from the community (qualitative and quantitive) and technical assessments. Normally, there is a "pruning" of the set of project alternatives to come up with $n$. Second, you want to choose the criteria that are the most important ones to making a decision/selection, not the minor/unimportant ones, to come up with the value of $m$. Sometimes, for different alternatives, there may not be the same number of criteria for each case. Usually, the approach to cope with this is to (i) pick $m$ to be the maximum number of criteria for any of the $n$ alternatives, and (ii) then lack of inclusion of some criteria $j$ for some alternative $i$ is simply represented by letting $f_{ij} = 0$.

**Converting Assessments to Criteria:** It is convenient to introduce a variable $a_{ij}$, $i = 1, ..., n$, $j = 1, ..., m$, that represents assessments that are then used to specify criteria $f_{ij}$. Assessments can arise from many sources including interviews, focus groups, surveys, or technical assessments like the ones discussed in Section 4.4.5. Assessments for criteria can involve the following:

1. *Mapping a range of assessment values onto a criterion:* In some cases, the assessment will lie on a range $[a_{min}, a_{max}]$ where $a_{min} < a_{max}$ and $a_{min}$ and $a_{max}$ lie on the real line (positive or negative). In this case, it simply may be physically impossible for assessment values to lie outside this range. Examples of this sort include the following:

   (a) Lickert scale.

   (b) The mean value of some group's responses to some question.

   (c) The percentage of responses that is used in some histogram.

   (d) A score representing to what extent a human right is met, or human capability achieved.

   (e) Cost, time, or some other resource needed.

(f) A rating on a scale of 0-100, 0-10, or 0%-100% that is the result of some technical assessment.

(g) The mean of the differences in responses in a dual-response survey.

For all the but the last case, $0 \leq a_{min} < a_{max}$ for the types of responses given above. In the last case, though perhaps uncommon, it could be that $a_{min} < a_{max} < 0$. How can these cases be transformed to a rating on $[0,1]$? Let $a_{ij} \in [a_{min}, a_{max}]$ be the assessment for criteria $j$ of alternative $i$. Consider

$$\frac{a_{ij} - a_{min}}{a_{max} - a_{min}} = f_{ij} \in [0,1] \tag{4.1}$$

Notice that whether $a_{min}$ and $a_{max}$ are positive or negative, so long as $a_{min} < a_{max}$ (to avoid division by zero) this approach scales to the range to $[0,1]$. In case 5 above, Equation (4.1) simply results in a division by the upper value of the range and hence it scales to the range to $[0,1]$. Of course, this approach may not make sense in some situations. For instance, one challenge can be what the meaning of $a_{min}$ is: if cost is being assessed, for instance, then transformation to the scale $[0,1]$ means that $a_{min}$ corresponds to zero and this may not be appropriate for some situations. To cope with this case, it sometimes makes sense to pick $a_{min}$ *not* to be $\min\{a_{ij}\}$, but some lower value. Such a choice depends on the situation.

2. *Inverse relationship between assessments and criteria:* Suppose that you have a variable where a low (high) value of $a_{ij}$ should correspond to a high (low, respectively) value of $f_{ij}$. This happens with cost and expected time to complete a project. One way to deal with this situation is, for $a_{ij} \in [a_{min}, a_{max}]$ for criteria $j$ of alternative $i$, to let

$$\frac{a_{max} - a_{ij}}{a_{max} - a_{min}} = f_{ij} \in [0,1] \tag{4.2}$$

When $a_{ij} = a_{max}$, $f_{ij} = 0$, and when $a_{ij} = a_{min}$, $f_{ij} = 1$.

3. *Coarse assessment of criteria:* Sometimes, for example if there are many criteria or most criteria cannot be assessed with any accuracy, it is best not to use the full continuous range $[0,1]$, but only a discrete assessment that is converted to $f_{ij} \in \{0,1\}$. In some situations, $f_{ij} = 1$ would simply represent the presence of some characteristic and $f_{ij} = 0$ would represent its absence. In other situations, a discrete set of values uniformly spaced on $[0,1]$ could make sense.

**Uncertainty in Criteria:** There are a number of problematic cases in dealing with assessments and $f_{ij}$ criteria related to uncertainty:

1. *Difficult to assess characteristics:* A characteristic can be difficult to assess quantitatively for a number of reasons: (i) the underlying variables may

change dynamically and you need a static representation of these; (ii) a variable may be random and its mean and standard deviation may not be an adequate quantification (but, if they are, then they could be used as two assessments for a criterion, and likely you would want to consider them two separate assessments for two criteria rather than one, one for mean and another for standard deviation); (iii) the characteristics of the criterion may be largely unknown and you may need to use an educated guess; (iv) for the technology selection case, the manufacturer of the product may claim some specification, but you may have on-the ground evidence that the claim is over-stated; and (v) it simply may be difficult (expensive or time-intensive) or impossible to quantify numerically an assessment and a qualitative (words only) assessment may be most suitable.

2. *Unknown assessments:* It may be impossible to assess some characteristic, or you may know that the assessment for a characteristic is within some range, and not know its specific value.

3. *Not comparable criteria:* It may be that two alternatives have some criteria that are the same and others that are important, but very different. In this case, you cannot specify $f_{ij} \in [0, 1]$ for all $i = 1, ..., n$ and $j = 1, ..., m$. When criteria are missing, it can be difficult to compare alternatives in some cases. One approach to cope with this problem is to re-define your criteria "at a higher level" of functionality so that all the alternatives share common aspects. Another approach is to consider this to be like the "unknown assessments" case above, where where the $f_{ij}$ are left as variables.

There are always uncertainties in specifying values for criteria, some of which can significantly affect decisions.

Here, we will assume that all these cases can be treated by leaving $f_{ij} \in [0, 1]$ as variables, perhaps with minimum $f_{ij}^{min}$ and maximum $f_{ij}^{max}$ values, where for all $i = 1, ..., n$ and $j = 1, ..., m$

$$0 \leq f_{ij}^{min} \leq f_{ij} \leq f_{ij}^{max} \leq 1$$

We consider the range $[f_{ij}^{min}, f_{ij}^{max}]$ to represent uncertainty in $f_{ij}$. When $f_{ij}$ are left as variables on these ranges we will need to consider all their possible values and how these change the ranking of the alternatives. Later, to do this, it is convenient to define, $f_{ij}^0$,

$$f_{ij}^0 = \frac{f_{ij}^{min} + f_{ij}^{max}}{2}$$

which is the midpoint between $f_{ij}^{max}$ and $f_{ij}^{min}$. The half-interval on the right of the midpoint has a width of

$$f_{ij}^{max} - \frac{f_{ij}^{min} + f_{ij}^{max}}{2} = \frac{f_{ij}^{max} - f_{ij}^{min}}{2}$$

The left-interval on the left of the midpoint has the same width. Also, define $\alpha_u$, $\alpha_u \in [0, 1]$, and note that

$$0 \leq f_{ij}^{min} \leq f_{ij}^0 - \frac{\alpha_u}{2}(f_{ij}^{max} - f_{ij}^{min}) \leq f_{ij}^0 \leq f_{ij}^0 + \frac{\alpha_u}{2}(f_{ij}^{max} - f_{ij}^{min}) \leq f_{ij}^{max} \leq 1$$

where if $\alpha_u = 0$ there is no uncertainty in the $f_{ij}$ values so $f_{ij} = f_{ij}^0$, and if $\alpha_u = 1$ there is the maximum modeled uncertainty in the $f_{ij}$ value so $f_{ij} \in [f_{ij}^{min}, f_{ij}^{max}]$. For intermediate $\alpha_u$ values, the $f_{ij}$ are on the interval

$$f_{ij} \in \left[ f_{ij}^0 - \frac{\alpha_u}{2}(f_{ij}^{max} - f_{ij}^{min}), f_{ij}^0 + \frac{\alpha_u}{2}(f_{ij}^{max} - f_{ij}^{min}) \right]$$

The $\alpha_u$ parameter is proportional to the amount of uncertainty in $f_{ij}$, and will be called the "level of uncertainty" for all $f_{ij}$. The higher the value of $\alpha_u$ is, without changing the preference rank order from the one when $f_{ij}^0$ is used, considering all possible values in the above range, the more robust the decision making is, in the sense that the same choices would be made even in the presence of the uncertainty.

> Priorities specify how important each criterion is for decision making.

### Priorities/Importance and Uncertainties

Suppose that the "importance" (priority) of each criterion is defined by the weights $w_j$,

$$w_j \in [0, 1]$$

$j = 1, ..., m$, for criterion $j$ ("0" means not at all important and "1" means very important). Sometimes, people like to provide such importance factors (or ratings) by specifying them on a scale of $[0, 10]$ or $[0, 100]$; however, if this is done, you can simply divide their ratings by 10 or 100, respectivly, to place them on the scale $[0, 1]$. You may get aggregated priority data from a group of people where you use, for instance, a mean priority to set $w_j$, and you may need to scale such data onto $[0, 1]$, for example, by using the idea in Equation (4.1).

Sometimes, priority ratings for each criterion are specified as being relative to each other. To do this, suppose that the "relative importance" of each criterion *relative* to all other criteria is defined via weights $w_j^r$, $w_j^r \geq 0$, $j = 1, ..., m$, for criterion $j$, where

$$\sum_{j=1}^{m} w_j^r = 1 \tag{4.3}$$

so that the weights are a percentage of importance relative to other criteria, but divided by 100. Sometimes, the relative importances are defined in terms of the (absolute) importances, $w_j$, via

$$w_j^r = \frac{w_j}{\sum_{k=1}^{m} w_k} \tag{4.4}$$

for $j = 1, ..., m$. Notice that with this definition, Equation (4.3) holds. This approach can make it easier to specify importance factors as you do not have to worry about adjusting other weights as each individual importance is specified, in order to ensure that Equation (4.3) holds. Also, the information from the surveys on priorities can be easily used in Equation (4.4) to obtain relative weights.

There are times when there is uncertainty in the weight values, for instance, if a person is somewhat ambivalent about some criterion, or if in combining

information from a survey on priorities it makes sense to consider the variability in responses across a group of people (e.g., variance or range). Uncertainty is handled in a manner similar to how it was for the $f_{ij}$ above. Consider the absolute weights, $w_j$ and for relative weights the uncertainty can be transformed by Equation (4.4) but the details of that case are not considered here as they are similar. Consider, for $j = 1, ..., m$,

$$0 \leq w_j^{min} \leq w_j \leq w_j^{max} \leq 1$$

The range $[w_j^{min}, w_j^{max}]$, with given $w_j^{min}$ and $w_j^{max}$, represents uncertainty in $w_j$. When $w_j$ are left as variables on these ranges we will need to consider all their possible values and how these change the rankings of the alternatives. Later, to do this, it is convenient to define, for $j = 1, ..., m$, $w_j^0$,

$$w_j^0 = \frac{w_j^{min} + w_j^{max}}{2}$$

which is the midpoint between $w_j^{max}$ and $w_j^{min}$. The half-interval on the right of the midpoint has a width of

$$w_j^{max} - \frac{w_j^{min} + w_j^{max}}{2} = \frac{w_j^{max} - w_j^{min}}{2}$$

The left-interval on the left of the midpoint has the same width. Also, for $\alpha_u \in [0, 1]$, defined above, note that

$$0 \leq w_j^{min} \leq w_j^0 - \frac{\alpha_u}{2}(w_j^{max} - w_j^{min}) \leq w_j^0 \leq w_j^0 + \frac{\alpha_u}{2}(w_j^{max} - w_j^{min}) \leq w_j^{max} \leq 1$$

where if $\alpha_u = 0$ there is no uncertainty in the $w_j$ values so $w_j = w_j^0$, and if $\alpha_u = 1$ there is the maximum modeled uncertainty in the $w_j$ values so $w_j \in [w_j^{min}, w_j^{max}]$. For intermediate $\alpha_u$ values, the interval for the values is

$$w_j \in \left[ w_j^0 - \frac{\alpha_u}{2}(w_j^{max} - w_j^{min}), w_j^0 + \frac{\alpha_u}{2}(w_j^{max} - w_j^{min}) \right]$$

The $\alpha_u$ parameter is proportional to the amount of uncertainty in $w_{ij}$, and will be called the level of uncertainty for all $w_j$. The higher $\alpha_u$ is without changing the preference rank order from the one when $w_j^0$ is used, considering all possible values in the above range, the more robust the decision making is, in the sense that the same choices would be made even in the presence of of uncertainty.

*In practice, there are often uncertainties in priorities.*

### Quantification of Alternatives: Preferences

The alternatives are quantified by combining the criteria and priorities. The approach to quantification must be designed for the selection problem being considered, typically by quantifying what it means for an alternative to be "good" in terms of the criteria and priorities/importances.

Sometimes what is defined to be a criterion and a preference can be interchangeable, and this will be called the "interchangeability property" of criteria

and preferences. Criteria are used to *judge*, and a preference is an aggregation of a set of criteria used to *judge* alternatives relative to each other. Clearly, these are closely related. For instance, it may be that a single criterion is an aggregate measure of other "subcriteria," and in this case such a criterion can be serving the role of a type of preference, and the (high level) preference combines criteria some of which can themselves be preferences. In the other direction, a preference itself can be naturally defined as a type of criterion, one in which different alternatives result in different values of the criterion that are used to make a selection. This interchangeability property can create some confusion, but most often it is beneficial: (i) it gives flexibility in designing the evaluation of alternatives so that the evaluation fits the context, and (ii) sometimes it can make it easier to quantify uncertainty and how it effects the selection. An example of the use of the interchangeability property will be given in Section 4.5.3.

**Preferences Via a Weighted Sum: Absolute and Relative Weights:**
To quantify alternative $i$, $i = 1, ..., n$, assume $P_i$,

$$P_i = \sum_{j=1}^{m} w_j f_{ij} \qquad (4.5)$$

Sometimes, this quantity is called a "preference" for the alternative, other times its meaning is set by the particular application. The $P_i$ results from *combining* (aggregating) the assessments made for criteria $f_{ij}$, via a weighted sum with the importance factors $w_j$ multiplying each criterion; in this way, unimportant criteria, that may be assessed highly, do not contribute as much to preference, and important criteria, that may be assessed lower, still contribute significantly to preference. Hence, for all $i$, $i = 1, ..., n$, $P_i \in [0, m]$, and less preferable alternatives have small $P_i$ values and more preferable ones, higher $P_i$ values. The most-preferred alternative, the one you may select, is denoted by $i^*$, and

$$i^* \in \arg\max\{P_i : i = 1, ..., n\}$$

(the $\in$ represents that there could be a tie and if there is, it can be broken by a random choice among the maximizers). Examples of using Equation (4.5) for defining preferences are given in the case that generated Figure 4.6 and in Section 4.5.3.

Sometimes, it is natural to split the criteria into multiple subsets and consider their relative impact on the preferences. For instance, if the criteria are split into two subsets, numbered by $\{1, ..., m'\}$ and $\{m'+1, ..., m\}$, then we can choose

$$P_i = \gamma \sum_{j=1}^{m'} w_j f_{ij} + (1 - \gamma) \sum_{j=m'+1}^{m} w_j f_{ij} \qquad (4.6)$$

where $\gamma \in [0, 1]$. If $\gamma$ is near zero, then the $\{m'+1, ..., m\}$ set of criteria are emphasized. If $\gamma$ is near one, then the $\{1, ..., m'\}$ set of criteria are emphasized. The parameter $\gamma$ is used to provide a linear interpolation between the two set

Quantification of preferences is performed by aggregating criteria taking into consideration priorities.

of criteria. Of course, you can simply view the two scale factors on the sums as being absorbed into the weights $w_j$ and if $w_j \in [0,1]$ and $\gamma \in [0,1]$, then $\gamma w_j \in [0,1]$ and $(1-\gamma)w_j \in [0,1]$ if you want to make sure the weights are between zero and one. The effect of varying $\gamma$ on the rank ordering of the $P_i$ can be studied, and is useful in understanding trade-offs between various criteria (e.g., community-derived vs. technical-assessment-derived criteria). Of course, similar ideas can be used for more than two subsets of criteria, and also in cases when the preferences are not just a weighted sum, but some other nonlinear combination as discussed below and in an example in Section 4.5.3.

If in Equation (4.5), $w_j^r \in [0,1]$ is used rather than $w_j$, then only difference is that for $i$, $i = 1, ..., n$, $P_i \in [0,1]$. Also, if $P_i^r$ is the preference when the relative weights are used, then for $i$, $i = 1, ..., n$,

$$P_i^r = \sum_{j=1}^{m} w_j^r f_{ij} = \sum_{j=1}^{m} \frac{w_j f_{ij}}{\sum_{k=1}^{m} w_k} = \frac{P_i}{\sum_{k=1}^{m} w_k} \qquad (4.7)$$

is the weighted mean of the criteria, and the last equality holds because the denominator is a constant, independent of $j$. Here, $\frac{1}{\sum_{k=1}^{m} w_k} > 0$ scales all the $P_i$ to produce the $P_i^r$. This implies that the preference's rank ordering for absolute and relative weights, so long as the relative weights are computed from the absolute ones via Equation (4.4), result in the same rank ordering so that

$$i^* \in \arg\max\{P_i : i = 1, ..., n\} = \arg\max\{P_i^r : i = 1, ..., n\}$$

which implies that using either $P_i$ or $P_i^r$ will give the same recommendations.

**Preferences Via a Community Development Index: The Weighted Geometric Mean:** Recall that above we had assessments $a_{ij}$, $i = 1, ..., n$ and $j = 1, ..., m$. These assessments can be based on income, health, and education as in Section 1.1.2 and also Section 4.12.2. Assume that $a_{ij} \in [a_{min}, a_{max}]$, with $a_{min} = 1$ (if this does not hold, normally a simple rescaling can be done), $i = 1, ..., n$ and $j = 1, ..., m$, so that $\ln(a_{ij}) \geq 0$. Motivated by the HDI in Section 1.1.2, consider a community development index (CDI) for each alternative $i$, $CDI_i$,

*Preference quantification can represent how each alternative affects community development.*

$$CDI_i = \left( \prod_{j=1}^{m} (a_{ij})^{w_j} \right)^{\frac{1}{\sum_{k=1}^{m} w_k}} = \exp\left( \frac{\sum_{j=1}^{m} w_j \ln(a_{ij})}{\sum_{j=1}^{m} w_j} \right) \qquad (4.8)$$

If the weighted arithmetic mean is used for the $a_{ij}$, it can be that there is a large variance in criteria values and that this is considered just as good as where there is a small variance. This may be unacceptable if the $a_{ij}$ represent aspects of a community like income, health, and education. The weighted geometric mean penalizes any inequalities between the criteria (see Section 4.12.2 for more explanation of this point). If $w_j = 1/m$ for all $j = 1, ..., m$ (equal weights, also

called the "unweighted case"), then $\sum_{k=1}^{m} w_k = 1$, and

$$CDI_i = \left(\prod_{j=1}^{m} a_{ij}\right)^{\frac{1}{m}}$$

For the HDI, $m = 3$ and assessments are made of some indicators for income, education, and health (see Section 1.1.2). To add in way to discount the CDI in the presence of inequalities within the $a_{ij}$ dimensions, the Atkinson inequality index can be used as it is in the IHDI in Section 1.1.2, Equation (1.5), with more explanations about this index in Section 4.12.2 and a definition via Equation (4.25).

The $CDI_i$ values could be considered preferences, rank ordered, and used to pick the best alternative. However, it is actually the case that there is a type of equivalence to Equation (4.7) that will be explained next; this equivalence is important as it means that other analysis (e.g., sensitivity analysis given below) developed for Equation (4.7) or Equation (4.5) will also apply to this case. To see the equivalence, let

$$f_{ij} = \frac{\ln(a_{ij})}{\ln(a_{max})} \in [0, 1] \tag{4.9}$$

Note that from the right side of Equation (4.8), the preferences, for $i = 1, ..., n$,

$$P_i^{cdi} = \ln(CDI_i) \ln(a_{max}) = \sum_{j=1}^{m} \frac{w_j f_{ij}}{\sum_{k=1}^{m} w_k} \tag{4.10}$$

Notice that $\ln(CDI_i) \ln(a_{max})$ is a monotonically increasing function of its argument $CDI_i$ so that the rank ordering of the $CDI_i$ and the $P_i^{cdi}$ are the same. Clearly, the right side of this equation is the same as Equation (4.7) showing the equivalence to the above methods. A CDI-based preference relies on a special scaling of the assessments via Equation (4.9) that results in a weighted sum approach. An example of the use of $CDI_i$ in project selection is given in Section 4.5.3.

**Other Methods for Defining Preferences:** Formulas other than those above, such as the weighted sum or weighted geometric mean, can be useful in some cases to aggregate the criteria and priorities to specify preferences:

- *Sum of criteria:* Suppose that you simply sum the criteria values to obtain the preference, without placing any special importance on any one criterion (i.e., use $\sum_{j=1}^{m} f_{ij} \in [0, m]$). In this case, pick $P_i = \sum_{j=1}^{m} w_j f_{ij}$ as in Equation (4.5), but pick $w_j = \frac{1}{m}$, $j = 1, ..., m$ as this places equal weight on each criterion and results in $P_i \in [0, 1]$. The rank ordering produced by $\sum_{j=1}^{m} f_{ij}$ is the *same* as the one produced by Equation (4.5). Of course, this also holds for the coarse assessment case above where criteria are simply counted; that is, if $f_{ij} \in \{0, 1\}$, $P_i = \sum_{j=1}^{m} w_j f_{ij}$, and $w_j = \frac{1}{m}$, $j = 1, ..., m$, then the same rank ordering is obtained as you simply count the number of criteria present to assess the preference.

- *Sum of squares:* You could define

$$P_i = \sum_{j=1}^{m} w_j f_{ij}^2$$

  which is a weighted sum of the squares. Since $f_{ij} \in [0,1]$, $w_j \geq 0$, and $\sum_{j=1}^{m} w_j = 1$, we know $f_{ij}^2 \in [0,1]$. This approach will tend to emphasize higher-valued criteria and discount lower-valued criteria.

- *Mini-max:* You could use

$$P_i = \min\{w_j f_{ij} : j = 1, ..., m\}$$

  which sets the preference equal to the minimum criterion weighted by its importance factor; thinking in terms of

$$P_{i*} = \max\{\min\{w_j f_{ij} : j = 1, ..., m\} : i = 1, ..., n\}$$

  being the preference value of the best alternative, and taking the perspective that you are trying to optimize this value, this approach results in maximizing the minimum criterion.

**Other Methods for Incorporating Uncertainty:** Here, uncertainty in criteria $f_{ij}$ and weights $w_j$ are incorporated via a range of possible values for each of these so that the preference values $P_i$ change with variations in these parameters. Another approach to incorporate uncertainty into the preferences $P_i$, $i = 1, ..., n$ is to use

$$P_i = \left[ \sum_{j=1}^{m} w_j f_{ij} \right] + \epsilon_i \tag{4.11}$$

(or one of the other definitions for $P_i$ above besides the weighted sum) where $\epsilon_i$, $i = 1, ..., n$, represents an additive uncertainty (e.g., normally distributed noise with a mean and standard deviation). This $\epsilon_i$ uncertainty could represent that you cannot use all the possible criteria relevant to a choice (i.e., $m$ is finite) or that there is measurement noise for the $f_{ij}$ and $w_j$. One interesting case is if you know that for $i = 1, ..., n$,

$$\epsilon_i \in [\epsilon_i^{min}, \epsilon_i^{max}] \tag{4.12}$$

analogous to how we did for the ranges of uncertainty for $f_{ij}$ and $w_j$. In terms of comparing alternatives via preferences, this will put a "band" of uncertainty around each preference value, and if any two adjacent preference value bands overlap, then you cannot distinguish the two ("robustly" as is discussed in more detail below). Here, we will set $\epsilon_i = 0$, $i = 1, ..., n$, but the idea is studied further in Problem 4.44.

It should be noted that it is also possible to use a variety of statistical methods to perform project selection. Sometimes, this is a natural approach

if, for instance, if survey data is used from many people. One such approach would use the weighted sum for the $P_i$, $i = 1, ..., n$, then use statistical analysis to compare the means of $P_i$, that includes considerations of the variances. In this way, you can become confident of one alternative over another. For such methods, see (Devore, 2004). Here, we took a different, non-statistical approach, due to its flexibility, lack of assumptions about distribution normality, and as the above approach is closer to standard engineering practice. This is not to say, however, that a statistical analysis is generally not useful or better for a specific case.

*Preferences are ranked in order, worst to best, and the best one is typically chosen.*

### Assess and Rank Approach

Once the $P_i$ values are calculated, you can rank order them lowest to highest. Then, you may consider selecting the highest ranked alternative, $i^*$, or the two options with the highest preferences. If you want to compare two alternatives in the set of candidates, say some alternative $i$ and the one with the highest preference, $i^*$, you can simply consider the value of

$$P_{i^*} - P_i \geq 0$$

and values of this difference represent the level of inferiority of alternative $i$ relative to $i^*$, with a larger value of the difference corresponding to a more inferior option. Hence, with this method you can *compare* alternatives. Indeed, in the case where we denote a "base-line alternative" by $i^b$ (see the definition of base-line below), if

$$P_{i^b} - P_i > 0$$

then alternative $i$ is worse than the base-line alternative and if

$$P_{i^b} - P_i < 0$$

then alternative $i$ is better than the base-line alternative. If $P_{i^b} = P_i$ then it is the same as the base-line alternative.

### Compare to Base-Line and Rank Approach

Here, it is assumed that there is a "base-line" alternative. In project selection, a base-line may be a project idea that was discovered during pre-assessment of the community, or one that has worked well in a similar community. In technology selection it may be the technology that is currently used, or one that is preferred based on previous experience. In technology design concept selection, it may be an existing technology or the most-favored concept.

Let $f_{ij}^b$, $f_{ij}^b \in [-1, +1]$, $i = 1, ..., n$, $j = 1, ..., m$, represent for alternative $i$ the value of criterion $j$ *relative* to the corresponding criterion in the base-line alternative that is denoted by $i^b$. In particular,

$$f_{ij}^b = f_{ij} - f_{i^b j}$$

$i = 1, ..., n$, $j = 1, ..., m$, that is, the $f_{ij}$ above are compared to the $f_{i^b j}$ $j = 1, ..., m$. With $f_{ij} \in [0, 1]$, $f_{ij}^b \in [-1, +1]$. If $f_{ij}^b = -1$ ($f_{ij}^b = +1$) then criterion $j$ of alternative $i$ is worse (better, respectively) than the corresponding criterion of the base-line. If $f_{ij}^b = 0$, then the two criteria are judged to be the same. For the base-line alternative, $f_{i^b j}^b = 0$ for all $j = 1, ..., m$, as when comparing the same alternative there are, of course, no criterion differences. All of the same types of issues encountered in specifying the $f_{ij}$ above also arise here (e.g., range of assessment value, unknown assessments, and coarse assessments).

Suppose $w_j \in [0, 1]$, $j = 1, ..., m$, are used to combine the $f_{ij}^b$ values to provide a preference for the alternative that is denoted by $P_i^b$,

$$P_i^b = \sum_{j=1}^{m} w_j f_{ij}^b \tag{4.13}$$

Clearly, if the $w_j^r$ are computed from the $w_j \in [0, 1]$ via Equation (4.4), then $w_j^r \in [0, 1]$ so this can be viewed as a special case of just using the $w_j$ in Equation (4.13), except the difference that $\sum_{j=1}^{m} w_j^r = 1$ which can impact the analysis.

We have, when $w_j$ are used as the weights,

$$P_i^b \in [-m, +m]$$

(and $P_i^b \in [-1, +1]$ if the $w_j^r$ are used as the weights). Also, $P_{i^b}^b = 0$ due to comparing the base-line with itself. Negative $P_i^b$ values indicate inferiority relative to the base-line $i$, and positive values indicate superiority relative to the base-line. The alternative farthest above the base-line, if there is one above the base-line, is the one that should be considered for recommendation (if none is above the base-line, then the base-line is the best). Note that if you rank the $P_i^b$ values, from smallest to largest (including the possibly negative values), then the best alternative using the compare-to-baseline approach is $i^*(b)$ is

$$i^*(b) \in \arg\max\{P_i^b : i = 1, ..., n\}$$

The $P_i^b$ have values that are generally different from the $P_i$ values of the last section and hence need to be interpreted differently; however, the basic idea is still the same when you consider the $P_i$ and $P_i^b$ values only. Hence, the major difference between the methods of this and the last section lie in the fact that here $f_{ij}^b \in [-1, +1]$ and these values are set relative to the base-line. Sometimes, this is a more natural way to think about the alternative selection process.

Finally, note that the cases in the last section that can be considered as options to the standard weighted sum also apply here. Consider two cases:

- Suppose you consider $\sum_{j=1}^{m} f_{ij}^b \in [-m, +m]$ which, for alternative $i$, is a sum of the criteria relative to the base-line which is sometimes used. Pick $P_i^b = \sum_{j=1}^{m} w_j f_{ij}^b$ and $w_j = \frac{1}{m}$, $j = 1, ..., m$ as this places equal weight on each criterion and results in $P_i^b \in [-1, +1]$. In this case, the $P_i^b$ are

not the actual values of the sum of the criteria relative to the base-line; however, the ranking that is produced by these $P_i^b$ is the same as the ranking produced by $\sum_{j=1}^{m} f_{ij}^b \in [-m, +m]$.

- In the "coarse assessment of criteria" case, here we have $f_{ij}^b \in \{-1, 0, +1\}$ to represent a criterion that is worse, the same, or better than the baseline. The same approach can be used by picking $w_j = \frac{1}{m}$, $j = 1, ..., m$, to get $P_i^b \in [-1, +1]$. In this case the $P_i^b$ have the same rank order as one that results from counting, for each $i$, the number of criteria that are better and subtracting off the number of criteria that are worse. Such an approach is similar to the "scoring methods" discussed on pp. 149-157 of (Ulrich and Eppinger, 2012) for the standard product design process in engineering.

**Equivalence of Rankings and Recommendations**

Assume that the same $w_j$, $j = 1, ..., m$, are used for both the above approaches, assess and rank and compare to baseline and rank. We have $f_{ij} \in [0, 1]$ and $f_{ij}^b \in [-1, +1]$, $i = 1, ..., n$, $j = 1, ..., m$. These are used to compute $P_i$ in Equation (4.5) and $P_i^b$ in Equation (4.5), for $i = 1, ..., n$. We had

$$f_{ij}^b = f_{ij} - f_{i^b j}$$

and

$$P_i^b = \sum_{j=1}^{m} w_j f_{ij}^b$$

Combining these two equations, for $i = 1, ..., n$,

$$P_i^b = \sum_{j=1}^{m} w_j (f_{ij} - f_{i^b j}) = \underbrace{\left[\sum_{j=1}^{m} w_j f_{ij}\right]}_{P_i} - \underbrace{\left[\sum_{j=1}^{m} w_j f_{i^b j}\right]}_{\text{Constant, independent of } i}$$

Hence, $P_i^b - P_i$ is the same constant for all $i = 1, ..., n$ and the constant is in $[0, 1]$. This implies that if you rank order the $P_i^b$ (or $P_i$), the $P_i$ ($P_i^b$, respectively) are all simply values shifted from these values by the same amount. That is, the rank ordering of the alternatives is the *same* for both of the methods. Also, this holds for the case where the $w_j^r$ weights, generated from the $w_j$ weights via Equation (4.4), are used in these equations rather than the $w_j$.

This implies that

$$i^*(b) \in \arg\max\{P_i^b : i = 1, ..., n\} = \arg\max\{P_i : i = 1, ..., n\} \ni i^*$$

so that the recommendations you would make from either method are the *same* in terms of picking the best alternative (the only case where the alternatives chosen are different is when there are ties that are resolved randomly). It also

implies that, under the above assumptions (linearity being the key one), that there is no reason to use both approaches as they give the same results. Still, however, you may want to pick one approach rather than the other, for example, if it is easier to think about comparing to a base-line alternative in specifying criteria, and for discussions with clients or a community who may be quite familiar with the base-line case.

### Mathematical Sensitivity Analysis: Effects of Information Changes on Preferences

Mathematical sensitivity analysis is valuable to provide insights and understanding, for example, to provide a way to analyze "robust decision making" and to support the computational approaches discussed below. The sensitivity analysis here shows how changes in criteria or weights affect changes in preferences, and therefore the rank ordering of preferences, and the resulting recommendations. In this section, only the "assess and rank" method will be discussed; however, all the ideas here also hold for the "compare to base-line and rank" method and can be developed using the same approach as here.

To illustrate some of the ideas, it is useful to briefly discuss how to do simple sensitivity analysis via the computer; however, below, a much more detailed computational analysis will be performed. It is useful to write a computer program, or use a spreadsheet, to compute the $P_i$ values per the above formulas. Such a program can be quite useful for doing the computations, and studying the effects of changing the $f_{ij}$ and $w_j$ values on $P_i$ in Equation (4.5). It can be useful to consider variations in these parameters for a number of reasons, including those given above. For instance, if you do not know the actual specific value $f_{ij}$, for a given $i$ and $j$, but only the range it lies in (even including the case when you know nothing about the criterion so it lies in the range $[0,1]$), then you can study how a range of values of $f_{ij}$ will translate into a range of values of $P_i$: for a fixed $i$, and changing $f_{ij}$ for one $j$, the minimum value of $f_{ij}$ in some range will produce the minimum value of $P_i$ and the maximum value of $f_{ij}$ will produce the maximum value of $P_i$, but the variation between the maximum and minimum can change the rank ordering of the alternatives by changing just $P_i$ for alternative $i$. While changing a single $f_{ij}$, for a given $i$ and $j$, only changes the value of $P_i$ and not any $P_{i'}$, $i' \neq i$, changing the $w_j$, for any $j = 1, ..., m$, can in general reorder the ranking entirely. Of course, the key case you are interested in is when the changes in $f_{ij}$ or $w_j$ values result in a different ordering of the $P_i$, and in particular, an ordering that results in some different $P_i$ becoming the highest value of all as this changes the selection. Note that as all variables are positive, for a fixed $i$, an increase (decrease) in one $f_{ij}$ or $w_j \in [0,1]$ will result in increase (decrease, respectively) in the affected alternative preferences.

**Criteria and Absolute Priorities/Importances:** Mathematical sensitivity analysis can consider the effect of a variation of the $j^{th}$ criterion, $f_{ij}$, on the variation of the preference of the $i^{th}$ alternative, $P_i$. Consider the change

*Sensitivity analysis considers the effect of perturbing criteria and priority values on the rank ordering of preferences.*

of a parameter (weight or criterion) of only one criterion and let its index be denoted by $j^p$; all other parameters besides this one are held constant. Only this single-parameter variation case will be considered in the mathematical analysis; however, in the computational analysis the impact of multiparameter variations on rank ordering of preferences will be considered.

First, consider the effect of a change in a single criterion on the change in the preference of an alternative. Using Equation (4.5), for each $i = 1, ..., n$,

$$\frac{\partial P_i}{\partial f_{ij^p}} = \frac{\partial}{\partial f_{ij^p}} \left( w_{j^p} f_{ij^p} \right) = w_{j^p}$$

and this holds for any $f_{ij^p}$ value (the slope is constant). Of course, this is for an infinitesimal perturbation of the $j^p$ criterion for preference $i$ per the definition of the derivative. It shows that the more important a criterion is, as defined by $w_{j^p}$, the more you can improve a quality assessment of a criterion by a very small variation of the criterion $f_{ij^p}$. For example, the biggest preference improvement for alternative $i$ will result from improving $f_{ij^*}$ for the most important criterion, $j^* \in \max\{w_j : j = 1, ..., m\}$.

In a similar way, you can fix the $f_{ij}$ and consider variations in the $w_{j^p}$ via

$$\frac{\partial P_i}{\partial w_{j^p}} = \frac{\partial}{\partial w_{j^p}} \left( w_{j^p} f_{ij^p} \right) = f_{ij^p}$$

This means that for the $i^{th}$ alternative, if you perturb the importance of a criterion $w_{j^p}$ up, the rate of increase of $P_i$ is $f_{ij^p}$, that is, if this value is big, then making it more important will have a relatively large effect on the preference. Sometimes, a small but acceptable change in an importance value can result in a change in the ordering of the preferences, and hence the selected alternative.

Infinitesimal perturbations are not made in practice, but finite changes in the $f_{ij}$ and $w_j$ are considered. The above analysis needs to consider this reality. Let, for a fixed $j^p$ and all $i = 1, ..., n$,

$$\Delta P_i = P_i^{new} - P_i^{old}$$

and assume

$$\Delta f_{ij^p} = f_{ij^p}^{new} - f_{ij^p}^{old} \neq 0$$

and

$$\Delta w_{j^p} = w_{j^p}^{new} - w_{j^p}^{old} \neq 0$$

Since $f_{ij}^{new} = f_{ij}^{old}$ for all $i = 1, ..., n$ and all $j \neq j^p$ (that is only one value is changed at a time), in this special case, for the form of Equation (4.5), a linear combination,

$$\frac{\Delta P_i}{\Delta f_{ij}} = \frac{w_{j^p} (f_{ij^p}^{new} - f_{ij^p}^{old})}{(f_{ij^p}^{new} - f_{ij^p}^{old})} = w_{j^p}$$

and similarly,

$$\frac{\Delta P_i}{\Delta w_{j^p}} = f_{ij^p}$$

that correspond exactly to the two above formulas for the case of infinitesimal perturbations.

Notice that for $j^p$,

$$P_i^{new} = P_i^{old} + \left[ f_{ij^p}^{new} - f_{ij^p}^{old} \right] w_{j^p}$$

(a similar formula holds for the weights). Hence, the new preference is a linear function of the new criterion. This shows that increases in the criterion value $f_{ij^p}$ lead to a linear increase in the preference. A similar formula holds for $\frac{\Delta P_i}{\Delta w_{j^p}}$. Consider the possibility of increasing some criterion value for the second best alternative, in order for it to become the most preferred alternative. To do this, let $i^*$ be the most preferred alternative and $\bar{i}^*$ be the second most preferred alternative. The question is whether there exists a $j^p$, $j^p \in \{1, ..., m\}$, such that it is possible to increase $f_{\bar{i}^* j^p}$ to get

$$P_{i^*} = P_{\bar{i}^*}^{new} = P_{\bar{i}^*}^{old} + \left[ f_{\bar{i}^* j^p}^{new} - f_{\bar{i}^* j^p}^{old} \right] w_{j^p}$$

Solving,

$$f_{\bar{i}^* j^p}^{new} = \frac{P_{i^*} - P_{\bar{i}^*}^{old} + f_{\bar{i}^* j^p}^{old} w_{j^p}}{w_{j^p}}$$

But, considering the constraint of $f_{ij} \in [0,1]$, there may not exist a solution to this equation for any $j^p$. A similar approach works for the weights. More analysis along these lines is in (Triantaphyllou, 2000).

**Criteria and Relative Priorities/Importances:** Next, consider the case where the $w_j^r$ are set from the $w_j \in [0,1]$ via Equation (4.4) and consider sensitivity analysis like above by considering how the $w_j$ affect the preference rankings when the relative importances are used. Recall that the preference of alternative $i$ when the relative weights are used is

$$P_i^r = \sum_{j=1}^m w_j^r f_{ij} = \sum_{j=1}^m \frac{w_j f_{ij}}{\sum_{k=1}^m w_k}$$

Note that if parameter $j^p$ is perturbed

$$\frac{\partial P_i^r}{\partial f_{ij^p}} = \frac{\partial}{\partial f_{ij^p}} \left( \frac{w_{j^p} f_{ij^p}}{\sum_{k=1}^m w_k} \right) = \frac{w_{j^p}}{\sum_{k=1}^m w_k} = w_{j^p}^r$$

so that compared to the $P_i$ case, the slope $w_{j^p}$ is different by a factor of $\frac{1}{\sum_{k=1}^m w_k}$. The relative ranking adjusts the rate of change of $P_i^r$ so that changes to $f_{ij^p}$ will change $P_i^r$ the most for the highest relative rank criterion. Similarly,

$$\begin{aligned} \frac{\partial P_i^r}{\partial w_{j^p}} &= \frac{\partial}{\partial f_{ij^p}} \left( \frac{w_{j^p} f_{ij^p}}{w_{j^p} + \sum_{k=1, k \neq j^p}^m w_k} \right) \\ &= f_{ij^p} \left( \frac{1}{w_{j^p} + \sum_{k=1, k \neq j^p}^m w_k} - \frac{w_{j^p}}{\left( w_{j^p} + \sum_{k=1, k \neq j^p}^m w_k \right)^2} \right) \end{aligned} \quad (4.14)$$

Simple algebra can be used to show that

$$\frac{\partial P_i^r}{\partial w_{j^p}} \geq 0$$

for all $w_{j^p} \in [0, 1]$. This means that increases (decreases) in $w_j$ result in increases (decreases, respectively) in $P_i^r$. According to Equation (4.15), the sizes of changes are scaled by $f_{ij^p}$, so that if this criterion is higher, then a greater change to $P_i^r$ occurs. Also, testing the second partial derivative of Equation (4.15), $\frac{\partial P_i^r}{\partial w_{j^p}}$ is monotonically decreasing in $w_{j^p}$ for $w_{j^p} \in [0, 1]$. Hence, it is maximized for $w_{j^p} = 0$. This means that if the value of $w_{j^p}$ is higher, then a fixed change to it will have less of an impact on changing $P_i^r$ than the same size change would have for lower values of $w_{j^p}$. The greatest change will occur when $w_{j^p}$ is changed from a value of zero.

### Computational Sensitivity Analysis Using a Spreadsheet

Sensitivity analysis is *essential* for the quantitative comparison of alternatives and is typically facilitated via a spreadsheet or computer program. Here, suppose that a spreadsheet is used to compute Equation (4.5) for either absolute or relative weights. You could make the rows correspond to the alternatives being considered, $i = 1, ..., n$, and the columns then correspond to the criteria $j = 1, ..., m$. Of course, the opposite is fine as it simply transposes the matrix defined by $f_{ij}$. The $w_j$ values could be listed along the top of the matrix as another row, with each element corresponding to the importance of each criterion, and if the $w_j^r$ are computed from the $w_j$ via Equation (4.4), those could be placed in another row beneath the $w_j$ values. Then, a formula can be entered to automatically compute Equation (4.5) using the weight values you wish to use. The values of the computed $P_i$, $i = 1, ..., n$, can be automatically ranked, placed in a column on the right, and the best/highest value highlighted as it corresponds to the highest preference. Indeed, it may be useful to color code the ranking and then fill in the cells in the right-hand column that correspond to the best (green), second best (yellow), and the rest (red) of the $P_i$ values. This coloring should be automated so that it is automatically set based on the $P_i$ values; this will allow you to perturb values of $f_{ij}$ and $w_j$ and immediately see the effects on the ranking, without having to scan the column of $P_i$ values and find the maximum and second-best by inspection. For a spreadsheet, if extensive perturbations are to be done, it may be useful to have a nominal set of values of $f_{ij}$ and $w_j$, and then stored/entered perturbation values that are entered in another part of the spreadsheet. This way, you will not have to remember what the values of the parameters were before the perturbations were made.

Starting with your spreadsheet tool that automatically ranks the alternatives per the computed $P_i$ values, the following provides a few ideas on how to approach a sensitivity analysis using the spreadsheet, using two steps:

1. *Perturb criteria, $f_{ij}$ for some $i$ and $j$:* For a fixed $i$, changing $f_{ij}$ for some

A spreadsheet can be used for an initial and simple, but limited, approach to sensitivity analysis.

criterion $j$ only changes $P_i$ and no other alternative $i' \neq i$. Hence, pick the top-ranked preference $i^*$ and perturb some criterion $j$ and see if it falls to be the second-ranked alternative. This is very easy to do for all $j = 1, ..., m$ via perturbing in order the criteria on the spreadsheet and seeing if the ranking changes. This same approach could be used for the second-ranked alternative (or any other one), perturbing to see if it jumps up to be the first-ranked, or higher-ranked, alternative.

2. *Perturb weights, $w_j$:* Changing $w_j$ for any single $j = 1, ..., m$ can completely reorder the ranking of the alternatives so that any alternative can rise to the top under a $w_j$ perturbation, for use of either absolute or relative importance weights. It is often relatively easy to study the matrix of $f_{ij}$ values, and use the ideas in the last subsection to see how to change a $w_j$ that will change the ranking in important ways, such as changing which is the top-ranked alternative. The spreadsheet simplifies this trial-and-error approach. In this case, it is often possible to find a $w_j$ perturbation that will change the recommended alternative.

Notice that in the above approach, only one parameter is perturbed at a time, which is consistent with how a spreadsheet works in that for each perturbation, it will automatically recompute the numbers and ranking. It is also consistent with the above sensitivity analysis as that only pertains to variations of a single parameter. Of course, there are often cases where you want to change multiple parameters at a time, and moreover, for uncertainty analysis you need to consider an *infinite* number of variations. The problem with the spreadsheet approach is that there are an infinite number of possible perturbations of each parameter and at times it can be difficult to know if you have, in an ad hoc approach, covered the important cases, ones where even small perturbations may lead to the top alternative becoming second-best.

In the next section, a program is developed and studied that goes far beyond what typical spreadsheet achieves in sensitivity analysis in that it shows how to cope with an infinite number of parameter perturbations in a systematic way to cope with uncertainty in the decision making.

**Computational Robust Decision Making**

In Figure 4.5, decision making is shown as having information inputs, and uncertainty, and as a result (for the kind of decision making considered here), a decision about which alternative to select (choose). Uncertainty can come in may forms; here, the uncertainty is in the information we have to make a selection, and in particular uncertainty in the values of $f_{ij}$ and $w_j$. Selection of the best alternative is "robust" if it is still the best for all levels of uncertainty. It has "robustness level $\alpha_u$" (or robustness with uncertainty level $\alpha_u$) if the choice does not change for all values of the uncertainty level in $[0, \alpha_u]$. A robust selection of an alternative is generally *much* better than one that considers no uncertainty. Indeed, the robustness analysis here is most often *essential* as it can make you confident in a choice, or confident that you cannot really distinguish

Selection of the best alternative is robust if it is the best for all levels of uncertainty.

between two alternatives. This second conclusion can be quite valuable in some applications.

Next, some mathematical background is provided that (i) quantifies how uncertainty impacts preference values, and (ii) makes the computational analysis feasible in practice. An example is used to show how to use a computational approach to making robust decisions. Following that, it is explained how to formulate project selection problems as robust multicriteria decision making problems.

**Mathematical Derivation for Computational Analysis:** In a computational approach, we need to consider all possible values in the uncertainty ranges of the $f_{ij}$ and $w_j$, and their effects on all the $P_i$ to determine effects on their rank ordering. Defined above, these ranges are, for all $i = 1, ..., n$ and $j = 1, ..., m$,

$$f_{ij} \in [f_{ij}^0 - \frac{\alpha_u}{2}(f_{ij}^{max} - f_{ij}^{min}), f_{ij}^0 + \frac{\alpha_u}{2}(f_{ij}^{max} - f_{ij}^{min})]$$

and

$$w_j \in [w_j^0 - \frac{\alpha_u}{2}(w_j^{max} - w_j^{min}), w_j^0 + \frac{\alpha_u}{2}(w_j^{max} - w_j^{min})]$$

and there are an *infinite* number of values on these ranges when $\alpha_u$ takes on any specific value, $\alpha_u \in (0, 1]$. At first glance, to compute the $P_i$ for all $nm + m$ ranges, it may seem logical to quantize (grid) these ranges, and the $\alpha_u$ range, and compute the $P_i$ at all the grid points. However, for even relatively coarse grids, and reasonable values of $n$ and $m$, this can be computationally prohibitive as the "curse of dimensionality" arises. For instance, if there are $n_g$ grid points on each of the $nm + m$ dimensions (i.e., for each parameter $f_{ij}$ and $w_j$), and also on the $\alpha_u$ range, then there are

$$(n_g)^{(nm+m+1)} \tag{4.15}$$

points where the preferences have to be computed. The exponent in this formula creates the problem of the curse of dimensionality. Even reasonably small numbers, for instance $n_g = n = m = 10$ result in a very large number, $10^{111}$ calculations of preferences that are needed (e.g., the number of atoms in the universe is estimated to be around $10^{80}$, assuming all atoms are hydrogen atoms). Modern computers cannot cope with that kind of complexity. Even if $n_g = n = m = 5$, there are $5^{31} = 4.6 \times 10^{21}$ preference calculations that are needed. Fortunately, some mathematical observations can drastically reduce the number of needed computations, as is discussed next.

Assume, for a moment, that we only consider $f_{ij}$ variations and that we let $w_j = w_j^0$, their nominal values. Using Equation (4.5) with $w_j = w_j^0 \in [0, 1]$, since all the $f_{ij}$ and $w_j$ are positive, the maximum values of the $P_i$ on the above ranges is

$$\sum_{j=1}^{m} w_j^0 \left[ f_{ij}^0 + \frac{\alpha_u}{2}(f_{ij}^{max} - f_{ij}^{min}) \right]$$

Similarly, the minimum values of the $P_i$ on the ranges is

$$\sum_{j=1}^{m} w_j^0 \left[ f_{ij}^0 - \frac{\alpha_u}{2}(f_{ij}^{max} - f_{ij}^{min}) \right]$$

Similar formulas can be given for the case where the $f_{ij} = f_{ij}^0$, their nominal values, and the weights are at their maximum and minimum values on the above ranges.

Moreover, the same idea can be used to specify the preferences under the general case where both the $f_{ij}$ and $w_j$ are varied on the above ranges. In particular, for all $i = 1, ..., n$, the minimum values of the preferences as a function of $\alpha_u$ are

$$P_i^{max}(\alpha_u) = \sum_{j=1}^{m} \left[ w_j^0 + \frac{\alpha_u}{2}(w_j^{max} - w_j^{min}) \right] \left[ f_{ij}^0 + \frac{\alpha_u}{2}(f_{ij}^{max} - f_{ij}^{min}) \right] \quad (4.16)$$

Similarly, the minimum values of the $P_i$, for all $i = 1, ..., n$, as a function of $\alpha_u$ are

$$P_i^{min}(\alpha_u) = \sum_{j=1}^{m} \left[ w_j^0 - \frac{\alpha_u}{2}(w_j^{max} - w_j^{min}) \right] \left[ f_{ij}^0 - \frac{\alpha_u}{2}(f_{ij}^{max} - f_{ij}^{min}) \right] \quad (4.17)$$

Hence, on each dimension the maximum or minimum is all that needs to be considered for each $i$, $i = 1, ..., n$ (e.g., in the hypercube defined on the $nm + m$ dimensions only *two* corners of the hypercube need to be considered, the one that corresponds to using all maximum values, and the other corresponding to using all minimum values). Using all maximum values of the parameters gives $P_i^{max}(\alpha_u)$, and all minimum values, $P_i^{min}(\alpha_u)$. The basic idea behind Equation (4.16) and Equation (4.17) applies to more general cases than just the weighted sum approach to specifying preferences; all that is needed is that in the preferences a type of monotonically increasing property in parameters like $f_{ij}$ and $w_j$. The nominal preferences

$$P_i^{nom} = \sum_{j=1}^{m} w_j^0 f_{ij}^0$$

for all $i = 1, ..., n$, lie at the midpoint between $P_i^{max}(\alpha_u)$ and $P_i^{min}(\alpha_u)$ for all $\alpha_u \in [0, 1]$. Note that in both Equation (4.16) and Equation (4.17), we can grid the $\alpha_u$ on $[0, 1]$ with $n_g$ values, and for each $\alpha_u$ on that range there are going to be two preference values to compute ($P_i^{max}(\alpha_u)$ and $P_i^{min}(\alpha_u)$) for each $i$, $i = 1, ..., n$ (the nominal values will also be computed in the example below, but they are not really needed in the analysis). Of course, for each of these we need to compute $m$ operations per the sum.

Hence, using the mathematical analysis above, we can consider an infinite number of values on the above ranges with the number of computations proportional to

$$2n_g nm$$

The increase in computational complexity, per the number of computations of preferences, with an increase in the number of parameters (dimensions) considered is *proportional* to the product $n_g n m$, unlike the exponential increase in Equation (4.15), and hence for most practical situations is easy to compute using modern computers. For instance, if $n_g = n = m = 10$, 2000 computations of preference values are needed (compare to the $10^{111}$ needed preference computations for this case above), something that is easy to compute on a modern computer. If $n_g = n = m = 5$, 250 computations of preference values are needed (compare to the $4.6 \times 10^{21}$ needed preference computations for this case above). Next, a computer program to perform these calculations is introduced.

> Computational analysis of robust multicriteria decision making is tractable for relatively large problems.

**Example: Computational Analysis for Robust Decision Making:** The program `RobustMCDM.m` computes Equation (4.16) and Equation (4.17), along with the $P_i^{nom}$, for all $i = 1, ..., n$ and plots the results. It also provides the ordering of the indices in descending order of preference values for the nominal case, in this case, 2, 1, then 3. In Figure 4.6, the case for varying $f_{ij}$ and fixed $w_j = w_j^0$ is shown. For the alternative with the highest nominal preference (#2), the horizontal dots at the top run horizontally through the diamonds that are computed values of $P_2^{nom}$ for $\alpha_u$ values (clearly, $P_2^{nom}$ is not dependent on $\alpha_u$). The top blue line, that slopes up, is $P_2^{max}(\alpha_u)$, and the red one that slopes down is $P_2^{min}(\alpha_u)$. For the $\alpha_u > 0$ values, the black vertical lines that connect the bottom red line to the top blue line, and run through the diamonds, represent the range of $P_2^{max}(\alpha_u)$ values for the given uncertainty ranges for the parameters for each $\alpha_u$. It is similar for the #1 and #3 cases.

Next, consider $\alpha_u \in [0, 1]$ in Figure 4.6. For $\alpha_u = 0$ (nominal case, no uncertainty), the dots on the left vertical axis show $P_2^{nom}$, $P_1^{nom}$, and then $P_3^{nom}$, top to bottom, showing the preference values for the rank order. However, at the point where the uncertainty $\alpha_u \approx 0.22$, the red line $P_2^{min}(\alpha_u) = P_1^{max}(\alpha_u)$. At this point, it is possible that due to uncertainty, the low values of the criteria for #2, and high values of the criteria for #1, result in a swapping of the preferences so that #1 becomes the most preferred alternative, and #2 becomes the second best. In this case, we say that alternative #2 is better than #1 up to an uncertainty of $\alpha_u \approx 0.22$, or we say that the choice of #2 is robust up to that uncertainty level. As $\alpha_u$ increases, there is more and more overlap between the vertical black lines for #2 and #1 indicating that you are less and less certain that #2 is better than #1. Using this type of analysis, alternative #2 is always better than #3 as the red line of #2 is above the blue line of #3 for all $\alpha_u$. However, at the highest level of uncertainty, $\alpha_u = 1$, #1 is not a robust choice relative to #3. Overall, you can view the lack of overlap between the black vertical lines between two alternatives in Figure 4.6 as indicating a robust distinction in choice between two such alternatives, at the level of uncertainty $\alpha_u$ where the black lines are located.

Next, consider $f_{ij} = f_{ij}^0$ and vary the $w_j$ weights. The result is shown in Figure 4.7. Interpreting the plot as in Figure 4.6, #2 is only a robust choice relative to #1 up to about $\alpha_u = 0.33$. Also, both #2 and #1 are better than #3
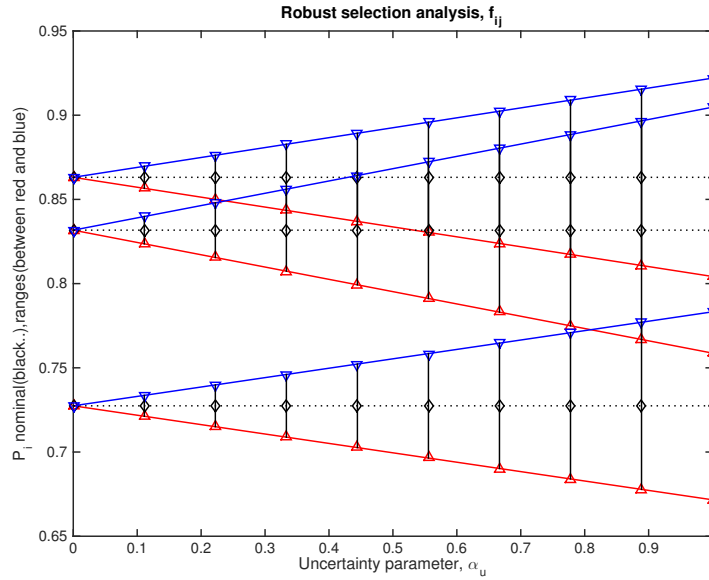
Figure 4.6: $P_i^{max}(\alpha_u)$ (blue lines, upside-down triangles), $P_i^{min}(\alpha_u)$ (red lines, triangles), and $P_i^{nom}$ (black dots, diamonds) vs. $\alpha_u$ for all $i = 1, ..., n$.

for all levels of uncertainty. Figure 4.8 shows the case for varying both $f_{ij}$ and $w_j$, which is in general a higher level of uncertainty than the cases in Figure 4.6 and also Figure 4.7. Notice that indeed, the distinction between #2 and #1 is only possible for lower values of the uncertainty level $\alpha_u$ relative to the other cases and above $\alpha_u = 0.67$, it is impossible to distinguish between any of the alternatives.

Above, there are a few key ideas in interpreting the plots in order to make a robust selection. First, to make a robust selection between two "adjacent" alternatives (e.g., the first and second best alternative as measured by $P_i^{nom}$) you need to have the distance between the two preferences big enough, the uncertainties associated with their information small enough, or both. This will allow you to be certain about your choice. Second, if the opposite of this occurs between two alternatives (close $P_i^{nom}$ values and larger uncertainties), then there is a second type of conclusion that is often valuable: you can be certain that you *cannot* distinguish between the two alternatives. If you use only the $P_i^{nom}$ values, you may be mistakenly confident in picking one alternative over another. Taking into account the uncertainty, you essentially come to "know what you do not know" and hence in making a selection you show the right amount of confidence, or lack of confidence, in your selection.
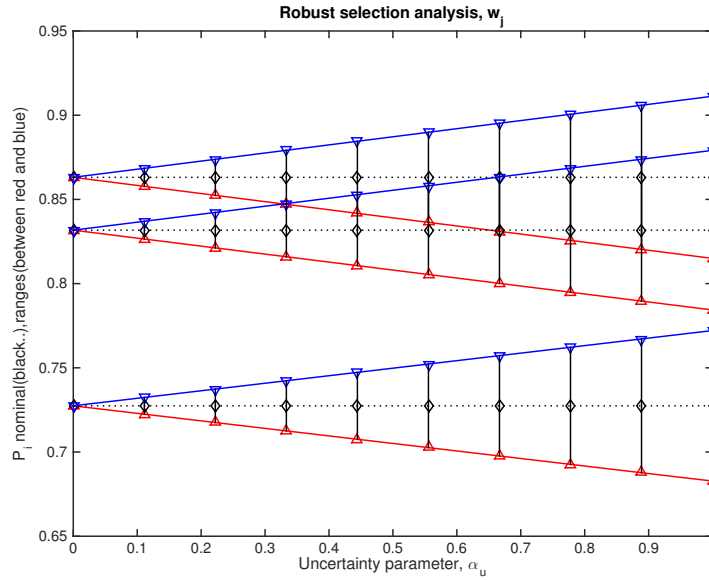
Figure 4.7: $P_i^{max}(\alpha_u)$ (blue lines, upside-down triangles), $P_i^{min}(\alpha_u)$ (red lines, triangles), and $P_i^{nom}$ (black dots, diamonds) vs. $\alpha_u$ for all $i = 1, ..., n$.

### 4.5.3 Robust Project Selection

Here, the multicriteria decision making approach is used for project selection. Due to the high variability in how to approach robust project selection, only some basic principles are identified and the reader is left to use the above ideas and tools (e.g., computer program) in a flexible and creative manner, one that adapts the robust selection challenge to the local situation.

**Guidelines for Quantifying a Project Selection Problem**

To start, you will need to decide which criteria to use, which weights, and how these are combined to specify preferences. Several options were identified above, from a simple weighted sum, to the weighted geometric mean that is related to community development, to several nonlinear aggregation methods. Key challenges in picking these include:

- The specification of project goals and their alignment with the preferences.

- Creating an assessment of the envisioned (estimated) impact of the project on the community (e.g., income, health, and education of the people). These are likely to result in the definition of some criteria and their importances.
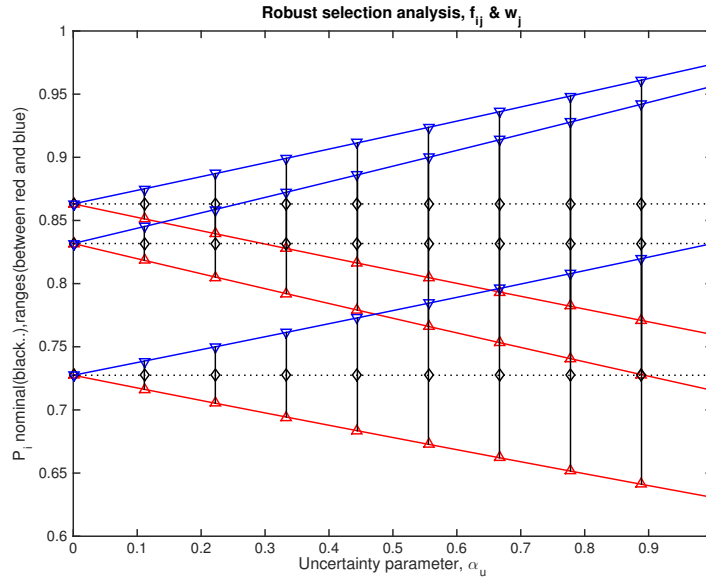
Figure 4.8: $P_i^{max}(\alpha_u)$ (blue lines, upside-down triangles), $P_i^{min}(\alpha_u)$ (red lines, triangles), and $P_i^{nom}$ (black dots, diamonds) vs. $\alpha_u$ for all $i = 1, ..., n$.

- The specification of the number, and types, of project alternatives.

- How to quantify data from community assessments, such as interviews, focus groups, and surveys into the criteria $f_{ij}$ and weights $w_j$. For instance, the minimum and maximum values of the criteria and weights can simply be set by the ranges of the collected data. Other times, mean values may be set equal to the $f_{ij}^0$ and $w_j^0$, and $f_{ij}^{min}$, $f_{ij}^{max}$, $w_j^{min}$, and $w_j^{max}$ the may be set by single, double, or triple standard deviations off the mean if there are a normal distributions.

Community and technical assessment information must be transformed into criteria, priorities, and preferences to make a project selection.

- An evaluation of how to integrate engineering technical assessments with qualitative or quantitative information gathered from individuals in a community. Sometimes, engineering assessments will lead to the definition of additional criteria and their corresponding importances (e.g., technical feasibility, cost, project length, and quality of match of the engineering team expertise to project alternatives).

- An evaluation of whether qualitative information can be quantified and included, or if it should just be "side information" that impacts, for instance, the project alternatives considered, final choice of top alternatives, or if it provides overriding evidence that all the recommendations from a quantitative analysis should be ignored.

- Sometimes, one of the biggest challenges is balancing and using all the information you have, qualitative and quantitive. Anecdotal qualitative information is sometimes very valuable; other times, it is a distraction. You may have a personal need to quantify everything and use, for instance, statistics and the above quantitative sensitivity/robustness methods; however, obsession with only one approach can lead to bad project selection.

**Example: Preferences Based on Community and Technical Assessments**

Suppose that Equation (4.6) is used for the preference formula, and that we have two sets of indices for criteria, $\{1, ..., m'\}$ and $\{m' + 1, ..., m\}$, and that $\gamma \in [0, 1]$. Suppose that the first $m'$ criteria quantify, for instance, needs (gaps), and the remainder quantify technical assessments for the project. As an example, suppose that $m' = 3$ and $m = 7$, that is, three needs and four technical assessments. We have

$$P_i = \gamma \sum_{j=1}^{3} w_j f_{ij} + (1 - \gamma) \sum_{j=4}^{7} w_j f_{ij}$$

that need to be specified for all $i = 1, ..., n$. As an example of how to specify these for a project selection problem, consider:

1. *Community assessments:* Community assessments (e.g., needs) need to be quantified with the term $\sum_{j=1}^{3} w_j f_{ij}$. To do this:

   - Use the gap between current and desired conditions to define $f_{ij}$, for three community-identified needs, $j = 1, 2, 3$ (e.g., if a survey is used, considering using the mean difference). Clearly, for a larger gap, $f_{ij}$ is larger, and hence this leads to ranking a project higher. The $f_{ij}$ must be properly scaled so their size makes the various cases comparable. Define, likely via community assessment, the priorities $w_j$, $j = 1, 2, 3$.

   - Projects must be selected based on what they can achieve, not what they hope to achieve. Hence, it may be more appropriate to avoid the use of community-expressed desired conditions, and instead use the conditions that your project can realistically achieve. Estimating such achievable conditions requires a clear understanding of current conditions and likely a technical assessment of achievable conditions for each project type.

   - For different values of $i = 1, ..., n$, the $f_{ij}$ values, $j = 1, 2, 3$, represent criteria based on assessments of *different* needs/gaps (otherwise the $\sum_{j=1}^{3} w_j f_{ij}$ term will be the same for each $i$ and hence will not have any impact on distinguishing between projects). To take this into account, if a project alternative, say $i'$ does not address need $j$, then

set $f_{i'j} = 0$, and hence different patterns and priorities of needs can be quantified. In this way, the $\sum_{j=1}^{3} w_j f_{ij}$ term for each $i$ can be different and thereby impact project selection.

2. *Technical assessments:* Technical assessments need to be quantified with the term $\sum_{j=4}^{7} w_j f_{ij}$. To do this, as an example, you could consider:

   - *Project cost:* Quantify project costs by converting expected costs via Equation (4.2) so that low costs are good (high $f_{ij}$ value) and high costs are bad (low $f_{ij}$ value). Call this $f_{i4}$ for each alternative, where costs will generally be different for each project alternative. Define $w_4$ to quantify how important cost is.

   - *Project time to completion:* Quantify time to completion of the project by converting expected project duration via Equation (4.2) so that short project durations are good and high durations are bad. Call this $f_{i5}$ for each alternative. Define $w_5$.

   - *Quality of match of team skills to project:* Rate on a scale of 0-1 how well your engineering team's skills match meeting the two needs above, and call this $f_{i6}$ for each alternative. Define $w_6$.

   - *Technical feasibility:* Rate on a scale of 0-1 the technical feasibility of the solution, and call this $f_{i7}$ for each alternative. Define $w_7$. This may take into accounts of risk of project failure for technical reasons.

Finally, the value of $\gamma \in [0, 1]$ needs to be chosen, and large $\gamma$ values emphasize the community assessments while small ones emphasize the technical assessments. If $\gamma = \frac{1}{2}$, there is equal weight given to each.

Next, it is important to define the uncertainty ranges for all the above $f_{ij}$ and $w_j$ parameters. Once you have this data, it can be input into the `RobustMCDM.m` program discussed above and used to make a robust project selection. Sometimes, it is useful to reevaluate the results of the robust project selection task by defining preferences in a *different* way, and seeing if the same sorts of recommendations are made. Next, one other alternative for defining preferences is discussed.

### Example: Preferences Based on Community Development and Technical Assessment

As another example of how to specify the preferences $P_i$ for the project selection problem suppose that the criteria $f_{ij}$, $j = 1, ..., m$ are defined by:

1. *Community development index:* $CDI_i$ in Equation (4.8) is used to measure income, health, and education, in a way so that $CDI_i \in [0, 1]$. Projections of the values of measures of the constituent variables, for example income, health, and education, must be developed for each project alternative.

2. *Project cost:* Quantify project costs by converting expected costs via Equation (4.2) so that low costs are good and high costs are bad. Call this $f_{i1}$ for each alternative. Define $w_1$.

3. *Project time to completion:* Quantify time to completion of the project by converting expected project duration via Equation (4.2) so that short project durations are good and high durations are bad. Call this $f_{i2}$ for each alternative. Define $w_2$.

In this case, the criteria of quality of match of team skills to the project, and the technical feasibility, are not included as they are not a concern.

The preferences for this case are defined using the idea in Equation (4.6) via

$$P_i = \gamma CDI_i + (1 - \gamma)\left(w_1 f_{i1} + w_2 f_{i2}\right)$$

where $\gamma \in [0, 1]$ can be used to emphasize meeting the $CDI_i$ objective or the cost and time constraints. Next, uncertainty ranges for all the parameters should be defined, and used in `RobustMCDM.m` to make a project choice. To do this for the $CDI_i$, it may be necessary to define the uncertainties in the assessments for income, health, and education, and then translate these through the formula that defines $CDI_i$ (e.g., uncertainty on the Equation (4.8) $a_{ij}$ values translated via Equation (4.9) and also Equation (4.10)).

There are many other ways to define the $P_i$, and you will need to specify an approach that fits your community and range of projects you may want to consider. Once a project choice is made, it is time to implement the project, which generally requires some type of project management, which was discussed in Section 4.3.3.

## 4.6 Humanitarian Technology

Assume that you use participatory development to identify client and community needs, and to understand the context the technology will be embedded in. Assume that you have chosen a development project. Now, we need to begin to address the development of technology solutions.

### 4.6.1 The Technology Spectrum: From Novelty to Maturity

The practice of humanitarian engineering "on the ground" has provided a number of general principles that should be attended to. In humanitarian engineering, generally, three situations can arise when trying to develop a technological solution concept to meet some community need:

1. *No technology available:* It could be that no one has ever developed a technological solution for a need, or that there is clearly no acceptable technological solution for reasons of cost, performance, reliability, lack of use of local materials, lack of infrastructural support, etc. Such situations can create very challenging technology development problems, ones that may require multiple years of advanced research and perhaps even discovery of new underlying science. Discovery of new technology solutions

requires both a detailed understanding "on the ground" of people and context, and a highly competent engineer.

2. *Related technology available:* Often, needs have been encountered by someone in the world before and solutions have been attempted, perhaps for different local conditions, or variations on the need your community has identified. The approaches to design used for such technologies should be considered as it is likely your team will learn a lot about modifying the technology to adequately solve the problem at hand (this is standard practice in some industries where "reverse engineering" is used to understand what a competitor is up to, and is not necessarily considered unethical so long as you credit your sources). Sometimes, when you start out trying to modify a technology you discover that you are actually in the category above where there is no technology that will fully and properly meet needs, and significant innovation is then demanded. Indeed, you should not underestimate the difficulty of modifying an existing technology; there is a spectrum between items 1. and 2.

> Community needs may have off-the-shelf technological solutions, a demand for modification of technological solutions, or need to invent novel technologies.

3. *"Off-the shelf" technology available:* There are an increasing number and diversity of technological solutions for needs arising from communities in the developing world (see references starting on page 718 for information on these). It is possible that conditions and needs in the community you are working with closely match those in other communities and hence solutions developed for other communities may be useful to you. In this case, there may be little if any engineering needed, just a *creative matching* of technologies to expressed community needs, that involves selecting a technology (see Section 4.6.5) and deployment of a technology, which of course can require some technological skills that engineers often have. In relatively rare cases, it may be possible to use technologies created for the developed world, however this is not common as needs and conditions are very different (e.g., use in the tropics, cost, cultural differences, reliability, or user demands) if context and community needs are properly understood. While it is normally dangerous to assume that a technology from the developed world will directly apply, it is likely irresponsible (unprofessional) not to consider the possibility, at least in case it gives you solution ideas so you can modify the technology for local conditions (i.e., the last case above).

Notice that creativity is required for *all* of the above cases, but the amount of creativity generally required decreases as you go from 1. to 2. to 3. A professional engineer will know where they stand with respect to where technology solutions are in their long-term advancement: very new technologies are often unreliable whereas old well-tested and widely-used technologies are "mature" and may provide elegant and reliable solutions, perhaps with some well-designed modifications.

To emphasize, the problem is not to find a technology, then hunt for a need. However, you have to know what is feasible when you are listening to community

needs so that you do not give false hope about effectiveness of solutions. If you are considering very large challenges, sometimes with no apparent solution, it makes sense to "bite off a small piece" and start on some tangible and feasible technology solution. This may require you to accept that you are not directly getting at "root causes," but hopefully you are "chipping away" at the root problem and not just treating symptoms. But of course, there are times when just treating symptoms can be valuable as for a number of situations you can argue that nothing is wrong with using technology to alleviate suffering.

It is important not to ignore cases where problems identified by a community seem completely intractable. You may not in the short-term take on such a problem, but it should be viewed as an "innovation opportunity." You may want to get an advanced research program started to try to address the issue (e.g., involving faculty and graduate students, or the research division of your company). Take a long-term perspective. If it is truly an important problem for the community, and you also determine that it is a widespread problem, you certainly want to pay attention to it.

### 4.6.2   Challenges of Extreme Constraints and Unusual Trade-Offs

From the extensive experiences in deploying technologies in the developing world, one thing that has emerged is that "design constraints" (what is acceptable, how the technology must perform, etc.) are often "extreme" in the sense that they are often far different from those encountered in the developed world. These arise from client and community needs, in a different context than the developed world (e.g., in the tropics or a desert). In a certain sense, using the word "extreme" is ethnocentric; constraints discussed below can be viewed as normal and natural in many parts of the world. It is often persons from the outside (e.g., visiting humanitarian engineers) who call the constraints "extreme" ("tough" or "demanding").

Another finding of humanitarian engineers is that "trade-offs" defined by clients and communities in the developing world are "unusual" ("unexpected," "strange," or "mind-bending") relative to what they have seen in the developed world. Clients' views must dominate your view of how trade-offs should be made in technology design. Clients and context are different so it should not be surprising that trade-offs are different. The proper attitude toward extreme constraints and unusual trade-offs is to view them as welcome challenges that can drive significant innovation and make sure that the participatory development process results in appropriate and good community impacts.

Next, a sample of extreme design constraints and trade-offs are listed; there is no intent here of listing all possible constraints and trade-offs as that is impossible. The main intent is to provide concrete examples so that you are on the look out for these issues, acknowledge them, and listen to what the client and community are saying, no matter how unusual it seems to you. This is critical for the success of a humanitarian technology.

Design constraints and trade-offs that arise from the local context can be quite different from those found in your own country.

**Extreme Design Constraints**

Consider the following cases:

1. *Ruggedness, reliability, robustness, and resilience:* These terms mean similar things in many contexts, and sometimes are interchangeable. Ruggedness, often, though, means that the technology can survive under harsh mechanically-induced conditions (e.g., dropping the technology). Reliability typically means that the technology will continue to perform adequately over a long period of time in spite of use under a wide variety of conditions. Robustness was discussed in Section 4.5.2, and is a general property present when a technology's functional performance quality is not sensitive to relatively small variations (e.g., mechanical or environmental). Resilience can be thought of as the same as robustness, depending on how these terms are used in different fields, but this term is often reserved for very large-scale complex systems (such as cities or in the wide-area technologies discussed below), sustainability studies for large regions, and in humanitarian engineering it often refers to community resilience (Amadei, 2014). Engineers in the developed world design such properties into *every* technology that has any chance of surviving with users and in the market in the developed world. Why? Competition with other industries drives this as they are often key properties in establishing long-term value of a product and through this, the success of the product. A similar concept can hold for the developing world. However, "extreme" demands along these dimensions frequently arise. For instance, will an electronic technology designed for the developed world with a temperate climate be reliable in, for instance, the tropics or arid regions of the developing world? Are humidity and temperature conditions going to result in premature product failure, or performance degradation? Products must always be developed for local conditions, and often tested for such conditions to make sure the design performs adequately, and over a long time period, before manufacturing and distribution.

2. *Low cost:* If you are taking a social business approach, clearly you can have severe cost constraints that result in a "price point" (what you determine the customer will spend) that is extremely low by developed world standards. Yet, of course, the customer wants top performance also. If you are developing a technology to sell to the aid community, then clearly cost will also play an important role: you may be competing with another company to provide the technology, or the aid agency will want it at the lowest possible cost so that they can affect more people (e.g., at a subsidized price). If you are working with a community on developing a technology and you plan on donating it at the end (since they participated, "paid," in other ways), then again, you have a motivation to keep all costs low as the money comes out of your own pocket. This emphasis on cost is not surprising: the very definition of engineering typically includes a comment on low cost, no matter where you are doing engineering.

The only thing "extreme" is typically a demand to make cost significantly lower than what an engineer who works in the developed world usually deals with.

3. *Local materials and maintenance:* Often, you want to put together a product that uses locally-available materials or other resources. Why? It drives down costs, and may not pollute as much (e.g., to transport materials). If you are engaged in social business, this can be a critical issue as manufacturing simply may not be feasible if you are relying on imported materials, or materials from very distant locations. Connected to this is the need for a good supply chain and support structure for the technology. For instance, what if the technology breaks down? Who will be able to service it? Are people with proper expertise nearby? Maintenance people? Technicians? Can a local person be trained for this? Can they be incentivized for this? Examples of such technical support are the many micro-businesses that have sprung up around the developing world to fix cell phones.

4. *Size and weight:* Often, for usability and cost reasons, it is best to make a product as small as possible, and to weigh as little as possible. Of course, for some technologies, making it lighter or smaller may cost *more* money. The key is to recognize the value of low size and weight in the context of the needs of your community.

5. *Safety and risk:* A principle of engineering ethics is that safety and risk depend also on local conditions and the types of clients that will use the technology, which can be different in the developing world. Are labels/warnings on a product in the local language sufficient? Or, to be responsible, must an educational program be associated with some technology that can impact safety and health of the user and the community? The safety constraints arising in the developing world may be viewed as "extreme," but must always be a central concern of a professional engineer. Examples here are health care technologies, energy supply approaches, some agricultural technologies, or water filtration methods for drinking water. For the last case, the contaminants can be "extreme" creating a very challenging filtration technology problem, sometimes where with affordable filtration you may not meet high standards of water quality. This can create significant ethical considerations, especially with respect to whose standards must be met for "potable."

6. *Environment and sustainability:* These issues are at least as important in the developing world as in the developed world, and often more important. In the developing world there may not be the funds to have recycling or waste remediation programs, or the community may exist in more fragile ecosystem, or have nearby rare species.

In many cases, these constraints cannot be thought of as independent of each other. Constraints can have complex interactions or coupling. Moreover, within

the "design space" (the range of all parameters of a design), there are "trade-offs" between the designs that will result in satisfaction of the extreme design constraints to various extents as is discussed next.

**Unusual Design Trade-Offs**

Some examples of the ways that clients and communities may view trade-offs in meeting their needs, which then translate to trade-offs in a human-centered design (IDEO, 2014, 2015), include:

1. *Ruggedness vs. cost:* In different contexts, and for different technologies, clients may favor a very rugged product that lasts a long time even if it costs more. This can happen if maintenance services for break-downs are not near by, are expensive, or if the technology has a continual impact on them (e.g., clean water on their health). In other situations, a client may accept a less reliable product if they at least get a year of good performance out of it; if this is all they can afford, and if the technology has a "return on their investment" in purchasing it, a low-cost relatively unreliable product may be acceptable.

2. *Ease of use vs. reliability:* In some situations it may be that clients may prefer a product that is difficult to use (e.g., requires more human labor) so long as it is more reliable and has a longer expected period of service/use. This may contrast with the developed world where such a trade-off may not be acceptable.

3. *Functionality/ease of use vs. cost:* Sometimes, a community may prefer a simple low-cost product over one that has what they may view as the "unimportant" or "peripheral" functionalities of a technology. Such peripheral functionalities may make the product easier to use, but they may happily invest their time or effort so long as the cost is low.

4. *Cultural issues vs. functionality:* It can be very difficult to know the impact of cultural values (e.g., religious values) on the design of a technology and how it functions. The culture you work with may have a view that the environment is a "spirit" (God-like) and hence greatly value not polluting with a technology. Or, they may be in such dire need that they have no concern whatsoever about the environment and just want needs met. In other cases, it may be that it is unacceptable for one gender to operate a technology if it functions in an "improper" manner.

Of course, several of these trade-offs may seriously challenge your own values and competence. For instance, should you accept their view of safety, where they may accept very unsafe operation in exchange for low cost, considering the central dictate of engineering ethics to protect the safety, health, and welfare of the public (see Section 2.3.3)? In the developed world that would generally be considered unacceptable. Or, should you accept their views of willingness to pollute considering the views of engineering ethics on sustainability, sometimes

arising from a concern that a polluted environment degrades human health? These are difficult issues; however, sometimes a very competent engineer can indeed meet client needs and respect the mandates of engineering professionalism and ethics. You should understand, acknowledge, and aggressively seek to meet such challenges, seeking technical advice from others as needed. It is your professional and social responsibility as a humanitarian engineer.

Of course, the above is only a brief but representative list. Also, such trade-offs can interact or are coupled: if you favor one direction for one trade-off you may want to favor a different direction for another. You certainly would not assume that you will encounter each of these constraints and trade-offs, or indeed, any of them. Or, in some contexts, some of these may be relatively similar to those in the developed world (e.g., cell phone functioning). Your situation for a community may be different, and ultimately the clients and community are the sources of information on constraints and trade-offs; you always keep the technology human-centered.

### 4.6.3   Appropriate Technology

Though Indian leader Mahatma Ghandi is often thought of as the "father" of appropriate technology, E.F. Schumacher popularized the notion of "small is beautiful" (Schumacher, 1975), and connected to this there has been significant work done on this ideas, and Schumacher's philosophy is often cited as a basis for the appropriate technology approach. There are a whole range of available definitions, but typically:

> "Appropriate" technologies are small-scale (e.g., personal), have suitable complexity for the need and scale, are simple to operate and maintain, are energy-efficient, use local materials (respect the realities of "supply chains"), are environmentally friendly, are low-cost, and are "human centered" (Hazeltine and Bull, 2003; Martin and Schinzinger, 2005).

There is a long tradition of openly publishing all details of how such innovations are made, but of course this may be at odds with a business approach to development where intellectual property and patents are important to protect a company. Humanitarian engineers think of appropriate technologies as ones directed toward helping people in the developing world, and as the key concept underlying humanitarian technology. Here, we will simply think of any technology that satisfies the extreme design constraints and unusual design trade-offs listed in the last section as being an "appropriate technology." For instance, technologies for homeless people, no matter where they live, are considered to be appropriate technologies (see Section 4.6.4), as are technologies for STEM education in a learning community (see Section 4.8).

Some examples of areas that appropriate technologies have been developed for include the following:

Appropriate technologies are ones that meet needs and constraints in a community.

- Water/sanitation;

- Food/agriculture;

- Energy (e.g., electricity, lighting, heating, and cooking);

- Health/medical technologies;

- Education (e.g., technologies for projects and laboratories discussed in Section 4.8);

- Shelter and infrastructure (e.g., homes);

- Information systems; and

- Environment/sustainability.

No technical details for any of these technologies are discussed here as: (i) they are freely available on-line or in easily accessible books or papers; and (ii) the field is continually evolving and advancing and it is therefore best that you adopt the approach of doing a literature/internet search (or attend a conference) to find the latest and greatest innovations that may be useful for the community you are working with. To give you a sample of what is available, a good source for appropriate technologies is

Village Earth: Appropriate Technology Sourcebook

but other sources are provided in references starting on page 718.

There are a number of ways to categorize appropriate technologies into groups. A common and logical approach is to group technologies according to the need they address. Here, appropriate technologies are categorized according to whether they are directed at individuals or communities as this often provides a clear line between two types of approaches for humanitarian engineering projects via participatory development.

**Personal Technology**

In a number of contexts in the developing world there a serious lack of infrastructure and services, and it is unacceptable to wait for these to be put in place by, for instance, a government. Needs must be met with a strong sense of urgency. In such situations, it is logical to seek solutions for individuals rather than groups (like a community, region, or country). Such a client-centered approach can work to meet a number of basic human needs such as:

- Water filtration systems (hand-held, effective, and low-cost);

- Sanitation approaches (e.g., see case below for homeless people);

- Electricity generation (e.g., a bicycle and generator, small wind-based, or small-scale solar panel are common approaches);

- Food production approaches like gardens (sustainable with effective agricultural technologies to enhance yield including irrigation); and

- A low-cost non-polluting transportation method (of course, the common approach world-wide is the bicycle).

Many examples of appropriate personal technologies are referenced starting on page 718 (including references in those sources); however, to provide concrete examples now, you can consider the cell phone or low-cost lighting which has been studied for many years and been developed by many organizations. A sample case is at d.light (however these systems are sometimes not used as personal technologies, but may also impact several people, for example, in a family).

In seeking to develop a personal technology it is important to keep the human-centered aspect of participatory development in mind, paying attention to critical needs, and the ideas in Section 4.1 on an engineer helping a single individual (if that is relevant). For instance, if cost is the dominant challenge for an individual, you may be able to use the "modularity principle" from design (see Section 4.7.8) to produce an expandable ("incremental") technology where one piece of the technology is bought at a time, and each piece provides some level of benefit and functionality, and later additions can be chosen by the client to meet needs, and fit within their earning pattern (e.g., earning daily wages, but periodically). There are a number of times when this is possible (e.g., in drip irrigation (Polak, 2009)), sometimes in surprising cases relative to what is found in existing technologies in the developed world. For example, consider the modular phone PHONEBLOKS, developed for sustainability reasons, but with obvious incremental cost implications that can be very important for affordability as discussed in (Banerjee and Duflo, 2012).

**Community Technology**

Lack of community-wide or country-wide (e.g., rural or urban slum) infrastructure is often the driver for these technologies. Water filtration, sanitation, energy generation, and transportation (a "village truck" for taking agricultural products to market or for moving water) can all be approached from a community (group) perspective by seeking technologies that meet the needs of multiple individuals rather than just one. In some contexts it may make more sense to address basic needs by doing so for an entire community together, rather than each individual in the community (e.g., for cost per person reasons and a desire to have wider impact).

A community technology approach has many advantages:

- It is naturally inclusive if executed properly;

- It hopefully improves conditions uniformly and hence does not create inequalities and bad feelings in a community where one person has an advantage over another;

- It often promotes the idea of sharing and cooperation and therefore not only empowers individuals, but also the entire community's functionings;

*There are many candidate personal appropriate technologies that can be used to help people.*

*Sometimes, it is more cost effective, and greater impact can be achieved, if a community appropriate technology is developed.*

- It may offer lower cost and less negative environmental impact per person;

- It *may* be more reliable if effective group operation and management strategies are used; and

- It also has technical advantages in some cases, such as centralizing a solution and having the resources to make that solution perform better (e.g., in water filtration maintaining more consistent reduction of contaminants, in electricity generation providing a more reliable source that does not periodically shut down, or in agriculture via community fields/gardens).

Of course, in some cases it can be much more difficult to succeed in a community-wide participatory development project as the objectives then often include infrastructure development (e.g., laying pipe, installing a large water storage tank, or stringing wire). Challenges also include acquiring initial development funds and putting in place approaches to operate and maintain the community technology as is discussed in the next section.

The idea of "modular" technology above also works for a community in some cases. One example, that could be either a personal or community technology, is "drip irrigation" (Polak, 2009) that has a water source, and pipes with holes for water to come out that can be connected to each other, and that can be expanded to larger and larger regions of fields, for more and more farmers, depending on availability of funds (e.g., an initial small purchase may result in increased yields in one year, so that profits can be used in the next to expand the system to cover a greater portion of a field, and so on–unfortunately, however, in practice the systems does not work so well always, e.g., due to clogging of holes).

Technical challenges to creating community technology may be more or less significant than personal technology. Each case is different. However, there is often a clear difference between engineering a humanitarian technology for individuals versus a community, often requiring different engineering expertise (engineering a personal water filtration technology is quite different from engineering a clean water system for a community 100 people). Also, special issues arise for community technologies in coordinating their use as is discussed next.

### Technology for Cooperation

Personal technologies are always designed to be human-centered (IDEO, 2014, 2015), and typically they are single-human-centered. Community technologies are designed to be community-centered and hence multiple-human-centered. There is a very basic difference in the two cases. In personal technology, issues like ease of use and operation involve one person. Naturally, the ease of use and operation for community technology involves a group of people with a "shared technology" and is going to create different challenges and opportunities.

**The Human Cooperation Challenge:** Some of the most complicated challenges associated with community technology are social. For instance, if you

work with a community using participatory development to install a community technology, should the community require financial, work, or time commitments from all individuals who obtain the benefits of the technology? Why do this? It clearly delineates ownership, has an empowering effect on those who buy in, and can have a broader impact on helping the community believe in its ability to work together to solve problems in the future. One approach is to use a cooperative strategy to make sure the technology will be "self-supporting," via pooled saved funds, for maintenance, repairs, and eventual replacement at the end of the life of the product. The community will need to come to an agreement on what each person has to give, in order to receive benefits. But, the details matter. For instance, how much money does each person (family?) have to contribute each time (per use-event, per month, or per year)? Does everyone pay the same amount, even though some may not have as much wealth as others? What is the dollar value of contributed work (e.g., a person who maintains the system)? Should prevailing local wage rates be used? Should an incentive be used to get people to buy in (e.g., one month of use at no cost)? Do all users get the same benefits from the technology (e.g., if your payments are family-based, then does a family of eight pay the same amount as a family of three?). What happens if someone "cheats" by skipping payments or by not living up to the agreement? Who decides the "punishment"? The group of users? A single leader? Then, there is the difficult question of whether an outsider can suggest a cooperation policy for the community? Can an outsider present the important concepts of how it "might work"? This issue is at least as complicated as the question about whether to suggest a technology for a need that was discussed above.

*Human cooperation of technology use and maintenance can be very challenging.*

**Technology Design for Facilitating Human Cooperation:** From a humanitarian engineer's perspective, the cooperation challenge is "socio-technical" (and perhaps "socio-eco-technical") as it involves individual and group human behaviors (and hence individual and group psychology), there may be significant cultural aspects (tendency to trust or cooperate with a basis in anthropology, sociology, and psychology), and the engineer must keep these socio-challenges in mind and try, right from the start, to design the community technology so that it is easier to implement an effective long-term community cooperation strategy for operation and maintenance. There are two general issues: how the technology and human group interact ("cooperate" with the view of the technology as an "artificial agent"), and how to design technology to promote cooperation. The first lies in the well-studied realm of "human factors" and "human-technology interface." The second will be discussed here in a bit more detail.

*Technologies can be used to promote human cooperation for community technology use and maintenance.*

Success of the community technology project can depend critically on the ability of your participatory development team to "design for cooperation." There are a few principles that may guide the development of cooperative technologies:

1. *Cooperation theory:* The engineering design team is going to need to study

the principles of human cooperation using a number of areas of social science (psychology, social work, sociology, economics, political science, anthropology) and natural sciences (evolution and behavioral ecology have much to offer by considering human and animal models) in order to design a good solution (e.g., see Section 4.3.1).

2. *Cooperative technologies:* The engineering design team is going to need to learn about cooperative technological approaches that exist for other applications. There are solutions for cooperative task processing, cooperative scheduling, cooperative resource allocation, cooperative choice (agreement or consensus), cooperative motion, cooperative leader election, etc. You should search the relevant literature, but be aware that this can be difficult as there are many terms used for "cooperation," or that have close meaning, like "collaboration," "crowd-based," "crowd-sourced," "group," "multi-agent," "team", "collective," or "coordination."

3. *Deployment:* The community should be involved in specifying the cooperation strategy and be given the autonomy to change the strategy if they feel it is not working; hence, it is likely that you will need to make it possible to change the strategy periodically, and this often then implies that a software system is used since it is then possible to produce a user interface that allows for changes (reprogramming). This also raises the issue of controlling access to making changes (e.g., should there be a software system that requires entry of multiple personal passwords from some number of community members, or via the internet to someone somewhere else?).

Socio-technical systems that achieve close human-technology interaction and effective human cooperation present fascinating and very challenging engineering problems. In Section 4.12.1 the ideas of this section are explored further, and in particular one strategy for "cooperative management of community technology" is introduced, simulated, and analyzed.

### 4.6.4 Example: Technologies for People Who Are Homeless

Section 1.1.2, but also Section 1.2.1, and Section 1.2.2, discuss issues with homelessness world-wide and in the US. While great suffering results from homelessness, there are humanitarian technologies that can help. Examples of humanitarian technologies for people who are homeless in the US include low-cost versions of the following:

- *Make-shift shelter:* For a make-shift (personal) shelter for living in, for example, the woods or street, some requirements may be: (i) use of free or low-cost local materials; (ii) weather-resistance to cold, snow, ice, and rain; (iii) protection from a possible wet, muddy, and cold ground which may require slightly elevating the shelter (e.g., via a pallet) or using a tarp; (iii) sturdy so it will not collapse under snow and ice loads; (iv) having

There are a range of technologies that can help people who are homeless.

convenient ventilation; (v) easily convertible between winter and summer living; (vi) rugged/durable to get a long life; (vii) good internal light; (v) possibly transportable (e.g., via carrying it or via the cart discussed below); (viii) secure against theft of the shelter and what is in it; and (vii) aesthetically pleasing and/or camouflaged so that people will not be as likely to be removed from various locations by authorities. Each person living outside may have different requirements.

- *Heating for a tent or shelter:* Some requirements may be: (i) safe and non/low-polluting so it can be used inside a tent or shelter that is closed in the winter, (ii) provides sufficient heat output during winter, (iii) low-cost fuel, and (iv) lasts all night without tending so people can sleep well.

- *Lighting for a tent or shelter:* Some requirements may be: (i) safe and non/low-polluting so it can be used inside a tent or shelter (e.g., energy via renewables like solar), (ii) provides sufficient light for reading or work, (iii) low-cost fuel, and (iv) lasts a sufficient amount of time.

- *Cooking methods:* Some requirements may be: (i) safe and non/low-polluting so it can be used inside a tent or shelter, (ii) provides sufficient heat for completely cooking meals, and (iii) low-cost fuel. It may be possible that cooking, lighting, and heating methods are all provided with one approach.

- *Sanitation methods:* Some requirements may be: (i) methods to capture human waste and dispose of it and (ii) methods to dispose of trash.

- *Cart for materials and belongings:* Some requirements may be: (i) larger wheels so the cart is easier to move over rough terrain such as in a woods, (ii) a cart that can be secured against theft, and (iii) water/weather protection methods. A pull-behind, rather than push-ahead, cart may be better for rough terrain. For example, a pull-behind piece of luggage may be suitable for personal belongings.

While these are aimed at the US, it should be clear that in various forms similar technologies could be useful on an international scale. The features of each technology above are *ideas* rather than definite requirements. Of course, participatory development (Section 4.2.4) and participatory technology development (Section 4.7) should always be used, complete with participatory action research to assess needs (Section 4.2.8). People who are homeless need to be asked what features of a technology are important to them. Of course, technologies such as those above would have to be better than what is currently used (e.g., in terms of cost and features), and it may be useful to simply provide the designs or instructions via prototypes, so that individuals can construct the technologies themselves. This may be better than donating an actual physical piece of technology, or even providing it at a subsidized cost. In some cases, however, for example for the severely mentally ill, such technologies could be provided by social support services in the area for free, at a subsidized cost, or at-cost (e.g.,

a homeless shelter that does not have enough beds for everyone in the winter could provide make-shift shelters using donations from the community).

Progress on some of the above technologies has been made here

<div align="center">Tech$_4$Community</div>

(Technology for Community) which was created based on ideas in (Passino, 2009). Tech$_4$Community is focused on working with an urban US community and having engineers work with the community to create useful technologies, typically, ones for individuals or families, analogous to a free medical clinic or legal aid clinic. Also, there is a focus on providing "technology services" for local service providers (i.e., engineering for helping the helpers), such as food pantries. While at the present time it is based in Columbus, there is no reason this model would not work in other US cities, and with adaptations, to other locations.

## 4.6.5 Technology Selection for Clients, Communities, and NGOs

When considering the range of options for a humanitarian technology for a client, community, or NGO there is often the challenge of comparing and selecting a technology from a set of candidate off-the-shelf technologies, or assessing available off-the-shelf technologies to see if there is a need for a humanitarian technology invention. Local problems are always different; hence, the need for the creation of new technologies is not necessarily an unusual case, or at least there may be a need to *modify* an off-the-shelf technology to adapt it to solving a local problem, and this can take significant creativity. Sometimes, NGOs need technical assistance in evaluating technologies that they want to purchase, typically ones for their communities or individual clients. The NGO may purchase these technologies with donor funds or receive them via in-kind donation and may give them away, provide them at a subsidized cost, at-cost, or simply by providing a recommendation to their clients. It can be difficult to match needs and context to technology solutions; there are typically too many technology options to consider, and to do a good evaluation may require significant technical skills and possibly experimental evaluations of technology options. This may create the need for a humanitarian engineer's assistance. Just like the case for clients and communities, the end result of such an evaluation may be that there is no technology that is suited for the problem at hand. One option for this case is to invent one.

**Making the Problem Statement**

To start, it is best if a very clear problem statement can be made that includes needs, context, and technology solutions. The inputs from the community and/or NGO, who typically know quite a bit about these issues, but possibly not the technology part, are crucial as discussed throughout the earlier sections of this chapter. The manner in which you phrase questions to the community or

NGO so that you can formulate the problem statement is important. Getting a good problem statement is a large part of the technology evaluation problem. All the above participatory development ideas (e.g., PAR) are relevant here.

Some typical questions you may want to consider asking are:

- What need do you have in mind? How many people have this need? How does this need rank relative to other needs? How will meeting this need help people? How were these needs determined? How much are end users willing to pay for a solution?

- Who is going to use the technology? How and where will the technology be operated? What conditions do the users live in? Can you tell us about the context within which the technology will be operated?

- What are the client/user expectations? To what extent do they expect their needs to be met?

- What technology is used now (if any) and what is wrong/right with it? What additional technology features would you like to see and why? Is increased performance for some aspects of the technology needed? Can performance be decreased for other features? Do you have alternative technologies in mind?

- What problems, that are not being solved now, should be solved with the new technology solution?

- What are the operational characteristics that should be present? Which features are essential and which are optional? How complex can the technology be? How easy should it be to use? Is the technology solving the real problems or problems that do not really exist?

- What is the price target initially and the price of operation and maintenance for the technology? Delivery costs? How complicated is operation and maintenance?

- If working with an NGO, can I meet the community/clients on-location to learn about needs and context first-hand? Can I see the current technology in operation? Can I survey the community (do PAR) about needs and current technology effectiveness? Can I run field tests on its effectiveness?

- What technologies are locally available? Is it acceptable to order technologies from other countries or locations?

- Can the technology be locally maintained, repaired, and replaced? Who is responsible for maintaining the technology? Are there affordable spare parts or service available?

Of course, some of these questions may be inappropriate for a particular case, or these questions may change for different communities and NGOs, needs, contexts, and technologies. Whatever questions you use, your goal in asking

these questions is to formulate a detailed problem statement for technology evaluations.

**Evaluation Methodology**

Given the problem statement developed in the last section, the next step is to begin work toward developing a technology recommendation for the community or NGO. There is no single methodology for evaluation of technologies, but some broad guidelines are as follows:

Try to follow or establish a systematic methodology for technology evaluation.

1. The starting point is the problem statement, with needs, priorities, context, and existing technologies defined.

2. Conduct fieldwork that includes PAR for needs, an evaluation of context (including operational conditions), and evaluation of current technologies if they exist.

3. Learn more about needs and contexts for other (similar) locations for a similar technologies.

4. Research and learn about the technologies (science, operational characteristics, technical specifications, cost, etc.).

5. Identify key performance metrics (e.g., how long it should be able to be continuously operated, reliability, ease of operation, the quality of the products it produces, affordability, cultural acceptability, sustainability, etc.).

6. Do a cost evaluation for each candidate technology that includes purchase/delivery cost, operational costs, and maintenance costs. Study supply chain issues for the technology and its components, and whether they are available locally.

7. Choose a subset of technology options, the ones that appear to be the best, and quantitatively and quantitatively assess each one and compare them to each other (see below). This subset could include an existing technology that the community/NGO is using, if there is one. The subset under consideration probably should not hold too many options as full evaluations for many options may not be possible, especially field tests. Moreover, sometimes it is simply obvious that some technology will not fit the needs.

8. Evaluate the technologies at multiple sites, repeat above as necessary, and adjust evaluations.

9. Do experimental evaluations of the technologies if needed and possible in a laboratory, and if feasible do the evaluations at the site. Conduct surveys, focus groups, and ethnographic observations of technology in use in actual environment. Gather data from customers, including end users in the community, and intermediary NGO personnel.

10. Develop a ranking methodology for the technologies using the set of qualitative and quantitative assessments (see below) along with an overall quality evaluation for each candidate technology.

11. Select and recommend a technology to the community or NGO, or a set of technologies to consider. Sometimes, this would include a technical report that includes all the above aspects, and perhaps the spreadsheet that would automate the computation and ranking of technology quality evaluations (see below).

12. Repeat above steps as necessary after getting community and NGO feedback on the selection and report.

13. Involve, for all steps above, the community and/or NGO as much as possible. Put them in the driver's seat.

This process is also more broadly iterative. After the chosen technology is deployed for some period of time, the whole process (including in the last section, and the next one), or parts of it, may need to be repeated to make sure a technology is properly meeting needs in context at the present time, or to try to find a better technology (e.g., if new ones have been developed) for current needs and context.

**Multicriteria Decision Making for Selection of Humanitarian Technologies**

Rather than providing a specific numeric example, here it is explained how to use the multicriteria decision making approach in Section 4.5.2 for the off-the-shelf technology selection problem. To do that, it is convenient to slightly change the terminology from that section according to:

- Preference $\rightarrow$ Technology quality (but both terms could work)

- Criteria $\rightarrow$ Feature (assessment of feature)

The term "alternative" is appropriate here, or "option." Normally, it will be natural to use "importance" and not priority, but that may not always be the case. All of the ideas on how to define the $P_i$ from Section 4.5.2 apply here, as do the ideas on sensitivity analysis and robust selection, and the use of the computer program `RobustMCDM.m`. Hence, the technology selection problem here is a straightforward application of multicriteria decision making, as is the project selection problem in Section 4.5.3.

## 4.6.6   Humanitarian Systems Engineering

The design of a humanitarian technology that affects a sizable system (e.g., a manufacturing system), a wide area problem (e.g., a whole country), and many people, but is a single integrated system (it may be centralized or "distributed") is created by humanitarian systems engineering. Assessing need for a wide-area

solution is difficult and may come from data gathered by, for instance, the UN or World Bank (see Chapter 1); however, the engineer should stay as "close to the ground" as possible, working with locals and talking to people (e.g., average citizens or experts in an NGO, aid organization, or government organization). While you may naturally think of the technologies below as applying to large regions, a number of ideas can be *scaled down* to local communities or specific locations.

### Engineering and Sweatshops

A relatively small-scale humanitarian systems engineering problem is the design and operation of manufacturing facilities in the developing world in a way that does not result in "sweatshop" working conditions and environmental degradation. Manufacturing engineering for such sites includes the following concerns, ones that can be broadly broken down into exploitation of low-income people and the environment:

1. Health and safety standards when there may not be laws, or at least enforced ones, protecting workers and ensuring healthy working conditions.

2. Worker rights, including a living wage, protection from abuse (e.g., from supervisors or being forced to work overtime), right not to work as a child, freedom of association with unions, and the right to strike.

3. Pollution and excessive resource use in order to operate the sweatshop at low cost and maximize profits.

See pp. 89, 131, and 135 of (Rivoli, 2009), and also Chapter 2 (e.g., Section 2.2.2).

What can an engineer do to improve the conditions at a sweatshop, or make sure that a manufacturing site is set up not to be a sweatshop in the first place? There are clear standards to be met for such sites, such as ones established for the developed world, but the key problem is whether raising standards will result in raising costs to the extent that the sweatshop is put out of business, only set up to run in a similar exploitative manner in another country (called the "race to the bottom," e.g., in Part II in (Rivoli, 2009))? Of course, that could be very undesirable as workers may be relying on a steady wage, one that is better than anything else available to them, and better working conditions (e.g., compared to working in rural agriculture (Rivoli, 2009)). See the discussion on this and related issues in Section 3.2.1 and also Section 3.2.4. Historically, however, locations that had won the race to the bottom, then later lost to another location, reaped some benefits for their people (e.g., see (Rivoli, 2009)). See Problem 4.51.

### Wide-Area Problems

There are a number of "wide-area problems" (in both development and disaster relief) that arise and that technology can be very useful for, and they often

involve "sensing" (getting information) and coordinating its use across large areas (see, e.g., (Davis and Lambert, 2002; Meier, 2015)):

1. *Natural and human-made disasters:* Information technologies may be useful for gathering data about conditions on the ground (e.g., via crowd-sourcing from individual cell phones) when some communication infrastructure is adversely affected by a hurricane or earthquake. War often creates great humanitarian need across large populations and areas. For both cases, there is a need for humanitarian technologies (e.g., logistics) to coordinate transport of essentials (e.g., food), coordination of services (e.g., refugee housing), all to avoid wide-spread suffering (e.g., famine).

2. *Coordination of services:* Information technologies can be very useful to coordinate services not only for disasters but for existing social services in a country (i.e., to make the "helpers" more effective). For instance, in Columbus, Ohio, it would be very useful to have a county-wide web-based information system to coordinate all social services, including: scheduling shelter, scheduling access to food pantries and soup kitchens, making the mental health services more effective with clients (e.g., via e-reminders to take medications), or having e-identification to avoid the problem of having paper/plastic identification getting lost or stolen.

3. *Digital mapping:* It can be useful to map information relative to poverty, development, and efforts to help (e.g., a digital map that uses global positioning system (GPS) information, coupled with other aspects such as population density and health service locations "overlaid" on a spatial map, to identify areas of need).

4. *Agriculture:* Digital mapping can be used for assessing moisture content and planning irrigation to reduce effects of drought and efficiently use water. Supplying weather information to cell phones may provide useful information for local farmers. Obtaining information about a distant market (e.g., via a cell phone) may be useful for a farmer to plan how to get the best price for her/his produce.

5. *Environment:* Monitoring and gathering information about environmental variables can be very useful in coordinating activities to reduce adverse impacts on the environment (i.e., an "eco-technical" system).

**Technology for Fighting Structural Injustices**

It is a principle that if you are trying to help a group of people solve a problem (e.g., poverty and development), you need a group of people to make it happen. This is highlighted in areas from social work (Homan, 2011) to social justice (e.g., consider the need for activism). Often, problems for groups of people arise due to "structural injustices" that you can think of as the "rules of the game" or "patterns of oppression or corruption" in economic and political systems, or even the workplace. Such problems are pervasive. They occur all the way from

the family and community, to the country and world levels (e.g., unfair trade policies, wide-spread discrimination, economic inequalities, and conflict/war). They are naturally "wide area," and social justice perspectives from Chapter 2 highlight the problems, provide us a broad understanding of the problems, and often give hints at solutions, at least by saying what "ought to be" (religious approaches), what is "ideal" (e.g., Rawls), or what to change to remove injustices or promote justices (e.g., Sen). While the environment is listed above as a wide-area problem, it is of course also a justice issue, as are the other issues above if you view poverty and lack of development as an injustice, which most do.

To be more concrete, some specific humanitarian systems technologies include:

1. *Open systems and structural problems at work, in economics, in politics:* Transparency is a fundamental strategy to fight corruption, promote participation, and ensure fairness. Specific examples include (i) open web-based database technology for publishing a government's budget and full real-time tracking of flow of all money; (ii) electronic media for promoting open communication to a populace from a government and vice versa, open communication to a government from the populace (including "data analytics" to interpret the data from the populace in a fair manner) to promote democracy; and (iii) open web-based information on all aspects of the market to ensure that it is free and fair. All of these ideas are technologically feasible today, requiring no fundamentally new technology; however, there is a need for basic advancements in systems theory (e.g., distributed algorithms) to address a number of these challenges, such as fraud detection (Finke, 2013). See Section 1.1.2, Problem 4.53, and also Problem 4.54.

   > Technologies may be useful in addressing some wide-spread injustices.

2. *Fighting systemic evil in illicit markets:* The significant problems of human trafficking (adult and child, female and male, for sex trade, slavery/forced labor, forced child soldiers, forced begging rings, etc.), the illicit drug and weapon trade, garbage trade, and organ and rare species trade, all demand more attention from engineers. In some cases, root causes certainly cannot be addressed by an engineer (e.g., root causes for why someone would capture and hold a child as a sex slave). However, there are ways to use technology in the fight against these injustices. For instance, sensing and data gathering via smart phones can, perhaps via geo-mapping methods, help identify sources of problems and patterns of flow that may help solve problems some times. For instance, (Chongsiriwatana, 2013) indicates an interest in humanitarian engineers developing distributed information technologies (data base and tracking) to help fight child trafficking. Data analytics could be useful in this context if the scale of the problem is large. See Section 1.1.2 and Problem 4.55. Similar concepts will, perhaps, be useful to fight the evils in other illicit markets.

Each of these systems is a large scale socio-eco-technical system that is incredibly complex, and each presents especially large challenges for "humani-

tarian systems engineering." It is unlikely that a small group of engineers can solve these problems by themselves. Team/organization expertise is needed in a number of areas, including social justice (religious and secular perspectives); social science foundations; information technology, data analytics, big data, distributed algorithms, and software engineering from computer science and engineering and electrical engineering; nonlinear dynamics and stochastics; feedback control theory and engineering; and a number of other areas like signal processing, communications, and computer networks. As usual, the principles of use of local knowledge and expertise on understanding the problem (context), how to fix the problem, and how to make sure it does not re-emerge are crucial for the success of humanitarian systems engineering. Clearly, to make this happen, significant advances in engineering technological systems that cooperate between themselves, and promote cooperation in human groups are needed (i.e., an expansion of the ideas on cooperation and technology for communities). For more relevant discussion, see Section 4.12.3.

For additional related issues, particularly in engineers' involvement in weapons development and law enforcement, see Problem 4.56, and for humanitarian military intervention, see Problem 4.57.

## 4.7 Participatory Technology Development

Participatory technology development (PTD) involves the use of helping theory (Section 4.1), participatory community development (Section 4.2), coupled with human-centered design (IDEO, 2014, 2015) and traditional product design (Ulrich and Eppinger, 2012), to provide a process for participatory humanitarian technology *product design*. The process of participatory development shown in Figure 4.2 is general enough to include PTD as a special case, and it is suggested that the reader use it as a guide for thinking about interconnections and dynamics in the overall PTD process. For Figure 4.2, challenges/needs are identified that have technologically-feasible solutions and these define the project. The participants in PTD typically include engineers, possibly from the outside. While PTD is a special case of participatory development, in this section, and sections to follow, we discuss specific details of the engineering participatory technology development process for products to make the process more concrete. *The reader should not, however, ignore all the issues discussed in Section 4.2.4; all those apply here also, but many of them are not repeated.*

### 4.7.1 Participatory Technology Development Up Close

To start, it is suggested that the reader view the YouTube videos of

<div align="center">The Water of Ayolé (search the internet for this)</div>

For this video, identify the key elements of participatory development for pumps, a technology product. See Problem 4.20. Next, view the talk

<div align="center">Creating a New Handpump Solution in Africa</div>

by Greg Bixler. See Problem 4.21. Compare the Ayolé and LifePump cases.

Next, view the (16:25) TED talk by Navi Radjou

<div align="center">Creative Problem-Solving in the Face of Extreme Limits</div>

from Oct. 14, 2014. What is the relevance of Jugaad innovation to humanitarian technology product development? See Problem 4.15.

## 4.7.2 Focus on Humanitarian Technology Products

In this section, technology "development" focuses on technology "products," and includes the entire process of creating or modifying a technology, from assessing user needs, to "design" of a technology to meet those needs, to manufacturing, marketing, and sales. Examples of products include the pumps discussed in the movies in the last section, and many appropriate technologies (e.g., see Section 4.6.3). Many types of engineers get involved in "product development" (e.g., mechanical, electrical, industrial, biomedical, and frequently other disciplines) and due to such a wide involvement, we focus here on products. Hence, the term "participatory technology development" (PTD) used here describes the application of the ideas on participatory community development (Section 4.2) to *product* design and development  to meet expressed needs in a community ("PTD" has been used as a name for related approaches in sustainable agriculture and natural resource management (Gonsalves and others, 2005)). The view here is that PTD is one form of (or approach to) community development (i.e., a special case of community development that also involves non-technological issues and solutions). The term "participatory product development" (PPD) is a reasonable alternative to the term PTD.

> PTD here means human-centered humanitarian technology product development.

To elaborate on the rationale for focusing on products, note that: (i) there are many *existing* humanitarian technologies that are products; and (ii) there are a number of similarities between technology product development and engineering development of other technologies (e.g., needs assessment and issues of sustainability and robustness). Even though the detailed participatory development of the myriad of possible technologies, such as those listed above, is clearly beyond the scope of this or any single book, the ideas on community and participatory development are very general and seem to virtually always be applicable for community technology development of any type. It is hoped that by showing how to apply community theory and participatory development to development of one class of humanitarian technologies, the engineer who works in other areas will assisted in doing this for other classes of technologies. Indeed, in some engineering disciplines " technology development" takes on a different meaning, and requires different approaches. For software, the software engineering approach is used (e.g., the "spiral method") by computer science (most often part of a College of Engineering) or computer engineers. Civil engineers have well-established approaches to designing bridges, buildings, and roads. Chemical engineers develop, for example, chemical processing technologies, and materials engineers develop materials processing and synthesis methods. Agricultural engineers develop new methods to increase yield or improve soil. Electrical engineers have

approaches to designing electricity generation, transmission, and distribution systems. Industrial engineers have methods for designing manufacturing systems. Environmental engineers have approaches to pollution remediation and management. Engineers of several disciplines are involved in the development of services (e.g., ones involving logistics) and creation of such services has a well-established methodology. A variety of engineers work on materials and methods for sustainable design.

### 4.7.3   Human-Centered Product Design

The PTD approach here is a type of human-centered design (IDEO, 2014, 2015) in that there is a central focus on meeting client needs, hopes, and aspirations (it is sometimes called "user-centered design"). Also, a "participatory" approach is inherently human centered as people from the community are to be involved in every step of the technology development, from needs/resources assessment, to "cooperative design" ("co-creation"), to helping run a manufacturing, sales, and distribution network for a technology if that is desired by the community.

Overall, the approach is human-centered and participatory in many ways, including for both the goals of engineering (participatory design and manufacturing) and business (participatory business model generation, financial management, business operations, marketing, sales, and dissemination). Approaches to product development cover everything from realizing that there is a market opportunity to delivery of the product to a customer. In the business approach to development, just like traditional product development in the developed world, the terms "market" and "customer" are natural to use. But, in all other approaches to development, such terms do not usually make sense. Hence, here we will use the term "community" rather than market, and if you are using a business approach the ideas directly translate to the market and marketing. Similarly, here we will use the term "client" rather than "customer" (or "consumer") so it is more generally applicable; however, all the ideas translate to the notion of customer. The essential "marketing" component (typically by business people) is not ignored, just re-framed. In your humanitarian project, you may ignore manufacturing, but here this important part of technology product development is included (in Section 4.10) in case you can work toward scaling up your product for wide dissemination and broader impact.

For the engineer already familiar with product development, you will see that there are many close connections between the PTD process and the *traditional* product development process in the developed world, so long as you are willing to think at an abstract level about the ways that the process proceeds. Many of the *ideas* in community development are already integrally embedded in the standard engineering product design development method. However, some ideas from technology development may not be explicitly identified in community development discussions by non-technical people, such as robustness of a solution (e.g., in a community, or community theory, people may simply say "we want it to work no matter what and for a long time"). Involvement of clients and a community may not be emphasized as much in traditional product develop-

ment since often such product development, or at least large parts of it, are done within the walls of a company. There are a number of other similarities and differences between the two approaches that will be detailed below.

## 4.7.4   Finding Opportunities in a Community

To start PTD, the participants (team of community members and engineers) should first evaluate community needs/challenges where there are opportunities for a project; usually the scope of the projects must, however, "match" team participant expertise.

### Finding Opportunities That Match Team Skills

An "opportunity," in this context, should be thought of as a broad class of needs or a general problem in the community (e.g., health or education), or an asset that your team can build on, though in some instances it may be a bit more specific (e.g., like a problem with contaminated water). The priorities of opportunities need to be assessed by the team. If you have in mind social business, "opportunity" may mean "market opportunity," that is, a chance to make money. In searching for opportunities in a community to promote change, to start, the proper attitude is to to try to specify many opportunities. Opportunities can be split into three situations, one where the team is familiar with the solution that is likely to be developed, another where the team is already familiar with the need that a solution is to address, and a third situation where the team is not familiar with the need or any solution method for it. Of course, it may be best if the team is familiar with both the need and solution methods, but may need a different approach due to different community conditions. Of course, uncertainty and risk of failure go up the less the team is familiar with needs and solutions to the needs. A completely novel situation for the team involves significant uncertainty and risk. Of course, risk can be quantified many ways, for instance in terms of not meeting performance specifications or product failure (for the physical device or in the market). Clearly, risk can give rise to important considerations of engineering ethics with respect to the safety, health, and welfare of the community.

> Matching opportunities to team skills can enhance chances of project success.

Typically, there is a whole set of opportunities that is generated, each that has a certain "value" (e.g., in terms of social or economic impact/return). It can be good to generate a wide variance in the type of the opportunities, as then there will be among the list ones of exceptional value and others that can be easily eliminated. Next, there is the problem of trying to decide which opportunity to select. Usually, it is good to think of the opportunities in the identified set as competing with each other in a "tournament" where scoring and winners are selected based on criteria in terms of values agreed upon by the team (the multicriteria decision making approach in Section 4.5.2 can be used). In searching for opportunities and down-selecting it is clear that the "degree of match" between team expertise and opportunities will play an important role. It may be that the community identifies the most important opportunity, the one

of highest value, but should the team try to address it, there might be significant uncertainty and risk since the team does not match well with the opportunity, and in this situation the team may select the second-best opportunity. Of course, there are other reasons to dismiss some opportunities such as lack of resources.

### Participatory Exploration of Opportunities

Steps for identifying project opportunities from (Ulrich and Eppinger, 2012) can be adapted to the PTD process. First, the PTD team must establish goals by trying to define the broad goal of the PTD process, whether it is to make money, try to meet the highest need of a community, or to focus only on one narrow set of topics, ones that may match the team's expertise as well as possible to community needs. Of course, if the PTD team defines goals too narrowly they may find no opportunities in a particular community; however, in many cases that simply means that you should consider other communities as opportunities and needs in the developing world are generally frequently occurring, deep, and broad. Regardless of how you define goals, it is useful to do so as it can narrow the search for opportunities, and later help select the best opportunities. It is often a good idea to generate many opportunities to take into consideration. There are several strategies you can use to generate these (see (Ulrich and Eppinger, 2012; IDEO, 2014, 2015)). First, you can "follow a personal passion," some technology or need that you are excited about. Second, you can compile a "bug-me list" of things that bother you or others (these are needs) by keeping lists or taking photos, and this list-making may be more effective if you immerse yourself in a community that has the need or similar technology you are interested in. Third, you can study your team's assets and use that to focus your search for opportunities. Fourth, you can study clients in a community (or communities) to understand needs, for example via surveys (this is called user anthropology (Chipchase and Steinhardt, 2013) or ethnography) as discussed in Section 4.4.3. The problem with surveys is that what people say on those can be quite different from how they behave in a natural setting. It is, therefore, good to observe clients behavior in the presence of needs or in community settings where the technology might be used. Clearly, the PAR approach can help significantly in this as if the clients, who are the users, are helping assess needs, then they are going to have better insight into what to look for and what to ask.

Exploration for opportunity discovery is the initial stage in PTD and it helps the team understand the community.

It is also good to consider trends. "Changes in technology, demography, or social norms often create innovation opportunities" (Ulrich and Eppinger, 2012), including in advances in humanitarian technology. The implications of each of these should be considered in turn with respect to your community. For instance, the fast diffusion of cell phone technology has a wide array of humanitarian technology implications (e.g., health, education, and financial services can "piggy-backed" onto the phone). Also, if there is a very successful technological innovation, then it may be good to reconsider if it is possible to improve it via modifications to better meet needs it was designed for, or meet new needs not considered before. In some cases, you may see that it is better to have a

more deluxe version, such as one with additional features, provided this does not adversely affect cost, operation, and maintenance factors. Or, in some cases it may be good to simplify a technology so that it is more affordable and this may imply a significant redesign requiring fewer features and balancing of trade-offs with respect to clients that are satisfied with a simpler product. Still other times, it may be good to study solutions in other communities (or countries) and use them in your community, with any needed changes.

The team should carefully consider all sources of information. There are often "lead users" (ones who identify a need long before the average member of a community) or "extreme users" (clients who use a technology product in unusual ways or have extraordinary needs, for instance, due to disabilities) in a community who have advanced needs, more than the typical person states, that are unmet and such persons must tolerate this or they innovate on their own. Such persons should be listened to as they may show the trend of needs in a community, and they may have highly innovative, low-cost, and useful solutions already that should not be discounted (e.g., since they did not come from the degreed engineers on the team); their solutions may be sufficient as is, or may need modifying and improving that the team can take on. Having a lead user in a community "lead" so that the source of the solution came from the community, and everyone in the community knows it, can be highly empowering for the community. Next, either natural social networks may provide useful sources of information on needs or trends. Finally, the existing technologies that are described in "the literature" certainly should be considered. You do not want to "re-invent the wheel." There are many good sources, and people often start with searching the internet, but then are often led to authoritative sources like conferences, journals, or companies or organizations that are trying to meet similar needs with similar solutions. This is discussed more starting on page 718 for wide array of humanitarian technologies.

Usually, to start, the team does not want to select only one opportunity, but a few of the best. Sometimes, community surveys or "multi-voting" (asking a group to vote on what are the best approaches, for example, in rank order, then aggregating the results using, e.g., the methods in Section 4.5.2) are used to select opportunities. Of course, persons on the team should consider the "value" of each opportunity to the community, the degree of match with team expertise, resource availability, feasibility, and other issues. In any case, it is important to reach out to the broader community to get their inputs. After selecting, more PAR should be done on solutions to the problem, and there should at least be some conversations with a few members of the community to discuss the choice. The goal is to reduce the uncertainty surrounding each opportunity with respect to cost in time and money. The team should reduce the set of opportunities by selecting the ones that are the "best," however that is defined by the participants. The PTD team may, at this point, still end up picking more than one opportunity. Finally, the team should think through the whole process of finding opportunities to make sure the methodology was good, nothing of great significance was missed, and that your community is excited about addressing the chosen opportunities.

There may be many different client needs and assets (see below) for any one opportunity in a community, and there may be many technology product solutions for any one client need (see concept generation below).

## 4.7.5 Flexible Planning for Participatory Technology Development

The technology "product plan" considers the set of technologies to be developed, and schedules these for introduction into the community by the participants. It considers the development of technologies for the set of opportunities found in the last section, and considering ideas from the team and history of the community's project activities, if applicable. There are a number of different types of PTD projects including "new product platforms" (a base or starting point for successive addition or modification of technologies), modifications to existing product platforms, incremental improvements to existing technologies that the team has produced, and completely new products coming from newly identified needs, scientific and technological advances, or acquisition of new team expertise. The product plan specifies what the participants should do and when they should do it, taking into consideration not only urgency of meeting high priority community needs, but also resource availability, and team time constraints (e.g., how long the engineers can visit). See Section 4.3.3, and also Section 4.2.10.

Planning in PTD must be very flexible as community dynamics and uncertainties make steps of a project highly unpredictable with respect to timing and outcomes.

Considering the dynamic and uncertain nature of PTD, often driven by social issues, but at other times by supply-chain problems, the team must: (i) develop a very flexible plan that expects things to go wrong and community dynamics to affect the process, and (ii) not try to plan every step out as if the PTD process will be deterministic and meet all deadlines (recall Figure 4.2 and the surrounding discussion). Often, there has to be a spirit of "learning as you go" or "learning by doing" that represents a flexible and adaptive approach that results in what could be called "engineering with finesse." With these issues in mind, the process for PTD planning, using ideas from (Ulrich and Eppinger, 2012), involves a number of steps. First, the team needs to pick opportunities for technology development. Using the last section, the PTD team needs to choose the type of product to be developed considering community desires, team expertise, and other resources. Next, the team needs to evaluate and prioritize projects. The most promising projects must be chosen by the community per the community assessment process Section 4.4.

Criteria for prioritizing projects for the PTD team include include a number of aspects. Sometimes a competitive strategy and segmentation must be considered. The level of importance of these depends on whether you are using a business approach to development. Then, the true market must be considered and you may choose projects that you are most competitive on (e.g., due to technology, cost, consumer focus, or imitative ability) in order to position yourself, or the community in participatory social business (see Section 4.10.3), to make money. In very competitive situations, the market is often "segmented" and you have to find your "market niche" in order to make money. With such

an approach, it must be acknowledged that you may both limit the type of community you work with, and sacrifice meeting needs of the community in your quest to work on projects that will make the most money. On the other hand, if you are not considering making money, you may still want to imagine a competition to ensure you feel pressure to develop the best possible product (e.g., via a client-centered orientation), and you can keep the priority of meeting the crucial community needs as top priority. If you are only focusing on one community, you have the significant advantage of being able to tailor a project specifically to the needs of that community, and not worry about whether the product is tailored to other communities; the downside, however, is that the solution you developed may not be easy to extend to other communities ("scale up," as discussed in Section 4.10).

Next, consideration should be given to technology trajectories and new technologies. New technologies (possibly your whole product or pieces or it) have a certain rate of adoption and incorporation into a product and rate of improvement of performance (e.g., as measured by speed or reliability) that typically follows the shape of an "s-curve" (with time on the horizontal and a performance measure on the vertical): initially performance may be relatively low, but it typically improves over time until performance "saturates" when it is "mature." The problem is that this curve is not known, changes dynamically, and hence you do not know how the curve will change in the future. However, important lessons can be learned from the recognition of the presence of the s-curve, such as if there is much excitement about a new humanitarian technology but it is early, an objective analysis may uncover that it is relatively low-performing and unreliable at its current stage of development and it may be unwise to pursue its use or deployment in a community as it will not provide robust operation, easy operation and maintenance, and long-term success.

Next, the team needs to allocate resources and develop a flexible schedule. Resources must be allocated to chosen PTD projects, including people, talents/skills, leadership abilities, time, money, materials, etc. and must be flexibly scheduled. Scheduling may be impacted by the urgency level of community needs. It may be good to work with the community to create a "mission statement" that provides a vision statement of the technology product to be developed that includes a brief description of the product, a brief statement of the target community, how it will meet community needs, envisioned performance levels, assumptions and constraints the drive the development (e.g., manufacturing or the environment), goals like the amount of time and cost it should take to develop the technology, and a list of the people affected by the technology's success or failure ("stakeholders"). Of course, such a mission statement should not be developed only by outsiders.

Finally, the PTD team should reflect on planning process and results, taking into account community desires and input, and make sure the plan makes sense in light of all the constraints. Frequently, re-evaluation by the team can result in "tweaking" the plan, or sometimes completely modifying it (e.g., based on failures of parts of the plan), to get important improvements. No one on the team should have the arrogance to think they can develop a rigid and perfect

plan for PTD for a community. A plan is needed, but a flexible one that respects realities on the ground.

## 4.7.6 Coupling Community Needs, Resources, and Aspirations to Technologies

This issue has been discussed earlier (e.g., for PAR in Section 4.2.8 and in Section 4.4), but here it will be reconsidered for the PTD process. As in the PAR section, the influence diagrams from Section 1.6.1, as explained in Section 4.4, can be useful in PTD for visualizing relationships, and as a tool to facilitate group discussions on issues discussed in this section.

In translating client needs, hopes, and aspirations into technology concepts (candidate solutions), it may be useful to think of the process as "empathic design" (IDEO, 2014, 2015), where via deep empathy with individual clients and a community you have formed relationships with, you have compassion, and a passion to create a particularly useful technology concept. This idea is closely related to the use of empathy in helping address a client's problem (see Section 4.1.2).

### Steps to Identify Needs-Technology Combinations

You must make sure that a technology product is developed to meet client and community needs, hopes, and aspirations, and, using ideas in (Ulrich and Eppinger, 2012; IDEO, 2014, 2015), this involves a number of steps. First, the team must gather data/information from clients in the community per Section 4.4. Recall that there are a number of ways to get information on client needs directly from clients, and that may involve PAR, including: (i) interviews of client's in the community that are "in context" (i.e., at their home, work, or somewhere within the community) and well-planned with a list of questions prepared to provide a "semi-structured" interview (but do "go with the flow" and let the interviewee control to some extent how the conversation goes); (ii) focus groups ("group interviews") run by a moderator/interviewer, perhaps a community participant, with a group of around 10 community members (representing a diversity of the community including men and women, and not just community leaders who are "power centers") where there is a set of questions and discussion points prepared a priori, but also open discussion and brainstorming about needs; and (iii) observing a technology in use in the community involving the team or an individual engineer working alongside a community participant within the community, using a technology, or explaining via a demonstration a need. It can be difficult to know how many clients need to be interviewed and for how long. In (Ulrich and Eppinger, 2012) the authors indicate that 25 hours of interview and focus groups often reveals enough about needs, and that talking to 10 persons is not enough, but that talking to more than 50 people is probably too many (these numbers are for only one "segment" or one community). You may be able to more effectively identify needs via "lead users" or "extreme users" (see above). Needs arising from such people may be "latent" or

PAR is a crucial part of PTD, and for technologies the team must also think about pairing needs with candidate technological solutions.

"unanticipated" or "undiscovered" needs of the typical population: designing to meet such needs may be quite welcome in a broader community. Overall, you should think carefully about how to best get information on client needs. You should be receptive to information. You want an honest explanation of needs, not one where you try to convince the client about what they need; you may suggest that you have a technological solution for a need, but if they are not enthusiastic about that, drop it. Information is usefully gathered via verbal discussions, via a question-answer format, and you likely want to have a prepared interview that asks:

- When and why do you use this type of technology?;

- What is a typical use scenario?;

- What do you like or dislike about a current technology approach (if one exists)?;

- What drives your decision to adopt (or purchase) such a technology?; and

- What improvements would you suggest to the technology?

In such a discussion, you should allow flexibility, and "go with the flow," perhaps use visuals/props (e.g., showing an existing technology), avoid expressing your own preconceived hypotheses about the technology product, let the customer demonstrate a related technology for some task, be aware of the possibility of "surprises" and statements of "latent needs," and watch for the client's non-verbal communications (e.g., to determine enthusiasm as a measure of priority in addressing a need). If possible, and acceptable to clients, it may be useful to document discussions with clients via audio/video recordings, handwritten notes, typing into a word processor on a laptop, or via photos (e.g., with a phone). Alternatively, you could give community participants cameras, journals, and questions and ask them to record their activities over a period of time, in particular, with respect to some opportunity/need (this is called "self-documentation").

After gathering the information about client/community needs and challenges, the team needs to interpret it as a group. The information must be carefully analyzed to uncover useful needs information (see Section 4.4.4). This involves expressing the needs in terms of what the technology product has to do and/or attributes of the product. The team should not misinterpret needs in terms of their importance; everyone on the team must honestly listen to what the clients are saying and use it to constrain what the product should be. It can be useful to create, from the diverse gathered information, a hierarchy of needs. To do this, the team would split the needs identified by clients into "primary needs" (most general needs, that lead to a class of technologies) each of which has a set of "secondary needs" and in some cases, tertiary needs. Secondary needs are special cases of each primary need (e.g., a specific functionality of a technology in the class of technologies). Then, the PTD team should determine the relative importance of needs as this will heavily influence the design of a

technology product, and will show how to manage constraints and trade-offs in terms of what the community wants and not some other arbitrary criteria. Constraints must fit context. Determining the relative importance of needs can be done via the team and entire community, perhaps even with more interviews and information gathering (or perhaps it could be collected initially as discussed in Section 4.4). Finally, the team should reflect on the entire client needs identification process, reconsider if the PTD team's conclusions are valid, and may even want to consider a team review with the broader community.

The assessment of opportunities in a community, together with the assessment of client needs, defines "desirability" of a technology solution (IDEO, 2014, 2015) and are crucial to guide a human-centered design and PTD process. A proper assessment of needs will help eliminate from consideration technologies that will not be easily accepted for cultural reasons, or for other reasons that result in the technology in the trash or as litter in the surrounding landscape.

### Can Outsiders Suggest Technologies? Only if the Community Strongly Affirms an Underlying Need

While PTD should be always driven by identified client/community needs, hopes, and aspirations, at the risk of being "paternalistic," there may be special times when an outside engineer may be able to suggest technology solutions to what they assume is a need. So long as the community then clearly and *strongly affirms* a need that would drive the development for such a technology, it may be acceptable to pursue such a technology development project. Keep in mind that by suggesting a technology solution you are presumptively also suggesting a need; the only way this can be acceptable is if the community strongly and unambiguously affirms the underlying need and buys into the whole corresponding technology development process.

The following lists some times where it may be appropriate to suggest a technology to a community, times where the engineer can help identify feasible solutions to needs also:

1. *Well-proven technology solutions found highly useful in other communities:* There are certain technologies that have been found to be useful in many communities, perhaps in other countries, for both economic and social reasons and that could correspond to needs the community is not thinking about. Sometimes, under the right conditions, it is possible for highly effective solutions to be "transferred" to other communities.

2. *Needs that the client might not identify as they see no solution:* Sometimes, needs may not be articulated as the client might think that there is no way to meet the need. A simple question from an experienced interviewer may uncover such a need and this may be affirmed by the client and broader community. Sometimes, an engineer may be driven to ask about such a need as they may have in mind a "toolkit" of feasible technology solutions for meeting the suggested need.

Engineers are professionally bound to suggest needs-solutions ideas, however this must be done with sensitivity.

3. *Chains of enabling technology:* Sometimes, a client may not identify a need as they believe that the underlying conditions that need to be met in order to fulfill that need do not exist, or are impossible to meet. For instance, a good example here might be a cell phone. They might not have electricity so they might not think a cell phone is possible and hence not bring up the value of communication; however, your team might be able to also provide an off-grid inexpensive electricity generation solution (e.g., via a bicycle-driven generator) that would enable such a technology, assuming a cell tower is close enough. It may be difficult for a client to understand such "chains" of enabling technologies. Your team may have nothing to do with putting cell phones in place (that might be done by a local company who also handles subscriptions/plans); however, you may provide the key enabling technology solution that allows a community to use a new technology and hence meet important needs.

4. *Technology solutions that you think are tangible and feasible, and match identified needs, but ones that may be lower priority:* If due to resources (team expertise, time, money) all that can be achieved is a lower-priority need, then it may be best to pursue it. In such situations, however, you may want to admit that your team skills are not a good match for the community.

The whole idea of suggesting technologies, and thereby needs, can be tricky. It can correspond to "technology push" rather than "pull" and "supply rather than demand." On the one hand, you must be quiet and carefully listen to the client and community. On the other hand, you have a professional engineering responsibility, and special technical knowledge, to bring to bear on issues. It is difficult to balance these two.

It should be acknowledged at the outset that it is clearly dangerous to suggest a technology solution as you are then also suggesting (from the outside) that you know what the client's or community's needs are: remember they are the experts on their issues, not you. That is a fundamental principle. They know what is culturally acceptable and what will work. They know what they are willing to work on with you; they should not feel even slightly "encouraged" (and certainly not "coerced" or "forced") to work on something, for example, just to be polite to you (if proper relationships are formed, this is a real concern–they may just be trying to be nice, and/or take whatever they can get). You have to be careful to recognize how they view you as an outsider: if you are viewed as someone from a high-tech developed country, they may have a tendency (too strong of one) to listen to what you are saying. You have to be sensitive, and realize that the community may accept something you want to do for now, simply with the view that you may later do something really useful for them (they may view what you want to do as an "investment" in the relationship so that it can be really productive for them in the future). True participation will not work under conditions where there is not a clear, honest, and authentic "shared interest." They know when and how much they will participate in PTD (e.g., giving their own time, hard work, or money). They know what they can take ownership

of and maintain to ensure long-term success. It is their hopes and aspirations you are trying to work with, not yours (e.g., wanting to do some project just see if you can rise to the technical challenge and succeed). It is the community you are trying to empower, not only you. This whole endeavor is about them, not you, even though you are likely to get a lot out of doing humanitarian engineering with a community (e.g., valuable knowledge about cross-cultural engineering and learning about user-driven technology development that can later significantly impact your own career and financial success, for example, in the developed world).

History is littered with examples of outsiders suggesting a need and then providing a solution to address it that then results in failure. If you feel some slight discomfort in making a suggestion on a technology solution, then it is unwise to do so. You have to go with the flow of conversations with clients and community group meetings.

### 4.7.7   Humanitarian Technology Product Specifications

Specifications (sometimes called "requirements," "technical specifications," or "performance standards") define what a technology product has to do and involve a number of issues (Ulrich and Eppinger, 2012). The team should agree on a list of metrics to measure the extent to which the technology meets client needs. In fact, the team must translate community needs into a set of (easily) measurable metrics that are  specifications such that if they design the technology to meet the specifications they will have met needs. The metric or metrics must be "complete" in the sense that they measure the extent to which all needs are met that are being addressed. The numeric values of metrics are dependent on aspects of the technology design (e.g., weight, cost, and functionality); however, some needs are difficult or impossible to translate into metrics (e.g., aesthetics). When there is more than one metric you may need to define "importance ratings" for each metric, or use an additive weighted measure of different metrics to obtain a single overall metric, analogous to how it was done in the multicriteria decision method in Section 4.5.2. Often, it is useful to compare the specifications and metrics to other similar humanitarian technologies to gain a sense of what is achievable and to identify the advantages and disadvantages of a solution (see references starting on page 718 for potential benchmarks). The team should seek to define ideal and minimally acceptable target values (and sometimes exact values or ranges of values) for metrics as this will give an idea of what is acceptable in terms of meeting community needs, and at the same time permit flexibility in the design process to trade-off aspects of choices according community needs (i.e., acceptable trade-offs as specified by the community). Finally, the team should reflect on the specification process and results by reviewing the specifications developed, how they were developed, and whether any revisions are needed to make sure that the specifications are properly tailored to the community.

Next, the final specifications need to be developed (Ulrich and Eppinger, 2012). This involves a number of tasks, including the development of technical

Specifications, quantified with metrics, measure how well a technological solution will meet needs.

models of a product that are physical approximations of the product, or analytical ones (e.g., mathematical or computational) and these are used to predict the values of the metrics for various design choices. Sometimes, it is much less expensive to use an analytical/computational approach, but in some situations, for a more realistic approach, it is essential to build multiple physical models, ones that adequately sample the "design space" (that is, the range of all design choices and parameters). Next, a cost model should be developed to try to gain confidence that you can develop your product at some target cost (target value of a cost metric, or "cost performance"). Costs also include manufacturing and materials (which you likely will want to be able to obtain *locally* to keep costs down, to ensure locals are used to working with the parts, and to make the maintenance strategy easier as, if parts need to be replaced for repairs, then they are easily accessible and hopefully at a low cost), and can simply be ranges of costs at an early point in design. Specifications may be refined by making trade-offs, and the team should find feasible combinations of design choices by using technical and cost models and "trading-off" one metric value with another (often increasing one metric results in a decrease in another–for example, driving cost down may decrease reliability or increase pollution). This will allow the team to settle on a final set of specifications that best meets client needs and the desires of the community. Sometimes, the team must take the metrics and specify how subsystems (pieces) of the technology must perform to ensure that the metric target values are achieved. Finally, the team should reflect on final specification development process and results by reviewing the process and results to ensure that a quality approach was used, one that used sufficiently accurate technical and cost models, so that appropriate conclusions are drawn about final specifications. Sometimes, at this point the team may want go to he broader community, or consult others, to ensure that good community-driven specifications are being used.

### 4.7.8 Participatory Concept Generation, Selection, and Testing

A technology product concept is "an approximate description of the technology, working principles, and form of the product" (Ulrich and Eppinger, 2012). It should describe how the concept meets client needs and may simply be based on a sketch or rough physical model.

**Strategies for Participatory Concept Generation**

In (Ulrich and Eppinger, 2012) the authors advocate a systematic procedure for concept generation that here is augmented with some ideas from (IDEO, 2014, 2015) and the participatory development process in Section 4.2. First, it is important to clarify the problem that the team is addressing. Often, in engineering problem solving, it is wise to make sure you have a very good understanding of the problem at hand that is intimately connected to community needs. Sometimes, perfecting a problem definition is very hard work. Providing a top-quality

solution to the right problem is the goal; clearly, providing a great solution to the wrong problem (or slightly wrong problem) is clearly unproductive, not to mention embarrassing. Often, a problem definition is improved by breaking the problem up (decomposing) into smaller sub-problems ("divide and conquer"). Such a decomposition may proceed by splitting the problem up according to different community needs, or the sequence of actions the community members take in using the technology. It often makes sense to start work on the most difficult sub-problems as they drive the overall process.

The team itself should work together on concept generation by exploiting their various skills and assets, and via open, non-critical, brainstorming as a group. For such brainstorming, team members should not be highly judgmental as ideas are proposed (or this will make members hesitant to suggest anything), many ideas should be generated (even ones that seem infeasible), and it may be useful to facilitate brainstorming with "collaborative brainstorming" on a white (or chalk) board, large piece of paper, or screen. Sometimes, individual brainstorming and group brainstorming can be useful, for instance in sequence. Generating new ideas is facilitated by making analogies, expressing wishes, or wondering if something is possible. It is also important to look to other sources for concepts. For instance, the team should look to all possible sources that can be imagined to generate technology concepts, including talking to "lead" or "extreme" users from the community, consulting experts in humanitarian technology, searching the open literature, often via on-line methods, and also consider benchmarking against comparable products. See material starting on page 718 for more details on how to use the open literature and a variety of sources on humanitarian technology. The team should systematically search for concepts for a technology and this may generate many possibilities, and it can be useful to classify the different concepts (e.g., in a "tree" or "table"), then the team should seek to eliminate less promising concepts, and identify approaches to the problem that are independent of each other. Finally, the team should reflect on the concept generation process and results. They should reconsider the entire process, its quality, and the results to ensure that the concepts are consistent with community needs and fit specifications.

> Open, non-critical, team brainstorming helps generate creative and properly tailored technology solutions for a community.

### Strategies for Participatory Concept Selection Testing

The team needs to select a concept according to community needs, and other criteria (e.g., available resources), and by comparing advantages and disadvantages of the various concepts. The concept could be chosen by an external person, an influential member of the team, by intuition, by multi-voting by the whole team, by a survey (e.g., to the community), via a list of pros and cons of each concept, via evaluation of prototypes, or by rating each concept (with weights on each feature, and a high importance typically given to cost). As specific individuals can become invested in various concepts, especially ones they developed or champion, the selection process can be emotional; hence, it is best to use an agreed-upon structured selection process that takes subjectivity out of the selection process. Such a process should be community-focused (to

make sure needs are met to the greatest extent possible), concepts should be thought of as competing against each other, criteria of ease of manufacturing and sustainability should be included in some cases, the amount of time to completion of the PTD should be considered, and as it occurs the process should be documented.

The approach to concept selection in (Ulrich and Eppinger, 2012) is based on "concept screening" and then "concept scoring" that is a special case of multicriteria decision making in Section 4.5.2. Concept screening seeks to narrow the number of concepts and simultaneously improve them. First, a "selection matrix" is constructed with rows that are selection criteria and columns that are the concepts. The body of the table is filled in with a rough rating of each concept against each criterion (e.g., $+1, 0, -1$ for good, neutral, and bad). Sometimes those ratings are given with respect to a "reference concept" (a base-line) so that they mean "better, same, or worse." Next, the ratings are aggregated for each concept. Then, based on the aggregate scores, concepts to be considered further are chosen. Sometimes, in this process, it becomes clear how to combine concepts. Concept scoring is used for a higher-resolution differentiation among concepts. Usually, a reference concept is chosen and relatively fine-grained numeric ratings relative to the concept are specified. Often, to aggregate the ratings for each concept, a weighted average of the ratings for each selection criterion is used, with "weights" being positive numbers with magnitudes reflecting the importance of meeting each selection criterion as selected by the team. Sometimes, in scoring it becomes clear how to combine concepts, but the objective is to select one or more concepts for further study. As always, at the end of the scoring process the team should reflect on both the process and results. The robust selection methods in Section 4.5.2 can be especially useful in evaluating and selecting the best concept as at the concept stage there is typically significant uncertainty in product features and performance. Sometimes, parts of the above selection process do not work very well. For instance, if the product selection criteria cannot be "decomposed" into logical pieces. Or, sometimes, there are important subjective criteria, ones that cannot be quantified numerically (e.g., some types of social effects, like how a technology installed in a community might promote the dominance hierarchy or marginalize people). Sometimes, it may make sense to consider concept selection to be an activity that occurs throughout the entire PTD process. At the completion of this concept screening process, the team should reflect on the process and results to make sure it was effective.

After down-selecting, the chosen concepts need to be tested. Either a product description (written, audio, video, photos, via simulations) or a prototype of the technology is constructed. Then, multiple copies are used by members of the community and they answer questions about the technology (e.g., a survey), including rating how well they like it (and if appropriate, whether they would buy it). The results are evaluated and then the team reflects on the testing process.

*It can be useful to try to quantify the quality of technology concepts in order for the team to evaluate competing approaches.*

*Modularity eases deployment challenges by facilitating a staged deployment.*

**Architectural and User Issues**

In the above process, it is also important to consider product architecture and usability. A technological product has function (operations and transformations) and physical pieces (parts or components) that implement those functions. The architecture is the approach to arranging functional elements into physical pieces and the way pieces interact. In a modular architecture, physical pieces may implement one or a few functional elements, and interactions between physical pieces are well-defined and basic to the main functions of the product. In contrast, in an integral architecture functional elements are implemented across multiple physical parts, one physical part may implement several functional elements, and interactions between physical pieces may not be well-defined. Sometimes, modular designs are preferred since it may be easier to change the product by replacing a module without possibly influencing other parts (e.g., for an upgrade, add-on, adaptation, or replacement due to wear). Sometimes, modularity also allows for more product variety (flexibility). Choice of architecture may affect manufacturability (e.g., modularity may help as modules can be constructed then assembled to obtain the whole). Modularity may also make it easier to use multiple suppliers to provide the various modules, then the modules could be integrated later. Moreover, modular humanitarian technologies may have the attractive feature of being easily expandable, where part of the technology can be purchased at one time and benefits received, then later an additional part can be purchased and additional benefits can be gained. This may fit the earning pattern of a low-income person (e.g., day laborer with periodic work).

"Industrial design" for a product focuses on usability (human interface, safety, ease of use, intuitive use, and ease of maintenance), appearance (e.g., form and color), and low cost. The team will have to assess the importance of industrial design to justify its costs, but clearly many of these issues can strongly affect the success of a humanitarian technology in a community. For instance, if the human interface is poor and the product is difficult to use it may fail, simply because it is not used. Lack of safety for a design raises ethical issues discussed in Section 2.3.3. Of course, ease and cost of making repairs for maintenance are crucial issues for long-term success in a community.

*Ease of use and maintenance can drive a technologies success or failure.*

## 4.7.9 Engineering Design for Environmental Sustainability

The objective of "design for environment" is to create products that minimize adverse impacts on the environment to create a more sustainable community. For background on pollution causes and effects, and the context for sustainable development, see Section 1.3. As discussed in Section 1.3, environmental impacts including global warming, resource depletion, solid waste, water/air/land pollution, adverse impacts to biodiversity, and ozone depletion. These impacts result in adverse human health impacts and ecosystem harm.

Often, it is actually possible to maintain or improve product quality and cost

and *simultaneously* reduce environmental impacts (e.g., energy consumption, natural resource depletion, liquid discharges, gas emissions, and solid waste). Strategies to do this include  using renewable energy, and choosing the right materials (often, ones available locally rather than ones available from distant places) so that they can be more easily recycled in the local environment. Usually, the environment should be taken into consideration *very early* in the design process (before concept generation) so that the product is inherently eco-friendly, and not later modified to try to be eco-friendly as that can result in less-than-desirable results.

There are two "life cycles" that are relevant to sustainable design. First, there is the life cycle of technology: use of materials for construction (resource depletion) and manufacturing/production (with pollution and possible recycling), product distribution and use (with pollution), end of product life (recycling and pollution), recovery (and re-use), and repetition of this cycle. Second, there is a related cycle in the environment: nonrenewable and renewable resources used in product materials and production, inorganic, organic, and toxic pollution from recovery/end of product life that causes deposits, some of which may naturally decay (be absorbed by the environment), that affects resources that then affect what is available for materials for products.

There are three challenges that arise out of the intimate connection between the two cycles: (i) the PTD team should try to eliminate use of nonrenewable natural resources; (ii) the team should try to eliminate disposal of synthetic and inorganic materials that do not decay fast; and (iii) the team should try to eliminate making toxic waste that is not part of natural environmental life cycles. All products pollute in some way, for instance, via their construction; but pollution should be minimized.

Design for environment is an integral part of the PTD process that sets additional constraints (Ulrich and Eppinger, 2012) on how community needs should be met.   To start, it is best to first have the team articulate the rationale for being concerned about environmental impacts.  The rationale may be driven by internal reasons: avoiding adverse impacts to health, creating an unpleasant and unsightly community, raising product quality, reducing cost, help operational safety. "External" reasons may include: meeting environmental laws now and in the future, demand for eco-friendly products, meeting competition in this arena, encouragement from trade organizations, suppliers may be moving in this direction, and social pressures. Once a rationale is established, design for environment goals need to be established. These are usually stated in terms of reducing environmental impact relative to current practice, hitting target values for reduced environmental impact, or having no impact along some dimensions for a new product. For the team that works on design for the environment, you may need an environmental chemist, materials expert, supply chain experts, sustainable manufacturing experts, etc.

In the entire product life cycle, from use of materials, production, distribution, use, and recovery, the impacts on all aspects of the environment should be identified and quantified. The PTD team needs to establish guidelines for the product development life cycle, taking into consideration environmental impacts

*Every PTD project must take into account the possibility of creating adverse impacts on the environment.*

*Sustainable engineering design is a process for taking into account the environment in technology product development.*

in the entire product life cycle. These guidelines must be used throughout the PTD process, including for concept generation, selection, and testing. Prototypes can also be used to study environmental impact. For the chosen design, the PTD team should assess the impact on all aspects of the environment for all aspects of product development and life cycle and assess if environmental impact goals are being met. Such an assessment may indicate a need to redesign in order to reduce environmental impact and may require reconsideration of other technologies.

The team and community should be intimately involved in all these steps, providing feedback, ideas for use of local resources, ideas for ways to reduce impact on their local environment, and assistance in identifying and balancing trade-offs with respect to product design and development and impact on the local environment. Finally, the PTD team should reflect on the design for environment process and results and reconsider the entire process to make sure that it was a good and effective methodology, and that goals were reached.

## 4.7.10  Prototypes, Robustness, and Everything Else

There are both physical prototypes (i.e., a physical approximation to the envisioned product) and analytical prototypes (a computer simulation or mathematical representation), and mixes of the two (e.g., in "hardware in the loop" simulation where part of the product is a computer simulation and it is interfaced via data acquisition to a physical part of the product).    Analytical prototypes are generally more flexible than physical ones (e.g., for evaluating design options), but physical prototypes may uncover unexpected phenomena. Sometimes, only parts of a product are prototyped. Prototypes are useful for learning (e.g., if the product will function and meet client needs), concept generation and redesign ("design tweaking" or "tinkering"), communication (e.g., to demonstrate to members of the community or team), making sure integration of components is possible, and showing progress toward finalizing product development. Sometimes, prototypes can reduce costly design iterations (e.g., making sure the product design is correct before it goes to manufacturing) and expedite some development steps.  Sometimes, a number of prototypes that are very similar to the envisioned product are designed and released to a small group of people in the community to use (i.e., a "pilot" or "beta test"): this can provide valuable information for redesign to meet client needs and uncover problems early before significant investments are made for the final products, or manufacturing.

Robust  design tries to ensure that a product will perform under non-ideal conditions (e.g., in presence of manufacturing differences, noise, disturbances, component variations, harsh environmental conditions, or rough use by the client). Often, there is a configuration of the product "parameters" (component characteristics, software parameters and design, etc.)  that is considered an "optimal robust design." This optimal design is a setting of parameters so that the product is not sensitive to unknown conditions (e.g., the ones listed above). A robust design approach can use an experimental (e.g., via a physi-

*Prototypes contribute to team learning, product redesign, and initial community testing.*

*Product robustness ensures reliability.*

cal prototype) or analytical approach (e.g., via mathematical or computational analysis) to determine the best setting of parameters. In one approach, the parameters that can be adjusted are identified, noise influences identified, and performance metrics defined (representing what would be good product performance). An "objective function" is defined in terms of performance metrics, then parameters are adjusted experimentally or analytically depending on the approach used. Parameters are adjusted to optimize (e.g., maximize) the objective function (and thereby some combination of performance metrics) in spite of the presence of noise, by adjusting parameter values. Often, the process involves choosing parameters to maximize mean values of the objective function and simultaneously minimize the variance of the objective function (to get a lack of sensitivity to noise and maximum performance).

Many other issues can arise in the PTD process sometimes these are called "design for X" (Ulrich and Eppinger, 2012) or "design for everything else," which highlights that there are many other characteristics that the team may want to design into the product based on community needs. These can include design for ease of use (e.g., "human factors" issues that arise in humans interfacing with technologies sometimes called "person-machine interface"), sometimes called "usability" that sometimes includes flexibility of use, and design for ease of understanding, or "understandabiity." It can also include design for maintainability (ease of service), as discussed at several points above, and design for expandability (either by later additions to the technology or for later versions), perhaps by using modularity. It may also be important to design for ease of distribution and sales. When it comes to social business, it can be important to design for popularity of the product or so it is "aspirational." A particularly challenging issue can be "design for culture," "design for social constraints," or "design for social justice" discussed in Section 4.5.1. These issues are only representative design objectives, and more design objectives may arise. If one of these objectives dominates your design process, then clearly you will want to look for a good source in the literature or on-line.

## 4.7.11   Economics and Project Management

Decision-making during the PTD process typically needs to be supported by economic analysis, both quantitative and qualitative.   Decision making may involve determining whether or not to even design a product to try to meet some need, and also at the various decision points throughout the rest of the process (e.g., concept generation, selection, and testing) to infuse cost considerations into development. In a social business approach, cash inflows (revenues) may come from donations, aid, and possibly product sales, and cash outflows (costs) occur due to product and process development, materials, components, labor, and possibly manufacturing and marketing. The net present value (NPV) (Ulrich and Eppinger, 2012) is the amount by which inflows exceed outflows and this takes into consideration past and expected future cash flows. If you are in social business, you want more inflow than outflow, at least by some margin. A numerical analysis of cash flows is a quantitative economic analysis. Sometimes,

Economic analysis of a PTD project must include both quantitive and qualitative approaches.

however, only a qualitative economic analysis is possible as parts of cash flows are not known (due to unknown aspects of a market, or if you are at an early stage of product development). In (Ulrich and Eppinger, 2012), the authors advocate a systematic process of economic analysis. First, they say to establish a base-case financial model. For this, start by estimating the timing and size of inflows and outflows, considering product development costs, "ramp-up" costs, marketing and support costs, manufacturing costs, and sales revenues.

I have heard of a case in the developing world where an engineering student in a university had a professor checking his design and budget and criticized him for not including the costs of bribes that were necessary in order to achieve product success (see Section 2.3.3). Similar "corruption" issues arise everywhere in various forms, and can come, for instance, with technology suppliers bribing (to some extent) a technology integrator so that the engineer at the integrator company chooses their component. Generally, such problems either drive product cost up, or its quality down, or both. Regardless, it is very difficult to understand costs like this without understanding the local community.

Next, the NPV is determined, and the team performs a sensitivity analysis by "perturbing" values (e.g., costs or revenues) in the financial model (e.g., in a spreadsheet) and determining how such perturbations change NPV. This may perturb not only aspects of cash flows, but also time. Then, sensitivity analysis is used to understand trade-offs. Community-generated trade-offs typically include cost and quality of performance or features. Hence, the sensitivity analysis may be useful in understanding the impact of cashflow changes on NPV and the extent to which community needs are met. Next, qualitative factors must be considered. There may be aspects of community needs that are difficult to quantify (e.g., empowerment, oppression, or discrimination) but that are crucial in the overall PTD. These must be carefully weighed; it should never be the case that the community is reduced only to numbers in a spreadsheet; such an approach could never result in successful community development. You should view the spreadsheet as only something that helps (informs) part of your thinking; you must confront what are often the more difficult issues which are the qualitative aspects of economic analysis. Accept and confront the complexity rather than demanding that everything reduces to numbers, histograms, and graphs.

Project management is an essential part to an effective PTD, and it has been discussed above several times (e.g., Section 4.3.3), where there has been an emphasis on a flexible planning approach. Here, participatory project management principles are briefly discussed, where the low-level details of planning are considered. That is, planning according to the ideas below is set in the context of (is a subset of) an overall flexible participatory development plan via Section 4.3.3. Planning here is *not* meant to be a rigid all-encompassing plan for PTD. For planning here, the individual or individuals that manage the project should be from the community, or the project at least should be co-led by an engineer and a community member. Also, to the greatest extent possible, the entire team and community should give inputs to project management.

Central to project management are tasks. There are sequential tasks (ones

that must follow one another), parallel tasks (ones that can be performed simultaneously), and coupled tasks (ones that influence each other). To determine how to order (schedule over time) tasks for a project, a common tool is a "Gantt Chart" which simply lists on the left column the tasks, and shows for each time going to the right (that is, along the horizontal axis) whether the task should be executed at that time. Pictorially, the Gantt Chart nicely shows progress over time in terms of task completion, shows how some tasks can be parallel, how others must preceed some tasks (sequential), and the coupling of tasks. Moreover, it is often quite useful in getting you to "think backwards" from the final target project completion date to make sure you can get everything done on time. Another common method to visualize task schedules is the "PERT Chart" (program evaluation and review technique) that envisions time as proceeding to the right, shows tasks as boxes, uses lines between blocks to show the sequential nature of tasks (e.g., a block on the left linked via a line to a block on the right which means that the one on the right follows it), blocks stacked vertically to show parallel tasks, and coupled tasks by putting their boxes together in a bigger box. The "critical path" in a PERT Chart is the longest sequence of tasks and knowing it can help determine project length. Another approach that may be useful is a standard "flowchart" that is used in designing computer programs.

To schedule tasks, the team must take into consideration people, budget, and resources. There are a variety of ways to make the task completion more efficient, including how to communicate with each other (e.g. upon one group completing a task), monitoring progress on a shared schedule, incentives, project update meetings, status reports, and other periodic reports. Project management is a complex undertaking for any community and if you are working on this part of the project, you should consider some of the references at the end of the chapter.

## 4.8   Humanitarian STEM Education

Science, technology, engineering, and mathematics (STEM) education is on the national agendas, and receives significant financial support, in a number of countries in the world, including the US. In Section 3.4.5 some evidence is provided that STEM education is a basic driver promoting development, at least in its positive alignment with typical development goals and measures discussed in Chapter 1. Moreover, from a historical perspective, STEM has had a significant influence on a country's development (see Section 3.1). In this section, the idea of humanitarian STEM education is discussed, and this whole area will be referred to by the acronym of "H-STEM" (that includes the word "education") following the approach of others who add on to the basic root "STEM" to qualify content and intent. Here, in spite of the practice in some circles of people to think of STEM as directed only at children and teens, H-STEM is directed at roughly someone in early childhood (e.g., 4 or 5 years old) to 27 or 28 years old (PhD level) when we are thinking of a "educational community"

(school or university). Even considering the problems discussed in Section 3.4, of illiteracy, and other problems of underdevelopment of educational systems in the developing world (infrastructure, educational materials, teacher competence, administrator effectiveness, etc., said to be precursors to good STEM education (Toyama, 2015)), according to the UNDP about 90% of children in the world, boys and girls included, receive primary education. Hence, H-STEM age ranges have significant overlap with the age range of many children in the developing world that are already getting some form of basic education. H-STEM also has utility for older school-aged children, such as at the postprimary level (see Section 3.4) even though in the developing world a lower percentage of students finish secondary education than primary. Moreover, there are also problems of underdevelopment of at least some universities in a relatively high percentage of developing countries (infrastructure issues, lack of educational support resources, and a low percentage of faculty who have advanced training such as a PhD). H-STEM focuses on these tertiary education levels also. In this section, the focus is on H-STEM in a more formal educational setting like in a school building or university and not informal community-based H-STEM where people live, and during participatory development in Section 4.2.4 or PTD as discussed in Section 4.2.6.

### 4.8.1 International STEM Education Up Close

Each of the following videos shows some aspect of the use of technology for education, or STEM education, for developing technological capacity. The (14:53) YouTube video by Nivi Mukherjee at TEDxStellenbosch

<div align="center">An Education Technology Revolution for Africa</div>

from Oct. 25, 2012 discusses education technology in Kenya. She discusses technology use in Kenya, provides statistics on education, and discusses attendance issues, student-centered learning, and the design of an e-tablet for learning. She also discusses the importance of context.

The (5:40) YouTube video

<div align="center">ICTs in Education</div>

from Sept. 8, 2014 discusses the use of information and communications technologies (ICTs) in international education by IICD. They discuss participatory program design (involvement of stakeholders) and participatory monitoring and evaluation (M&E).

The (14:07) YouTube video by Francis J. Brochon at TEDxLausanne

<div align="center">Changing Patterns of Development Through Technical Education</div>

from Feb. 9, 2013 discusses problems of having low technological capacity in the developing world. He says that technical education is theory-based and teacher-centered, and that there is no training equipment and no "practicals" (practical hands-on training, for instance via a laboratory). He helped create

an educational model that is student-centered, hands-on, and results in a three-year diploma. They implemented the model in Africa. He discusses impacts of the program, including getting jobs and impacting the community. He also discusses scaling up the educational project.

## 4.8.2   Principles of International STEM Education

There are a wide range of issues to consider when one tries to prepare for a global educational initiative of any sort. Broad principles are considered here, and a number of detailed issues that arise with respect to global STEM education are considered after that. First, the broad global problems and context of education underdevelopment must be understood, for instance the educational issues discussed in Chapter 1. Second, the social justice viewpoints on education should be reconsidered (e.g., the right to education) in Chapter 2, such as the rights to education in the UN Declaration on Human Rights, and Amartya Sen's perspectives as he insists that we think of human development in terms far beyond economic ones, ones that include education. Third, a variety of the principles of development from Chapter 3 are directly applicable, for example per Sachs's and Banerjee and Duflo's ideas. Of course, Section 3.4 that covers the education perspective on development should be read before reading this section.

**STEM Education Aligned With Utilitarian and Transformative Approaches**

Per Section 3.4.3, there are two approaches to STEM education, utilitarian and transformational. Utilitarian focuses on the economic market, pragmatic skills, and getting a job. Transformational focuses on social justice and how to achieve it (e.g., oppression, discrimination, and inequalities). It is not clear where the engineering education community, world-wide, comes down on the question of which is best, a utilitarian vs. transformative approach, but it is probably along the utilitarian lines, broadly speaking. On the one hand, in my experience, engineers are often very pragmatic (due to them choosing the field, or an influence of the field on them) and highly concerned about getting a good high-paying job. However, I have known many engineers who would certainly lean toward a transformational philosophy, especially among those in humanitarian engineering and engineering ethics.

> STEM can follow either a utilitarian or transformational approach, or both.

A balance is probably the right overall approach if you take a global perspective; however, the approach, in my view should be chosen by the local community and not some outsider. It has to fit the relevant context to succeed, and must use the standard participatory development approach (see Section 4.2.4). Regardless of what is correct, it seems that there has been relatively little done on how to use STEM education to support a transformational approach. One of the objectives of this section is to begin to develop STEM education to support a transformative approach, as opposed to what is often STEM education for support of a utilitarian approach. I think, however, that the real challenge is

to mix the best of both approaches by also providing pragmatic basic skills to help people succeed in their everyday lives in a host of ways.

**STEM Educational Targets: Basic, Social Justice, Sustainable Community Development, and Industry**

The STEM education project described at

<div align="center">

iSTEM: International Inclusive STEM Education

</div>

is on-going, and one of the drivers that guides the design of our experiments is depicted in Figure 4.9. In this figure, the circles indicate different STEM experiment/project types. At the bottom, there is a class of experiments that only teach STEM fundamentals (e.g., Newton's laws) and there is no clear learning objective aside from those. Such experiments may be transformational or utilitarian, but that is not explicit in the experiment, and most likely the only knowledge gained by the students is a deeper understanding of STEM.

Objective-driven STEM experiments focus on learning for social justice, community challenges, or local industry.
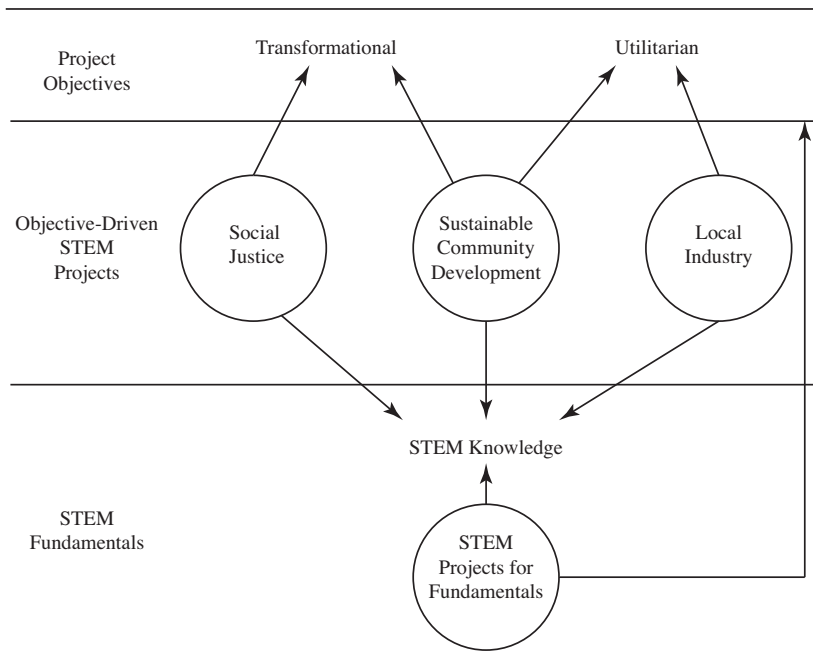


Figure 4.9: STEM experiment/design objectives.

One level up in Figure 4.9, there are three types of "objective-driven" STEM projects. First, there is the STEM project that focuses on teaching social justice which has a clear transformational impact (Section 4.8.4 below covers this case, as does Section 4.8.5). Second, there are STEM experiments that teach students how to solve problems for their local community: these are humanitarian-engineering-directed STEM experiments, and ideas from Section 4.6.3 can be

useful to design such experiments (e.g., for solar cooking). However, if this approach is taken, then all the ideas on community assessment (see Section 4.4) apply so that the education is directed at an appropriate community need. Such experiments can be transformational or utilitarian, or both, and could emphasize sustainability (e.g., via an experiment on recycling). Third, there are experiments directed at teaching students about the challenges of local industry (e.g., the greenhouse case below). To learn about such challenges may require a visit to the industries. Such experiments could help students get a job, and hence their primary focus is utilitarian.

### STEM for Breaking Socio-Economic Barriers

In the US, the emphasis in STEM education (and research) has come at all levels, from kindergarten to the most advanced degree in STEM, the PhD. Many have gotten involved in STEM education, particularly at the K-12 level ("12" indicates inclusiveness of all high school students, having completed 8 years of primary school, and 4 years of high school, or about age 18). The idea is to educate and motivate children and teenagers, especially from disadvantaged and racially diverse backgrounds, along with girls and women (due their under-representation in engineering), to choose STEM fields for a career. In engineering, the hope is to enhance diversity in the university at all levels from students to professors, and there is a similar objective for companies in the US.

STEM has assisted with social mobility in some countries.

Engineering in the US has a long tradition of being a "stepping stone profession," in the sense that, in the past, often parents of engineers have traditionally not been professionals themselves (e.g., in Ohio, years ago, the engineering student was typically the son of a farmer, sometimes going into agricultural engineering, fitting the mission of a "land grant" large public institution in a state with a significant agricultural industry), and perhaps not college-educated (e.g., in my own case). More recently, however, the sons and daughters of engineers have gone into engineering, or business, law, medicine or some other profession. The hope with H-STEM is that this stepping stone idea will help give people all over the world the motivation and opportunity to fully use their talents, and thereby help their country develop. There is a strong historical evidence that technology has a major impact on development (see Section 3.1): we need STEM education to promote technology development also in the developing world.

### Values and Bottom-Up vs. Top-Down Approaches

As you can tell from the broad historical and conceptual framework in Section 3.4, education is often deeply controversial, and it seems that this is due to a whole host of reasons including how much people care about their children, support or lack of support of the values instilled via the educational approach (e.g., via religious and secular topics), and the potentially strong connection to a child's future economic potential and their broader fulfillment (physical, intellectual, and spiritual). Most people understand the foundational importance of education in human development, feel like "experts" since they were once young

and in school, or see the practical and financial impacts of a good education (e.g., on themselves, family, relatives, and friends), and hence are quite willing to argue with others about what is best for educating the young. Opinionated people's attitudes fall on many spectra, like along the liberal–conservative or secular–religious continua. Culture drives opinions and actions on education (e.g., consider in the US the generally strong values on education in some Asian communities). Hence, you may want to revisit Chapter 1 in the discussion on culture, up-close and from a distance. For example, revisit the World Values Survey questions at their web site (see Section 1.4.5) and resulting data having to do with education, especially focusing on a county or region different from your own that you are considering working with.

The view espoused here is that educational "experts" and policy-makers must never dismiss out of hand the opinions of others, especially the community that the school or university is embedded in. I believe that good education happens via strong grass-roots involvement (e.g., parents volunteering in the schools of their children, parents demanding that schools get it right, and a good supportive environment at home for education), students' willingness to attend and commit to education which is often culturally-driven, parents' willingness to make kids go to school if they do not want to, and being fully participatory in the sense discussed in Section 4.2.4. That does not at all mean that I reject a role for "top down" provision of public education via a government or aid agency, in spite of the fact that (at least in the US) no matter how much people care about education, it frequently does not translate to voting in a democracy that results in spending more on education; this is perhaps paradoxical, but more likely a result of a variance on attitudes about how to  provide a good education (e.g., via public or private education) and who should pay for it (individuals making choices in an educational "market," or via progressive public taxation on wealth that funds public education, or even subsidizes private education, both connected to the key social justice issue of distributive justice).

You can think of an analogy here in the "development strategy battles" by economists like Sachs and Easterly (Chapter 3) between supply and demand, and Banerjee and Duflo's discussion on supply wallahs and demand wallahs in Section 3.2.4. Just like in approaches to development for health and economics, many people have seen things work very well in limited contexts, and then using that anecdotal evidence, insist that the approach is most certainly the best one everywhere in the world. This is a form of "extremism" that is generally not productive. I personally believe the right approach is in the middle somewhere between bottom-up/top-down and demand/supply philosophies (at least in the US), a "balance," consistent with Banerjee and Duflo's perspective for the developing world, and respecting the local culture, context, and conditions (i.e., what is best locally, and what is best at the "micro-local level," that is for individual students, such as an appropriate self-paced learning opportunity as I have personally used as a child and that Banerjee and Duflo identify as a need in the developing world Section 3.2.4). I freely admit however that this is a global philosophy, local conditions can clearly dictate that an approach on either end of any spectrum makes perfect sense in a local context based on the

The emphasis here is on bottom-up creation of STEM education.

values of a particular community; short of clear injustices like not allowing girls or minorities to go to school or providing them with fewer resources, you generally need to be flexible and accepting of local views. Basically, many forces drive what ends up happening in practice (the result of a big complex competition over many years, in a sense, and also simultaneously having the educational establishment learn what to do via experimentation), and it is unfortunately not clear that the best interests of those most affected, the children, are always kept in mind in spite of generally significant life-long dedication of many individuals, professionals and parents and leaders, all over the world. Many people in the US still do not feel that we have "gotten the K-12 educational system right," that it is "evolving toward something good/bad;" perhaps such a diversity of feelings is prevalent in many corners of the world.

### Abstract/Theoretical vs. Relevant/Useful Content and Delivery

Another issue highlighted in the EFA in Section 3.4.2 and by Banerjee and Duflo in Section 3.2.4 is what to teach (content) and how to teach it (delivery). Both those sources call for practical skills that are clearly useful in every day life, in the place where the students live, nurturing children at the bottom of the class, and not being "theoretical" and focusing only on the top students via an "education of the elites" type approach. They say the approach needs to have a heavy focus on "basic skills."

The focus on basic skills is completely consistent with the discussion in Section 4.2.6 on "synergistic education" in a community about development, operation, and maintenance of a technology for a community. It also resonates with typical engineering education philosophy in some ways as most agree that a theory-practice approach, based on science and math, coupled with laboratory experience, is valuable. Virtually no one would want to eliminate engineering laboratories where students get hands-on experience to learn the theory and sharpen skills for practice. Moreover, over the last few decades the "capstone design experience" has become more prominent and required for accreditation in the US. Quite often, a component of that experience is to both design and build some physical technology, even if it is only a small-scale prototype.

It appears, however, that doing something at the international level that is STEM, relevant, and of practical use in everyday life for the student is both challenging and complicated, and certainly requires a type of "needs and context assessment" that involves some type of PAR and grass-roots community participation, ideas, buy-in, and ownership. The same philosophy of community development discussed in approach in Section 4.2 and community assessment in Section 4.4 is needed. Also, the problem of not being theoretical when delivering STEM education can be challenging at times. It must be basic and clear, age-appropriate, level/prerequisites-appropriate, and focus only on the key idea, not all the surrounding complications. It must be tangible and hands-on, motivating, and exciting. It must show the fun in STEM.

STEM education should focus on relevant and useful content.

**Teaching the Teachers/Students**

The objective is to create educational strategies that will meet the specifications which are a direct reflection of educational community needs. First, it must be decided what the target audience is. Should H-STEM focus only on "educating the educators" and then let them educate their students (as depicted in Figure 4.10)? Or, should you teach one level how to teach the levels below them (e.g., teach university students to teach K-12 students or high school students to teach K-8 students)? If you use one of these approaches, or a teach-the-teachers approach, should this occur by having the older group together with the younger group and then teach them all at once the first time: this way the older group learns (typically faster than the younger group) and can simultaneously help teach the younger group. In some contexts, this can help overcome language barriers, which can be greater for younger children. For example, in some cases, children speak an indigenous language at home, then learn a colonial language in school. Then, for example, high school students may have very good colonial language skills *and* indigenous language skills; such high school students, if properly trained, can be very effective in teaching younger students STEM projects (and in the process it may be that the high school students are empowered and perhaps even motivated to become a STEM teacher). In some cases, this idea may also hold for middle school students.

**Instruction in Context: Breaking the Language Barrier**

Via (Anderson, 2013), one approach to overcome the significant problem of language barriers, is to produce "pictures-only instructions" for STEM experiments that students would do (this can include, for instance, pre-exercise science or mathematics instruction, and if an experiment is used, instructions on how to construct the technology). Then, by simple (non-verbal) tinkering with an experiment, much can be taught (including via an outsider, who can simply point and demonstrate). Even if it is only on a sheet of paper, such an instructional tool is a form of cross-cultural humanitarian technology. Examples of this pictures-only approach are given at iSTEM.

Another useful approach to cope with the language barrier was mentioned above in Figure 4.10: fully involve the locals in the educational process. This could be done, for instance, via teachers (or older students) who understand your language and then translate and work with younger students. At the university level, there are also language barriers, but often they are not as significant as professors may want to challenge their students to learn your language.

**Instruction in Context: Example from the University Level**

In terms of the strategy for delivering lectures in the university, as part of a theory class or laboratory teaching, or in the classroom with children, it is important to think carefully about context and culture and try to connect ideas with these. With a little bit of creativity this is often possible, even for very sophisticated ideas and theory in the university.
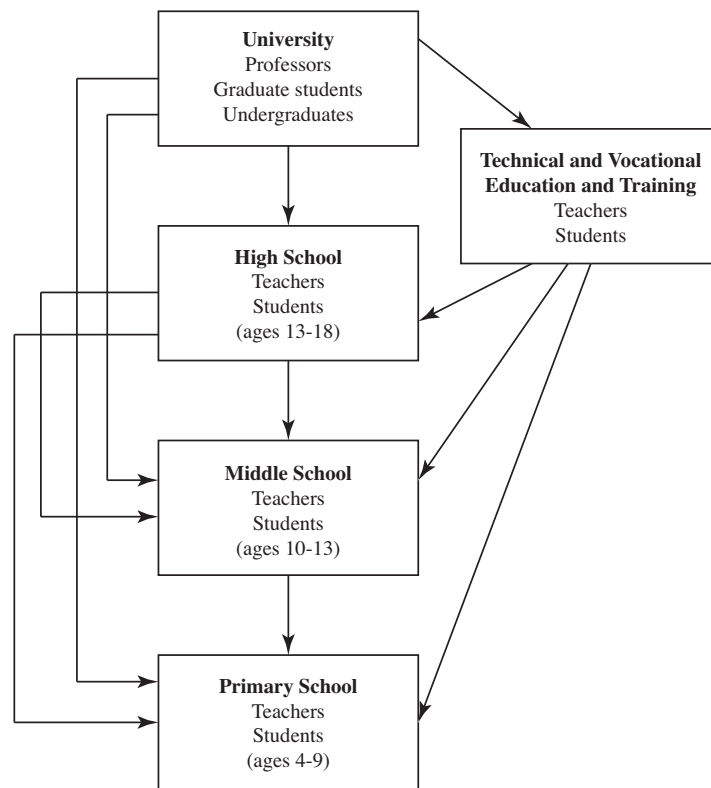
Figure 4.10: Strategies where the older/more advanced students teach the younger/less advanced STEM students. Arrows indicate teaching, with the base of the arrow the teachers, and the head of the arrow the students.

To provide an example for the university case, suppose you are teaching theory and algorithms for optimization (e.g., see Section 3.6.3). Think of optimization as trying to find the peak (highest point) on a function $f(x)$ of some variables that can be adjusted $x$ ($x$ is a vector of $n$ variables and $f(x)$ is a function, for example quadratic so that it is an inverted "bowl"). If it is quadratic, and $n = 2$, then the optimization problem is simple. You start with an initial guess $x(0)$ at step zero and if $k$ denotes the step number, at $k = 1$ you make a step by choosing the direction to move that corresponds to the "direction of steepest descent" and then repeat (that is the direction an aggressive person on

skis would choose to move to get to the bottom of a snowy slope the fastest).

Figure 4.11, on the left side, shows a "contour map" of the elevation (number of meters above sea level) of a region surrounding Colombia, South America. The black line shows zero elevation, or sea level and in the figure, that is the shoreline. The blue regions show "negative elevation," that is, regions below the sea or ocean. The yellow, orange, and red (highest elevation) show the ranges of the Andean mountains. Figure 4.11, on the right side, shows a different view, one where the height of the Andean mountain ranges, and depth of the Pacific Ocean, are clearer. To view this as an optimization problem, use $f(x)$ to represent the vertical axis (elevation) in Figure 4.11 and the two components of the vector $x$ are latitude and longitude. Maximization of this surface corresponds to adjusting $x$ to maximize the value of $f(x)$, that is to perform mountain-climbing. While teaching this, it would be good for the lecturer to know the point of maximum elevation in Colombia so that it can be discussed. You may also want to identify some "local maximum" points (points where in some smaller region the maximum elevation is achieved), such as those near where you are lecturing. I have used this approach to lecture in Colombia, and also developed and lectured on optimization algorithms to find the maximum elevation or the region where coffee is grown ("la zona cafetera") by modifying $f(x)$ to find the elevation ranges where Arabica coffee grows best. Comments after the lecture indicated that this approach to teaching optimization was more effective as it was set in context, and was about something that Colombia is proud of, their excellent coffee. Of course, a similar approach could be taken for any location on Earth. The data and code for this example can be obtained by clicking here.

Even though some STEM theory may be abstract, it is sometimes possible to set it in the context of the local community or country.
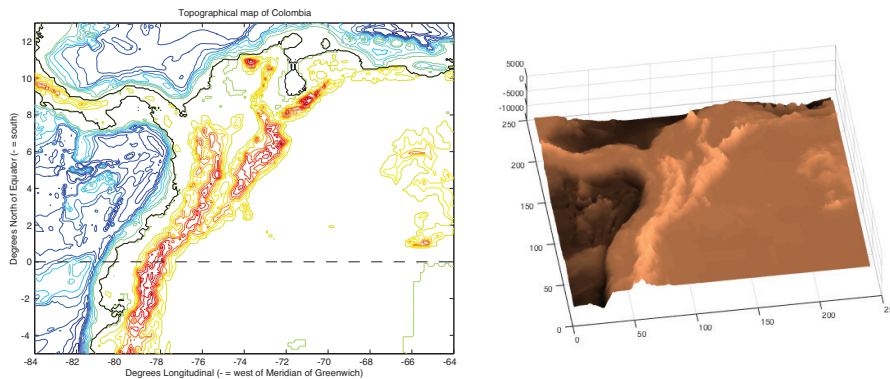


Figure 4.11: Left figure: Topographical contour map of Colombia (the topographical data were obtained from the US Dept. of Commerce, National Inst. of Geophysical Data). Right figure: Terrain for plot on the left.

### Technological Capacity at All Levels

Keeping in mind the clear importance of "technological capacity" for promoting development as discussed in Section 2.1.2 and also Section 3.2.1 based on (Sachs, 2006), there is a clear need in the developing world for humanitarian STEM education, via tight collaboration with local partners, and that may only involve the transfer of ideas (not any tangible technological product). The "synergistic educational component" of participatory development discussed in Section 4.2 is a form of H-STEM, tangible and important to a community, provided participatory development is executed properly. Technological capacity is important at all levels, K-PhD in a developing country since people with more education tend to teach those with less education in schools and university (clearly a deeply ingrained social justice issue is at play here if you consider Farmer's quote at the start of Chapter 2 and the later discussion on the technological capacity "haves and have-nots" in Section 2.1.2). Below, such issues are discussed for H-STEM, with a focus on classroom instructional delivery, experiments/projects, and for the full range of levels of education for technological capacity. However, since the "synergistic education" component of participatory development has already been discussed, the focus here is directed at formal education in schools or universities.

> STEM capacity is needed in communities, industry, and from K-PhD.

### Developed-World STEM Education for the Developing World? No.

There is a very basic tendency to first try the things you know how to do, and have seen work in your own country first hand, in another country. Just like the attempts to directly transfer technologies from the developed to developing world, this is likely to fail if you take a rigid attitude about the superiority of your approach. You may have some interesting, and perhaps even good, ideas for a partner educational community in another country; however, you should not *presume* this is the case. It may be that their approach is better, and you may learn a lot. A flexible, culturally-open attitude should be taken. Any language difference must be confronted. Context and culture must be fully considered in educational program and equipment design. In spite of the potential lack of value of one approach being useful in a different context, to provide some background on one approach, you can consider the US approach, if you would like, via the references provided in Section 4.15. It would also be useful to study the model for your own country, the country you want to partner with, and the general area of international and "comparative" education in order to develop an approach.

> Developed-world STEM education can provide ideas, but good solutions require respect for community inputs, context, and culture.

To give a more systematic approach to the design of a local STEM education, building on the participatory development approach in Section 4.2, and the participatory technology development approach in Section 4.7, a "participatory education development" method is presented next.

### 4.8.3 Participatory STEM Education Development

Most of the principles from participatory development directly apply to the design of a suitable and effective H-STEM strategy for a school or university. Why? A school or university is a type of community. Education is clearly a form of community development. The group of students, teachers, staff, and administrators are "clients." Hence, in the spirit of Homan's perspective on community development (Homan, 2011), general participatory development ideas inSection 4.2, and mirroring PTD in Section 4.7, the following steps are suggested as an approach to develop a STEM program that respects people and context.

**School or University Opportunities, Needs, Assets, and Context Assessment**

There are a number of elements of a complete assessment strategy that seeks to determine what is the right STEM education approach. First, begin by assessing student, faculty, staff, and administrator needs, resources, hopes, and aspirations. Normally, this would be done with individual interviews or a structured group meeting (type of focus group) along the lines of what was described in Section 4.4. Heavy emphasis should be on the student; however the rest of the people who help deliver education to the student population clearly must be consulted (e.g., such persons typically clearly understand school/university assets, resources, constraints, student background, value of content, and relevance to living in the local community). While these, and the issues below, are about "context" there is also an overriding social contextual issue of culture, and hence the challenge of cross-cultural STEM education, which is also often present in the developed world. Language barriers can create significant problems. What is the proper way for an outside person to interact with educators (should they always be addressed very formally, and in what way? What is the proper formal address in the local language? It should be learned and used by a visitor, especially when any child is present) and students. In some cultures it is unacceptable for an outsider to even touch a child (Anderson, 2013), while in others, there are many times a pat on the back is considered normal and useful to provide the student encouragement, and in some cultures if an outsider spent significant time on STEM education in a school they may play games with the children during lunch break, or even publicly give a child a hug goodbye if the child initiates it.

Assessment for education helps ensure program success.

There is also the challenge of educating for the social context, whether you support either a utilitarian or transformative approach. What topics are of most value to the school or university? STEM foundations for a local product from their country that everyone is proud of? Technology-mediated connections to aspirations of working in a company, or their love of the local sports team (e.g., soccer) or popular musician (e.g., electronic music)? Will this make STEM career paths clearer for a student? Show relevance? Properly working with the educational community to determine needs, develop solutions, and implement

them will promote educational community empowerment, program ownership by demonstrated buy-in, reduce dependency, promote community ownership, help with maintenance, and help ensure long-term program success.

Next, educational assets, resources, limitations, and infrastructure context must be studied. Will staff and administrators support the efforts in concrete ways? Will educators get time off from other duties, or financial incentives/support, to learn more about STEM, STEM education strategies (i.e., professional development), and for delivering STEM education? Will space be committed if it is needed (e.g., for a laboratory)? Will there be financial support if materials and supplies are needed, or computers and internet services? Is there an adequate library? Are there supporting educational materials for an educator (e.g. a book, lesson plans in the right language, or on-line educational support if that is feasible)? For the students? Textbooks? Are they needed? Is the support structure in place to exploit on-line education, for administrators, educators, staff, and students? Or, is it locked up and largely inaccessible to many? What are policies on putting materials on the web? Is it open and feasible for all teachers or administrators to post at a web site? Or, does any posting have to go through a slow bureaucratic and obstructive vetting process? Clearly, costs can matter a lot in many areas of the developing world, and culture and values drive decisions on how to provide technological support for education. However, does it cost more to pay the people to implement the bureaucracy, than it does to buy better software and hardware (e.g., a better server and more memory) so you can open up use? Aggressive web site censoring, both internal and per external access, along with firewall policies, can be especially problematic from an open-thinking and expansive view of doing research, education, and learning in an increasingly interconnected world. There are clear connections between all these issues and the transformational approach to education.

### STEM Program Specifications: Context and Curricular Issues

Develop specifications on all aspects of the educational program so that it meets community needs. These specifications can include the length of instructional period (so that students can pay attention), frequency of offering, prerequisites, and syllabi that identify all topics in some detail (content), and that has a schedule for their coverage, along with proper coordination between successive courses and years in school.

Consideration should be given to whether to "piggy back" other educational strategies onto the STEM education approach (i.e., STEM as an educational delivery "vehicle"), and whether the program should be utilitarian, transformational, or a mix of these two. For instance, consideration could be given to the following utilitarian and transformational STEM content ideas, based on educational community willingness to do so:

1. *Entrepreneurial STEM (E-STEM):* In Ohio there is a K-12 entrepreneurial-STEM (E-STEM) program where business skills are also taught with the

*Educational program specifications should be tailored to the desires of the community.*

intent to encourage business formation based on technological innovation, manufacturing of technologies, marketing, and sales, that would all promote economic development. Topics for children may include basic concepts from marketing or positive and negative cash flows. There is a clear connection in this philosophy to the utilitarian perspective on education. However, I see no reason why you could not teach a social business approach to STEM, as it is discussed in Section 3.5, and this could then be a clear mixed utilitarian-transformative approach.

2. *STEM for Social Justice (SJ-STEM):* The approach of using STEM for teaching social justice is a central theme of this book (e.g., the mathematical and computational approaches to analytically study poverty in Chapter 1, social justice in Chapter 2, development in Chapter 3, and socio-technical analysis in Section 4.12) and strongly aligns with a transformational approach to education for international development that applies K-PhD in all senses, classroom to lab, and to children (see more below); however, there are aspects also of the utilitarian perspective in even religious perspectives on social justice (e.g., in the Catholic social doctrine case, the importance of the opportunity and participation in work by all, worker rights, all to promote human fulfillment and the ability to contribute to a person's family and more broadly the "common good;" in this sense, their doctrine can be viewed as a utilitarian approach to education). Hence, in some ways, SJ-STEM shares the characteristic of being a mixed utilitarian and transformational approach, of course, depending on what people choose to emphasize in a local context. Background instructional materials may need to have a full integration of engineering and social justice ideas, including nonlinear mathematical analysis, such as the stability analysis of poverty traps, as appropriate. SJ-STEM has the potential to have some world-wide applicability as it has broad agreement on the basic ideas coming from religions. Of course, as highlighted in Chapter 2, this approach can be controversial. The local context matters in every sense of culture, religion, or lack of it, included. Finally, there is a clear need for hands-on, age/level, and culturally appropriate SJ-STEM experiments. Some approaches for this are provided below.

You will also need to specify if STEM education will be integrated into an existing class (e.g., science, math, or engineering) or whether it can be a standalone course. Should the program be based on "educating the educators" and when should such education be scheduled? Evenings? On the weekend? During some break? Summer or the appropriate period of lengthy break in a country that may correspond to other times? A cost model should be developed that includes not only money, but money-equivalents of people's time, and of course all resources and infrastructure needed. Clearly, cost can be a big driver in what is possible.

### Educational Strategy Concept Generation

There are a number of potential educational strategy "concepts" that can be considered and the team should brainstorm internally, and study external sources (educational "models" from other countries) or consult outside experts, to develop a set of alternative concepts. In some cases, it may be possible to design the strategy to be "scalable," e.g., within the broader cultural context of a country.

There are many educational concepts; however, the chosen approach heavily depends on local needs, desires, and context.

Should outside H-STEM educators (e.g., humanitarian engineers) directly teach the students? Should a program only focus on students? Or, should a mixed approach be used where, for instance, technological support for educational leaders, teachers, and professors is also considered as in Figure 4.10? Should a chalk and slate-only approach be used (perhaps appropriate for mathematics)? Or can a student-participatory approach be used where physical experiments are constructed and tested in hands-on projects, perhaps with educator guidance and a lecture before or after on the principles of STEM that are being illustrated by the experiment? Are local materials available to construct such experiments? Should movies or other demonstrations that show direct connections to the community be provided? Can education be directed to, and use, local objects, devices, and other contextual aspects of the built or natural environment? This will facilitate students' making concrete connections between STEM concepts and the local context they live in every day and thereby facilitate learning and show them relevance. Is space available? Should experiments be designed so that students also construct them from basic components as part of the learning experience, and so that staff do not need to do this? Are experiments very low cost so that they can be easily replicated, and then sent home with the student for further experimentation and to show to their parents and friends? A key idea is that such experiments should be designed to illustrate important STEM ideas, sometimes ones that are being taught in the class that the H-STEM program is embedded in, and other times they must correspond to key concepts in a "theory-only" course that is a pre- or co-requisite. Would online instructional videos be useful and feasible via existing educational support structure? Would this support a self-paced STEM study option? Clearly, there needs to be conversations on what exactly students need to learn from the perspective of the teachers/professors and administrators, taking into at least some consideration what students will want to learn, and should include an assessment by local educators about student background and feasibility of teaching specific STEM ideas. Even the simplest STEM experiments have the potential for almost infinitely deep and advanced scientific, technological, engineering, or mathematical study; how deep should you go?

### Pilot Programs: Initial Evaluation of Strategy in Context

The prototype to test the feasibility and effectiveness of an educational strategy is a "pilot" program that is typically small scale (e.g., testing it in a few classroom settings with a few teachers/professors/students). For instance, you

may spend an hour on each of three different approaches and try to quantify the success of each approach, perhaps using a brief test at the end of each class, or at least via a qualitative assessment (such as a set of discussions on some pre-established questions). If you are working with a partner in another country it makes sense to have a trip to do such a pilot study before a program is put in place (e.g., via the "assessment trip" discussed in Section 4.11.3). Actually trying out an educational approach once can give you concrete ideas about how to make it better, and can be especially useful to uncover unexpected constraints and trade-offs that were difficult to imagine being an issue, and that may be difficult for anyone on the participating team to identify (e.g., a cultural issue). It is difficult to identify such issues since in the culture you are working with, since they live it every day, they naturally do not think of anything as being "different" or "unusual" as for them it is not. For the visiting team, it is also problematic as it is very difficult to understand cultural issues if you have not lived in a culture. This challenge must be openly acknowledged by the team, and then the team as a whole needs to watch out for such issues, and fix any discovered problems in order to tailor a program for the local context.

> Running a pilot educational STEM program can teach you how to "work out the kinks."

The chosen STEM education strategy should be fully implemented and used a sufficient amount of time and then it should be assessed and considerations should be given to how to redesign it so that it is more effective. It is basically impossible to get it right the very first time. Of course, the primary metrics to judge success should be student-centered, including, perhaps quantification of amount learned, long-term impact in a longitudinal study (e.g., whether it impacted getting jobs, career decisions, recruitment and retention, or enhancement of diversity in follow-on STEM programs), and a qualitative assessment of issues like the level of student enthusiasm and excitement about STEM, attitudes toward it, and how easy it is to teach.

### 4.8.4   K-PhD Educational Technologies

Technologies supporting H-STEM can be broken into three categories: administrative, instructional, and laboratory/experimental. All three have infrastructural and operational components that are composed of human capital (e.g., teachers) and physical capital (e.g., buildings, computers, and experimental equipment).

> Low-cost and effective instructional technologies show how STEM can help education, and can help with STEM education.

**Instructional Technologies: Infrastructure**

There are a number of technologies that can establish educational infrastructure and assist at the operational level in the classroom where real instruction occurs. Some mature and well-tested ideas from the developed world may be useful, especially ones that are cross-cultural in a more diverse country, and ones that are the result of a design philosophy being consistent with "appropriate technology" in Section 4.6.3. Some approaches include:

1. *Technologies for educating the educators:* As highlighted above, there should be instructional technology support for educators, staff, and ad-

ministrators so long as these are all effective in the first place (Toyama, 2015). Moreover, attention needs to be paid to approaches to educating the STEM educators, perhaps via in-person programs or technologies for viewing on-line courses if there is sufficient available internet bandwidth.

2. *Infrastructure for crossing the digital divide:* The famous case addressing this issue is the "one laptop per child" (OLPC) program of Nicholas Negroponte (see Problem 4.46 at the end of the chapter). There are many extreme design constraints and unusual trade-offs for humanitarian educational technology and the OLPC approach sought to meet these challenges and hence serves as an good case study in approaches to promote the crossing of the digital divide, the reasons for doing so, and the advantages. Obvious issues like whether there will be electricity available, the language barrier (both spoken and written) and cultural barriers can be significant challenges in any approach like the OLPC. Moreover, there is a very basic problem with the OLPC approach in terms of long-term impact. They sought a low-cost solution and this dominated the design approach. However, today, there are competing or better laptop/tablet technologies in terms of cost and performance, but perhaps not in terms of durability or environmental impact (though some have criticized the OLPC program for having bad environmental impact). Other concerns about the OLPC program are discussed in (Toyama, 2015).

**Experiment Specifications**

Specifications for each of the two levels, K-12 and university level, are similar, but also have some differences:

1. *K-12-level experiment/project specifications:* At the K-12 level, experiments must be simple and straightforward to operate, be hands-on, easy to construct/operate considering the level of motor skills, create enthusiasm and excitement in students, motivate students with visuals/tactiles, and have clear educational value with respect to at least one important STEM concept (Anderson, 2013). It must be possible to explain the project, let students do the experiment (with educator guidance, for instance, by walking around the room and visiting students to answer questions and help), and for the group to reflect (process) on what happened and what they learned within 30-40 minutes (Anderson, 2013). It could be useful to do a pre-project assignment to prepare them, perhaps based on a pre-project lecture the day before. Also, it could be useful to have a post-project assignment or quiz.

2. *University-level experiment specifications:* The level of difficulty of an experiment should be consistent with the level of the student (e.g., undergraduate or graduate), and the background they have before they take the laboratory course where they do the experiments (or as an homework assignment for what is largely a theory course, but the philosophy is that

Experiments for STEM education provide humanitarian engineering projects directed at education.

you can ask the students not only to do mathematical and computational studies, but experiments in the lab). The general goal is to create experiments to illustrate key theoretical topics from class. To keep experiments low cost, it may be necessary to select only certain theoretical ideas to illustrate. Generally, "pre-lab" assignments are given to prepare the student. Next, the student conducts experiments and often gathers data, or makes observations. Then, there is an assignment to analyze the data and relevant principles via a mathematical or computational approach, or both. University students are increasingly familiar with on-line instruction so such a strategy might be effective in putting together a self-study and self-paced laboratory experience, for example, based on multi-lingual educational videos on each experiment that are posted on-line. Finally, there are two over-arching principles in designing university-level experiments: (i) you never sacrifice educational value due to low-cost constraints, even though it is recognized that this creates significant technical and educational challenges; and (ii) you should try to have at least some experiments that are sophisticated enough to be useful in graduate research (theses and dissertations) and that can be used as a basis for scholarship in publishing in conferences and journals.

**Experiment Examples from iSTEM**

A source for STEM experiments for the whole range, K-PhD, is

<p align="center">iSTEM: International Inclusive STEM Education</p>

At the site, there are fun experiments for the K-12 level, including the "Jeopardy" game, audio speaker, audio equalizer, "OSU circuit" (well, if you live in Columbus, Ohio, and are a OSU Buckeye fan), and several others (Anderson, 2013). Also, there are university level experiments for temperature control, resource allocation, an electromechanical arcade, and others. Several of these experiments have been converted for use in an international context, and others are easy to convert. For example, the OSU circuit that displays those three characters could be changed to display a child's initials (if the child has four initials, it is easy to add one more display), a culturally-relevant aspirational concept like the initials of a favorite local soccer team, or the name of their religion, city, or country. For the audio speaker, it is possible to add a radio, and after speaker construction, play local news or music in their own language. Some experiments are industrially-relevant such as the greenhouse experiment for Colombia where there are many greenhouses supporting their huge flower export operations. Some of these experiments, and others, are discussed in more detail in Section 4.8.5. Instructions can, and are, being converted to sequences of pictures as discussed above, to overcome language barriers (Anderson, 2013). Finally, often at the K-12 level it is useful to also create a "lesson plan" for a teacher to use and for this see (Wilson, 2015) (at the book web site, downloadable documents).

**Experiments for Teaching Social Justice**

A central theme of this book is the integration of engineering into social context, including in the understanding and analysis of social justice ideas, especially ones with global impact, and especially with socially embedded technology. Some principles that are relevant include:

1. *An educational-cultural context for ethical STEM can be promoted with STEM:* One goal is to provide a cultural context for ethical STEM. Here, in addition to the strategies in this book for this in the earlier chapters, we discuss ideas for creating physical and computational experiments that can be used at the K-PhD levels, as appropriate, for the context and culture to teach some version of social justice. I acknowledge that this may be quite offensive to some, such as religious people who would claim that it is impossible to teach religion via science, technology, engineering, and mathematics. Please keep an open mind. Only the social justice piece of religion is considered (if they can be separated at all). Also, there is no claim here that all social justice ideas can be taught via STEM experiments in a classroom (e.g., spiritual and God-centered ideas or love); however, you might be surprised that a STEM-inclined individual may learn key ideas very well with such an approach: different modalities of thought, such as the use of mathematics and computation, should be respected. It is important to also respect intellectual diversity, and the range of modes of learning by people. Some learn best via one or all of the following: listening, reading, watching a human lecture, pictures and diagrams, open discussion, reflecting, solving problems, watching videos, or these same approaches but via the medium of STEM by doing calculus/differential equations or statistics, the scientific method, programming and computational analysis, tinkering to construct a technology, and hands-on work with technological experiments. I see no reason why STEM is not potentially a valid approach to learning ethics (especially ethics for science and engineering) along with social justice, at least for some people who think in these ways.

2. *Groups of humans/one central technology:* The ideas in Section 4.6.3, and specifically in Section 4.12.1, provide the concept for this approach, and a number of opportunities to try to improve existing humanitarian technologies that are community-based. Learning may occur, for instance, at the undergraduate or graduate levels, via prototypes at home, and installation via working with a community abroad.

3. *Groups of humans/groups of technologies:* Overall, it seems to be important with any approach to an experiment to have a human-technology integration (that is, human actions as an integral part of the experiment) and due to the fundamental "social morality" approach of social justice, that multiple humans interact with the technology (or multiple pieces of an overall technological system) in a synergistic sociotechnological experiment that will often be spatially and computationally distributed across a

classroom so that everyone can see everyone else's reactions to the group dynamics of, for instance, cooperation. An example of how a group of people can interact with a group of technologies is in Section 4.12.1.

4. *The challenge of human complexity:* It is clear that one central challenge is the creation of technology that really achieves sociotechnological integration. Will the individuals in a group even respond to a technology? Will they reliably respond? Will the people-technology interface be properly defined to promote the interaction? What is the role of the intangibles like emotions?

To be more concrete, consider the following experiments, aimed at a typical-size classroom of say greater than five students (but, the ideas are not technologically constrained by some upper bound on the number of students):

1. *Classroom-based cooperative centralized technological approach:* There are a number of ways to teach cooperation, which is a central principle of many systems of social justice, via technology. For instance, there is a

   "balls-in-tubes" experiment

   where a ping-pong ball is pushed up through a tube by a computer fan, an ultrasonic sensor measures the ball height, and then a "feedback controller" (computer algorithm) regulates the ball to a desired position (this experiment is described in more detail in Section 4.8.5). Next, a "manifold" is used to connect the air-intakes of multiple (e.g., four) tubes so that if the computer-voltage controlled fan pushes one ball up, it takes air from other tubes so that their balls come down. The challenge is to design an automated cooperative algorithm that will push all balls as high as possible, but at the same height. If the computer is removed, then one human can control each tube, and people work together (cooperate) to maximize the uniform ball heights. This is a dynamic cooperation challenge and it teaches that if you are too greedy (push your own ball to the top), then others cannot at all lift their balls; achieving uniform height requires you to give up some potential height so that others can do as well as you in achieving height. There are a number of other cooperation examples implemented in technology here. See also Section 4.8.5.

2. *Classroom-based distributed sociotechnological approach:* Indeed, the "app" ideas for individuals or groups in both Chapter 1 and Chapter 2 are already candidates for SJ-STEM at the high school or university levels in the developed world; however, such approaches may not work in the developing world due to a lack of the number of teens owning smart phones (at this point in history) that would be needed in an effective classroom hands-on experiment. In the developed-world case, even if a few students do not have a cell or smart phone, this can provide an key educational opportunity on "haves" and "have-nots" and sharing to promote everyone's

STEM experiments can be designed to teach principles of social justice.

learning. For instance, it would be relatively easy to use a networked set of phones, and an student-designed app, to implement the social justice game in Section 4.8.5. Such an approach has clear connections to understanding the differences between charity and changing structural problems (the rules of the game) in a system of social justice that is embedded in a country.

### The K-12/University Synergy

As you study the types of experiments and instructional strategies that are feasible at both levels it becomes apparent that there can be significant cross-fertilization of approaches, or even "dual-use" educational experiments that can in fact work for all levels K to PhD with some relatively obvious modifications.

It may be that an advanced university-based experiment can be simplified for use at the K-12 level so long as the instructional approach is appropriately modified. For example, consider the university-level "smart lights" experiment at the iSTEM web site that led to the K-12 smart lights experiment at that web site (Anderson, 2013). This transformation in use of experiments will also work in other cases such as via the temperature control approaches at the iSTEM web site (though those might be boring for K-12 students since they can only see light bulbs going on or off, or getting brighter/dimmer, unless the experiments were modified to also make it possible to "see" or "feel" temperature, for example, via a material whose color changes based on temperature as we have experimented with in our laboratory). Simpler versions of the "electro-mechanical games" called the "arcade" and "juggler" at the iSTEM web site can capture the imagination of the current generation of students at any level, K-12, and also provide a valuable and exciting educational platform for important STEM concepts.

It may be possible to either: (i) provide full educational context for an existing K-12 experiment, including use of calculus, differential equations, and scientific principles; or (ii) make additions to an experiment originally developed for the K-12 level to obtain an experiment that is advanced enough for a university level laboratory, especially if the instructional strategy is made more advanced and utilizes advanced science and mathematics, and there are also such requirements in the pre- and post-lab assignments.

For K-12 experiments, it seems that it is often possible to make them more advanced, to "transfer" them to the university level. For example, the K-12 motor experiment at the iSTEM web site can be expanded to a university level experiment by: (i) adding an "encoder" to sense angular rotation by simply cutting a notched paper disk out, attaching it to the motor shaft, adding a light-photosensor pair to detect on-offs as the notches on the disk move past it due to rotation (Pavlic, 2013), and then building a circuit to implement a feedback control system out of a simple operational-amplifier to implement a gain (for visual effect it also might be useful to add a flashlight bulb driven by a circuit that interfaces to the voltage/current input to the motor from the feedback controller); (ii) require the students in pre-lab to create a mathematical model

STEM experiments developed for K-12 can often be transformed to university-level experiments, and vice versa.

(a low-order differential equation will suffice) and simulate (e.g., in Matlab if it is available, but any programming language will work) the performance of the control system for variations in the (proportional) gain; (iii) conduct the experiment by first constructing it, then getting it to operate and if data acquisition is available (e.g., via Arduino) gather data for later analysis, making sure to focus on principles like dynamics, tracking, and disturbance rejection (a reasonable "disturbance" is to simply grab the motor shaft and retard the motion and see how the control system reacts, especially by considering the relationship between desired and actual shaft speeds, and the reaction of the controller as visualized by the flashlight bulb, as the disturbance is induced); and (iv) perform a post lab with appropriate mathematical and computational analysis (including the possibility of statistical analysis based on running the experiment many times).

You educate some children in STEM so that they grow up to do university-level STEM, and you should give special consideration to promoting diversity at all levels. Little engineers grow up to be big engineers. At the same time, university students should understand the connection to the K-12 STEM education challenge as they can serve as great "STEM ambassadors" to the schools they graduated from, perhaps themselves teaching STEM to children or talking about STEM education at their current university. There is a long tradition of undergraduates finishing their STEM degrees and becoming "teaching assistants" for professors in laboratories. Then, this results in some of these persons going to industry, and perhaps helping with STEM education in their community, or graduate students choosing to be a professor in STEM education, perhaps leading students in "STEM Outreach" activities for local schoolchildren. This is the "STEM pipe-line" that needs support (both emotional and financial) from the local community and the broad academic community. Indeed, even government or aid/donor community support can be very useful.

It is my hope that this pipe-line is culturally sensitive, context sensitive, is driven by the educational and broader local community, and has a pervasive culture of diversity (in all senses of that word), and social justice promotion, consistent with the transformational perspective on education for the developing world (Maclure et al., 2012). It is relatively obvious how to create STEM education programs for the utilitarian perspective. I feel that there needs to be much more attention given to the development of STEM programs that support the transformational perspective so that a better educational balance is achieved.

### 4.8.5   STEM Education for Sustainable Development

This section brings together many of the ideas of this section to show how to put together an educational program (i.e., a sequence of sessions, components, or "modules") on STEM education that is directed at sustainable development. To start, some relevant sources for educational initiatives along these lines are outlined. Following this, a specific sample educational program is described.

**Initiatives on Education for Sustainable Development**

A good general source for sustainable development is (Sachs, 2014) that includes a book and on-line course. There are world-wide efforts in higher education to promote learning about sustainable development (Weber and Duderstadt, 2012), and in particular STEM for sustainable development (Johnson, 2012). Moreover, UNESCO has information on education for sustainable development in the form of reports (e.g., (UNESCO, 2014)) and the web site

UNESCO Education for Sustainable Development

which has information on a whole range of issues in sustainable development. There is also the

US Partnership for Education for Sustainable Development

with a

K-12 and Teacher Education

component. Focusing on Europe, there is the United Nations Economic Commission for Europe,

UNECE Education for Sustainable Development

Also, there is the

Education for Sustainable Development Toolkit

in English and Spanish.

**Educating Children on Sustainable Development**

The key elements of the educational program described below are as follows:

- *Participatory program design:* It is assumed, without discussion, that if educational programs of the type discussed in this section are introduced, it is done with a participatory approach as discussed in Section 4.8.3 with full involvement of local teachers and administrators.

- *Teaching humanitarian engineering to children:* The focus in this section is on how to teach some key ideas of this book.

- *Centered on UN sustainable development goals:* The program below is directed at teaching children about the 17 sustainable development goals (SDGs) in Section 1.3.8. Taken together, the educational exercises address components of each and every one of the 17 SDGs, and the specific goals addressed in each case are identified. Of course, you may want to add components that address other issues (e.g., business), delete components, or teach the ideas in other ways.

A STEM education program for the SDGs must be designed to fit the local context by local people.

- *Teacher preparation:* A good source for teacher preparation on these topics is (Sachs, 2014) that has a free on-line book and course.

- *Target age range:* The focus is on middle school to high school students (ages 10-12 to ages 18-19). Some of the components below would work for the age range of 4-9 (e.g., the M&M and lemonade approaches), but then some of the projects would have to be more of a demonstration rather than having students construct technologies themselves. The university level is not considered as that is the focus of this book and many related existing books and courses (e.g., see (Allenby, 2012; Weber and Duderstadt, 2012; Johnson, 2012; Elliott, 2013; Sachs, 2014; Amadei, 2014; Blewitt, 2015)). Yet, the ideas in Figure 4.10 clearly apply here so older students may learn by helping teach younger students.

- *Team or individual work:* In the cases below, some can be either individual-based or team-based, and you will need to decide how best to proceed in each case.

- *Preparatory and wrap-up instruction:* It may make sense to have classes before the educational exercises below to provide background and context, or basic scientific principles. This may occur immediately before a session starts, or on a previous day. Moreover, there is likely a need for some follow-up classes to address issues that arise from the sessions below. Clearly, it would make sense to simply embed the educational modules below in an existing science and social studies curricula.

- *Need to adapt program to local culture and context:* The program here is only meant to be a sample, not a recipe, that will need to be adapted to local context and culture. For instance, the ideas in Section 4.8.2 may be useful in making changes, for example, to include some local-industry-relevant components, or to tailor STEM projects to local community development issues. Below, the approach is both transformational and utilitarian (see Section 3.4.3).

- *Need for visuals, demonstrations, and field trips:* Below, in a number of cases there is going to be a need for additional visuals (e.g., photos or movies), demonstrations (e.g., of real full-scale operating systems such as a solar system), perhaps outside speakers (e.g., a local person who works on helping provide clean water or renewable energy), and perhaps field trips to local renewable energy installations, water filtration facilities, or electric utilities, if these are available.

**Poverty, Social Justice, and M&M Candy**

Children need to understand something about poverty if they have never lived in it, and one way to do that is via teaching about inequalities in the context of social justice. You could assign background reading or videos on poverty and social justice (e.g., ones given in Chapter 1, and also Chapter 2). Here, an

engaging approach is used to promote active learning, one based on "The M&M Game" (of course, any favorite candy from any country could work just as well as M&Ms). This subsection provides education for SDGs #1, #4, #5, #11, and #16 in Section 1.3.8.

Poverty can be taught via inequality and fairness ideas.

**The M&M Game: Charity Vs. Changing the Rules of the Game:** There is a game used to teach children social justice called the M&M game. The main point of the game is to teach the difference between charity (e.g., giving away money) and social justice ideas (trying to change the rules governing economic and political systems so charity is not necessarily needed). Here are the steps of the game:

1. *The lottery of poverty and wealth:* You will distribute cards to the $N$ students in the session (e.g., class). In a standard deck of 52 playing cards, there are 40 numbered cards (if you include the aces with those), and 12 face cards (jacks, queens, and kings). If there are more than $N = 52$ students, then you can use multiple decks of cards. Separate the numbered cards from the face ("royalty") cards. You will distribute numbered and face cards in a percentage that corresponds to poverty and wealth rates either in the country you are teaching, or in the world. For instance, about 80% of people in the world live on less than \$10/day so if there are $N$ students in the class you would distribute $0.8N$ numbered cards and $0.2N$ face cards (of course, if the numbers do not come out even, just pick the closest whole number of cards). The reason for the percentages of each card type should be explained. If $N = 20$ students, you *randomly* give 16 students numbered cards and 4 students face cards, by shuffling the cards in front of the class and then drawing off the top for each student. Children who get face cards are called royalty. Once a card draw is made and the child handed the card, they are simultaneously given either two M&Ms (numbered cards) or a whole bag of M&Ms (face cards). Suppose $N_f$ is the number of royalty and $N_n$ is the number of numbered cards distributed.

2. *Rewards and costs of maintaining a standard of living:* Bags of M&Ms come in different sizes. You will need to check roughly how many M&Ms are in the bags you gave out. Suppose it is $M$. Next, you put rewards in $N_f$ envelopes (e.g., gift certificates, cash, etc.), the number of royalty. You tell the students that it will cost "a few less than" $M$ M&Ms to purchase an envelope, and that they can at most purchase one envelope. Explain that what is in the envelope represents what you need to maintain not only a good standard of living, but a great one, and the students with numbered cards immediately know that they cannot get a reward.

3. *Rules of the game, and play:* While students with numbered cards will not be happy with the seemingly unreachable goal of getting a reward, you tell them that the royalty can give them M&Ms, if they can convince them to. Yet, the royalty are not required by the rules of the game to give

their M&Ms away. The game proceeds by students walking around to ask each other for M&Ms until it appears that no one is giving any away, then the game ends.

Some discussion questions for the children after the game are:

1. Is the game fair? Explain that it is based on "charity."

2. How would you change the rules of the game? Explain that changing the rules of the game is a central issue in "social justice."

3. Is whether you are rich or have low-wealth random (just good or bad luck)? To what extent is it based on where you were born, something that is beyond your control? To what extent is your wealth determined by your parent's wealth, again something you cannot control as you do not pick your parents.

4. How much does it cost to maintain a decent standard of living? What percentage of people can afford that?

5. If you work hard, can you always earn enough money to maintain a decent standard of living?

6. Does everyone have the same opportunities (e.g., to work, to get an education so you can get a good paying job, or to get health care so you can work)?

**Extensions: Taxation, Democracy, and the Rich Get Richer:** There are a number of ways to modify the M&M game that have educational value:

1. *Progressive taxation:* Impose a policy of progressive taxation to force the royalty to give to low-wealth people. You will have to decide what the taxation policy is and whether to apply it uniformly to all students who are M&M-wealthy, or just to a high percentage of them (e.g., ones that do not cheat on their taxes). Also, you will need to decide how collection is done, and distribution. One approach for that is to have the rich each put a certain number of M&Ms in a central location, then have each low-income student take some percentage of what is there.

2. *Democracy:* For the last item, you could have a vote (democracy) on how many M&Ms must be given each minute by the rich to the low-wealth student (i.e., the tax rate). You will need to decide what constitutes a majority for the vote. Clearly, if there are fewer rich than low-wealth people, a democracy is likely to result in more redistribution. This is like the democracy in Section 2.4.4.

3. *The super-rich:* While the game is being played, have the teacher randomly distribute two large bags of M&Ms to the royalty, not low-wealth students, to represent the power of wealth to produce more wealth. Will

this encourage the "super-rich" to give, especially if they are in a situation where they can only buy one envelope and they have many extra M&Ms that they do not really need (aside from to eat).

Of course, many of the above discussion questions still apply, especially "is it fair?" or "did they play fair?" For instance, you can ask if progressive or regressive taxation is fair. Or, you can ask if democracy is always fair (e.g., consider the tyranny of the majority). Is it fair that the rich typically have more opportunities to get richer? Do the super-rich give away more of their wealth? Are great inequalities fair? What problems do inequalities cause?

*Cooperation is basic to addressing inequalities and our shared environmental future.*

### Cooperation: Juggling and Synchronization

Next, it is shown how STEM can be used to teach cooperation, which forms a basis for a number of ideas in social justice including helping others meet their human rights, the common good (Section 2.2.2), democracy, and advocacy to mention a few. Moreover, it forms a basis for environmental sustainability discussed in the next section as it can help defeat the tragedy of the commons. This subsection provides education for SDGs #1, #8, #10, #11, #16, and #17 in Section 1.3.8.

While there are many ways to teach children to cooperate (e.g., sports), here we consider using STEM to teach cooperation as it simultaneously teaches STEM principles and cooperation. Consider the following two experiments that are described in full detail at iSTEM:

1. *Group juggling:* The approach to teaching this method of cooperation could include multiple steps:

   - Pre-STEM explanation: If you have someone who knows how to juggle, it would be good to have a demonstration for the students. Also, if more than one person can work together to juggle a set of balls that would be useful.

   - *Explanation of experiment:* Suppose you have a tube with a ping-pong ball in it. The top is capped. At the bottom, there is a small fan or blower that is driven by a battery and that directs its air into the tube to push the ball up when it is on strong enough, and it naturally falls with the fan is off or is on a low setting. The fan is controlled electronically and is interfaced to a switch (for on-off control) or a potentiometer (for continuous control). For this single tube, it is designed so that a single individual can switch the control on an off and thereby lift the ball, and indeed balance it at a position the individual chooses. In this case, the person is juggling a single ball. Next, take, for instance, four such balls in tubes, and place them next to each other and make the inlets to all the fans come from a single box (manifold) that has an appropriately-sized single hole in the bottom. In this way, the fans must share air at their inlets. Suppose one person operates each switch for each fan and

tries to maximize their own ball height. When one person's ball lifts, it steals the air that can potentially be used by other people to lift their balls.

- *STEM component:* Explanations of the switch, electronics, and motor can all be given; in fact, it may be useful for the students to construct the experiment themselves or at least a key component of it.

- *Playing the cooperation game:* Have groups of four students take turns trying to raise all four balls as high as possible but keep them at the *height*. This can be as challenging as a good video game, and a lot of fun. If the experiment is designed properly, the students will be able to succeed, but it will be challenging to do so. The game takes good cooperation as at every instant, the person with the highest ball must turn off their switch, and the ones with low balls must turn theirs on. The students may want to invent cooperation strategies such as "the person with the highest ball turn off their switch, the person with the lowest ball turn on their switch, and the other two keep their setting the same." Another strategy can be "the person with the minimum height ball turn on their switch." Such strategies should be discussed with the students and they should be asked to suggest a strategy of their own.

2. *Synchronization:* The approach to teaching this method of cooperation could include multiple steps:

- Pre-STEM explanation: Start by asking the students to applaud for something (e.g., another student who did good on some recent assignment or sports game). In many cultures, this will result in random clapping. Next, ask them to repeat, and keep up the clapping; during their clapping, ask them to synchronize their clapping (you could do this simply by joining in yourself with an emphatic-type clapping and the students will likely synch to your clapping leadership). Explain to the students that they had to cooperate in order to synchronize. Some students had to slow their clapping rate, while others had to speed up. If possible, you could show a video of the fireflies in southeast Asia that synchronize their blinking (there are several such videos on YouTube) to give them an idea of synchronization as it occurs in nature.

- *Explanation of experiment:* At the heart of the experiment is a battery, switch, and a light-emitting diode (LED) . A single student could turn on and off a light just like they do the switch in the room or a flashlight. However, in the experiment the switches are configured so that all the switches have to be on simultaneously in order for the light to go on. Students are asked to turn the switches on and off at a certain rate, and by working together, to get the light to go on and off at a certain rate.

- *STEM component:* An explanation, and possibly an exercise in connecting switches together, along with an explanation of batteries, lights, and series circuits could be conducted.

- *Playing the cooperation game:* You ask the students to all flip the switches at a rate such that they synchronize and the light goes on an off at some rate. Next, you can ask them to synchronize to a given rate of on-off switching.

Some discussion questions for the children after the games are:

1. What was your team's strategy to juggle or synchronize?

2. For the juggler experiment, do you think you could have set the balls to have the lowest on the left, next highest, a bit higher, then highest on the right?

3. For the synchronization experiment: (i) could your team have done it blind-folded? (ii) could you have achieved some rate at synchronization and then increased the rate, but stayed in synch?

4. How does a switch work? What is a series circuit? What are the basic principles that make a motor work? What is a difference in potential? What is current? How does an LED work?

5. What role does cooperation play in reducing inequalities (e.g., economic or educational)? We cooperate to build schools and educational programs. Participation in a highly inclusive fashion in cooperative endeavors is very important as if people are excluded, then the group's objectives generally only focus on meeting the desires of those who are cooperating. How good would your team be at juggling if you took your best game player and removed them? Is democracy a type of cooperation since it is a way to compromise on what is best to do for a group?

Principles of cooperation also apply to the next section where sustainability and the tragedy of the commons are studied; indeed, the juggler dynamics are similar to the dynamics of the tragedy of the commons but with ball height inversely proportional to resource depletion.

### Environment and Sustainability: Sharing the Lemonade?

Following Section 1.3, the next topics to teach are about the relationship between development and environment, pollution, and sustainability. First you need to define the word "development" which in simplest terms means "ending poverty" and in more detail it means "raising standards of living via higher income, more education, and better healthcare." Second, you should explain to the students problems with pollution of water, land, and air (see Section 1.3). Third, you will want to define the word "sustainable development," probably in a slightly simpler way than the Brundtland Commission did (BC, 1987):

Sustainable development focuses on the environment, inclusion, and human development.

> Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs.

as, for instance, via

> Sustainable development makes sure you get what you want, without making it impossible for your kids and grandkids to get what they want (e.g., if all the materials used to make things are used up).

Next, point out that richer countries pollute more and use more resources (e.g., water) than lower-income countries do. Explain why, for instance, in terms of resource use. If we end poverty, and the once-low-income people pollute as much as the rich, will we destroy the planet (e.g., via climate change)? This is *the* central concern in sustainable development and hence it must be clearly communicated to the students. Readings and videos on the key ideas in sustainable development may be useful, such as the ones in Section 1.3, but here we take a different more active approach to learning with a focus primarily on sustainability. Poverty was considered above, and pollution will be considered in the next section. This subsection provides education for SDGs #2, #6, #10, #12, #13, #14, and #15 in Section 1.3.8.

**The Tragedy of the Lemonade:** The Foundation for Teaching Economics has a way to teach about the tragedy of the commons that you can learn about here, and that is presented below in a slightly modified form (quotes below are from that web site). One approach is to use lemonade via the following approach:

1. *Set up before class and getting drinks:* Get a large opaque water jug and partially fill it with lemonade (soft drinks could be used equally well, but the liquid must be in an opaque container). Tighten the lid on the jug. Get some paper drinking cups of various sizes, more than the number of students in the class. Put a sign that says "Free drinks: Thanks for being such a great class!" on the jug, or near it, and place the cups next to the jug. Put the jug, sign, and cups in a location so that as the students enter the room, they will see them all. Sometimes, you may need to point out that the drinks are there. Likely, provided you did not put too much lemonade in the jug, the lemonade will run out before all the students arrive, or the late-comers will only get a little lemonade compared to the first ones to take lemonade, and in particular ones who chose a larger cup.

2. *Class starts, begin discussion:* Once everyone is seated, start a discussion by asking the students the following questions:

   - "Why there was not enough lemonade for everyone?" Some may say that the ones coming in first, or the ones using the bigger glasses were greedy. Some may say that there was not enough lemonade in the first place.

- "Was it fair that there were different-sized cups?"
- "Who owns the drinks?" Of course, the answer to this question is not so clear, considering the presence of the sign. Some may say the teacher, but once the drinks are poured, are they the students'?
- "Did anyone take more than they drank?" Ask them why? There was no penalty for taking too much.
- "Why did the drink run out before everyone got some?" As the discussion begins, you will want to point out that there was no incentive to save any lemonade, and that there may be an incentive to get a big drink as it tastes good and there may not be enough later. Also, point out that due to the sign everyone felt that they had the right to drink, but there was no person or group that protected or rationed the drinks. Note that in smaller classes, in some situations, there may be enough for everyone to drink. In this case, you can ask the class what they think would happen if they were in a larger class, and one where they did not know the other students.
- "What would have happened if there were twice as many students in our class?"
- "What rules should there be for rationing lemonade?" Who should enforce the rules? Teacher? Student committee?

**From Lemonade to Climate Change:** The lemonade is a type of "commons" as there is free access to it, and you only benefit by taking more, at least in the beginning. It is different from some types of commons where there is "resource renewal" at some natural rate (e.g., fish growing and reproducing, or grass growing). However, it is easy to see the analogy between the lemonade commons and commons based on water, soil, and air. For instance, there is only so much we can pollute the air before we irreversibly damage the climate, what we call the "tragedy." Discuss the following with the students:

1. Can the climate handle all the pollution (e.g., from cars and factories) we create?

2. Is it fair for some to pollute more than others?

3. Who owns the air?

4. Should we have someone regulate amounts of pollution released? Who?

5. How do these questions relate to the case of the lemonade?

For the above discussion, you need to emphasize how important the problems are and what a tragedy it would be to destroy the commons (with explanations about impacts on ecosystems and human health), far beyond something like running out of lemonade!

**Water Pollution and Filtration: Getting the Bugs Out!**

To convey in a concrete way how pollution impacts us, and how pollution can be removed in some cases, this section focuses on water pollution and filtration. It provides education for SDGs #6, #11, and #14 in Section 1.3.8.

At iSTEM, there is an experiment on removing contaminants (pollution) from water. For this experiment:

Pollution is bad as it affects our health, but it can be cleaned up.

- *Filtering layers:* There is a set of different filtering "layers" or "stages." First, there is a layer of larger rocks that removes large items (e.g., sticks or bugs). Second, there is a layer of smaller rocks that remove smaller items, like some large pieces of dirt. Third, there is a layer of sand that can remove dirt and smaller items. Fourth, there is a layer of cotton that can remove very small items. Still though, the small "bugs" (bacteria) or viruses will not be removed by this method. The children will construct this filter.

- *Dirty water, clean water:* Have the children mix up some dirty water. First, put in food coloring to make the water red or orange. This color will not be filtered out entirely. Second, put in some dirt to make the water look bad to drink. Third, put in some small sticks and plastic bugs. Have the children pour the polluted water through the filter to show the filtering action, and in particular that relatively clean water will come out (but do not let them drink it). Next, gently pour out the filter contents and have them inspect where the various types of contaminants were removed (e.g., stick and bugs at the large or small rock levels vs. some of the dirt in the cotton).

For discussion, you could consider the following questions:

1. How is water polluted? For rivers/creeks? Lakes? Oceans?

2. In the layered approach to water filtering, big items are removed by passing contaminated water through larger items, with larger holes in between them. Smaller items, like sand grains, have smaller holes between them and hence do not pass through smaller sized contaminants. How small must the filter holes be to remove bacteria, ones which can make you sick if you ingest them? Hint: E. coli bacteria, some strains of which are not good for you, are 1-2 micrometers long. Another approach to remove such "bad bugs" is to use chemicals (e.g., chlorine) to kill them.

3. It is very difficult to remove viruses and some minerals (e.g., arsenic) which are smaller than bacteria. How can we protect our drinking water from those?

4. How clean must water be in order to drink it without getting sick? To bathe in it?

5. How much pollution does it take to kill wildlife, like fish? A bear? A cow?

**Renewable Energy: Free Electricity!?**

The use of renewable energy is on the rise around the world. It is called "renewable" as the basic energy source comes from sunlight, where each day the sun shines (well, up to cloud-cover considerations), or from other sources like the wind, that either persistently or periodically blows depending on where you are at. Renewable energy generally offers reduced pollution and less resource depletion than the use of "fossil fuels" like oil or shale gas as these must be burned and cannot be replaced after they are used. This subsection provides education for SDGs #7, #9, #11, and #13 in Section 1.3.8.

Renewable energy pollutes less than burning oil or gas.

It is possible to teach students about various types of renewable energy in small-scale classroom projects. For instance, some ideas are:

- *Solar power:* Small solar panels (e.g., the size of an envelope or less) are relatively inexpensive. These can be attached to a battery and used to charge it, then the battery can power various devices. Functionality will depend on the size of the panel (number of Watts), the battery, and how long the battery is charged. Solar panel systems are relatively easy to set up and explain, and students find the panel fascinating as all that is provided is sunlight, and electricity come out for free! One application is "solar lanterns" that have a panel, battery, and LED light. The panel can be set out in the sun all day, and then it will typically give at least four hours of light for use for working or reading at night. Another application does not use a solar panel, but only sunlight in order to cook. In such a "solar cooker," with one design given at iSTEM, there is a reflective material used to focus sunlight to create heat to cook food.

- *Wind power:* The primary energy source can be wind, provided there is enough in the region you are in. Generally, the wind blows and turns a blade connected to a generator that generates electricity that is stored in a battery. A table-top version of this can be created with a small fan blade, a small generator, and a battery. You could turn the blade with your hand, or simulate wind via an electric fan (but that, perhaps, defeats the purpose of the illustration as it needs electricity to generate electricity).

Of course, there are many applications of the electricity that either approach would generate.

Some discussion points for these renewable energy experiments are:

1. For wind or solar power, is there any pollution generated during operation? How about polluting the beauty of the landscape? To make this point, you could show them a picture of a wind or solar farm.

2. For wind or solar power, is there any pollution generated before or after operation? There are material resources used to construct solar panels or wind turbines, including the structures used to hold them. Moreover, there is pollution as the result of the manufacturing processes for both, along with problems of disposal and/or recycling after end-of-life for all components.

3. Is the wind or solar power free? To you? Solar and wind power systems cost money, and a key question is how soon they provide a return on the investment on the equipment (panels or turbines) before their natural end-of-life, and a return that is greater than the expenses of maintenance of these systems. Also, in terms of use, there is the issue of whether they provide electricity at a competitive price relative to electricity generated via fossil fuels (e.g., a coal-fired power plant).

**Sustainable Shelter: Keeping Warm and Dry**

This educational exercise is designed to teach children something about what it would be like to live outside, without a home. This subsection provides education for SDGs #9 and #11 in Section 1.3.8.

Shelter is important for survival, and can be designed not to use too many resources.

In Section 4.6.4 candidate technologies to help people who are homeless are discussed. Each of these could provide good classroom projects, but we will consider only the make-shift shelter design challenge. This exercise will have some differences from the others in this section in that it will require creativity, and not as many instructions. All that is provided is a set of materials, and a set of constraints how the design. Then, the students work individually or in small teams of 2-4 people to invent their own solution.

You will need to acquire various materials and have them present in the classroom. These may include plastic, tarps, wood, poles, etc. You should have enough materials and tools present so that the students can succeed in their design, at least a a certain extent, by meeting the design requirements below. You may need more space than is provided in a standard classroom, unless you have the whole class act as a single team, or perhaps you only have two teams. It could be nice to have the two teams compete to produce the best design, with a rubric set by the design requirements below, and the teacher serving as the judge. You could explain the whole project in one class and give teams a few days to work together to construct their shelter.

Following Section 4.6.4, some requirements for the designed shelter may include:

1. Use of free or low-cost local materials;

2. Weather-resistance to cold, snow, ice, and rain;

3. Protection from a possible wet, muddy, and cold ground which may require slightly elevating the shelter (e.g., via a pallet) or using a tarp;

4. Sturdy so it will not collapse under snow and ice loads;

5. Having convenient ventilation;

6. Easily convertible between winter-summer living;

7. Rugged/durable to get a long life;

8. Good internal light;

9. Possibly transportable (e.g., via carrying it or via a cart);

10. Secure against theft of the shelter and what is in it; and

11. Aesthetically pleasing and/or camouflaged so that people will not be as likely to be removed from various locations by authorities.

After completion of the construction of the shelter(s), and possible judging, some discussion questions include:

- How warm and dry would a person be in your shelter?

- Is the ventilation sufficient for breathing, and to avoid sweating?

- How much would your designed shelter cost?

- Can it be constructed will locally-available materials?

- How "sustainable" is your design? Does it deplete nonrenewable resources? How would it be disposed of after it is used? Recycled?

### Sustainable Development Goals: Getting Children on Board

It can be useful to have a session at the end of the program that integrates the earlier ideas ("tell them what you told them"). One way to do this is to connect the local learning in the program to the world objectives in sustainable development, that is, the sustainable development goals in Section 1.3.8. This can give the students a strong sense of belonging in the world, and help to emphasize that to meet the SDGs we need "all hands on deck." One idea for how to achieve this is via a session with a lecture-discussion format as is discussed next.

A restatement of the sustainable development goals from (UN, 2015), but for children is in (Bardales and Arenas, 2014) (in Spanish, English, and other languages). A wrap-up session could be designed around this document, with a lecture that summarizes the goals, connecting them to the earlier sessions (connections to the goals are provided above in each case). Then, there could be a discussion component. For instance, in (Bardales and Arenas, 2014) there are some questions for group discussion with children (quoted):

1. What goals are most important for children? List the goals in order of priority.

2. Is there anything you consider very important to ensuring children's rights that is not reflected in the document?

Other questions that could be discussed include:

1. Should all children have the right to an education? To finish high school?

2. Should all children have the right to get help from a medical doctor?

3. What is the biggest pollution problem in your neighborhood?

Of course, questions designed for the local context may be more appropriate. The above questions simply provide ideas on what to discuss.

## 4.9 Assessment of Outcomes

Technology project solution outcome (or impact) assessment should be integral to the development process, and not an afterthought. In the past, there have been times when humanitarian technologies are deployed, a team leaves, then the technology soon fails, if it ever worked properly when the foreign team was present. Often, problems arise due to poor maintenance, as it was discussed above, or poor designs that do not properly consider reliability in context. This section emphasizes the importance of outcome assessment to ensure technologies are operating properly and perform according to specification, or according to what is expected. In addition, in this section we highlight some potential project failures and unintended consequences, some of which are not technical matters.

### 4.9.1 Outcome Assessment Rationale and Community Participation

The following are some of the reasons why humanitarian  technology solution quality needs to be assessed:

Assessment of success is a key component of a project.

1. To ensure that claims of success in humanitarian engineering are valid and quantifiable (e.g., outcome assessments beyond just counting the number of technologies deployed);

2. To ensure that the desired effects are found in practice in terms of positive impacts on the people helped (e.g., their health, education, quality of life, or economic well-being);

3. To ensure that undesirable effects or unintended consequences are not found (e.g. a side-effects of pollution, wider adverse economic impacts, or other human aspects discussed below);

4. To provide a measure of solution quality to assess whether there is a need for a redesign to improve the technology solution;

5. To provide a base-line for comparison of solution quality for later iterations on a design; and

6. To provide an on-going quality assessment to ensure long-term success of a project (e.g., via an automated monitoring system or annual visits with assessments done by a humanitarian engineering team).

Just like participatory action research, PAR, technology solution outcome assessment should be participatory, and typically should be to the greatest extent possible via involving a number of people in the community. Involving the community in outcome assessment:

1. Provides more accurate assessments of technology solution quality as the community members are most often the end-users;

2. Provides better continuous monitoring of solution quality as the community members live alongside the technology and operate it;

3. Provides the best information as by having the community involved in solution quality assessment they will be "close" to the technology and hence be able to provide good information needed for operation, maintenance, and redesign; and

4. Gives the community "ownership" of the assessment process, and hence the "right" to point out whether the technology solution is working properly or not. Good honest feedback should lead to continual improvements over time.

## 4.9.2 Unintended Consequences and Failures

There are a number of unintended consequences and failures of humanitarian engineering projects, that include:

1. *Social failures of the team:* The first type of problem can arise purely in the social realm. For instance, a team member may make culturally-insensitive statements or attempts at humor (e.g., about the traditions, food, or religion of the locals) that are offensive to community members. Or, an engineer may make condescending remarks to others on the team about having a lack of technical skills or ability to solve some technical problem (e.g., they can act like a "know it all"). An engineer may make inappropriate comments that highlight local problems, and contrast them negatively with problems (or lack thereof) in their home country (e.g., "we do not have that problem" or "your problems are much worse than ours"). The engineering group should be integrated with the community and not function as a separate "club" of only degreed foreign individuals or there can be an uncomfortable "us-them" dynamic that grows and is unproductive for the project. It is very important that social issues such as those above are discussed pre-travel.

   Team members need to be aware of project pitfalls to avoid project failures.

2. *Technology failures:* Technology reliability, and the operational and maintenance issues discussed in this chapter, are crucial for long-term project success. Clearly, we do not want to litter the world with "technology trash," an all-too-frequent problem in the history of development projects.

3. *Unfinished projects:* Another type of engineering failure is the "unfinished project" that sometimes results from over-optimistic engineering goals. A

faculty/staff can "own" part of such a problem as the project goals are normally set before travel, sometimes in a class that prepares the students for travel. Other times, over-optimistic goals are set "on the ground" and with the full input of the community. It takes good engineering expertise and judgment to know what is "too much to do," often past experiences with developing and implementing a technology in a developing community.

4. *Student engineering failures:* Some students traveling on humanitarian engineering trips are not yet very experienced engineers, and may never have been out of their own country. While at many universities, engineering faculty or staff travel with the students, this is not always the case. What happens if a student group working with the local community is in the process of failing to engineer a good humanitarian technology? These students are often given a grade for their work. Is "D" work acceptable? In such situations, the faculty/staff often step in an make it "A" work so that the community benefits (then, of course, grading the students accordingly for their personal lack of success). But, what if there is no one to step in to make a project succeed? See Section 4.11 for more discussion on grading and the accountability issue.

5. *Environmental and health impacts:* As emphasized in participatory development, the engineering team should pay significant attention to the impact on the environment over the whole life-cycle of the technology. Of concern here is the possibility that the technology will pollute significantly after installation, in particular, if there are degradations to the technology during operation that result in extraordinary pollution. Such pollution can cause health problems, either in the immediate or surrounding community, or via adverse impacts on a wider-area ecosystem. Other health problems can be created from technologies, such as those that arise when ethical issues arise in the creation of technologies that cause health problems (e.g., a poorly designed water filtration system for drinking water).

6. *Social and economic impacts:* Another unintended consequence can be a degradation in social cohesion due to technology, such as when information technologies are introduced and people talk less face to face. Other labor-saving technologies can free some individuals from toil and give them more time for socializing, which *may* be good. Labor-saving technologies can also have unexpected economic impacts in that they can free persons from toil and make them available for other work that may disrupt the local labor market. Also, sometimes a technology or technologies can disrupt the local economy by replacing the "middle-man" or by competing against a locally-manufactured technology.

A key question is whether we can learn from failures, readjust approaches, and improve outcomes (Easterly, 2007). Discussion on this issue is also in (Smillie, 2000), in Part I "The Failure to Learn from Failure," and is often found in the development literature.

### 4.9.3   Quantitative and Qualitative Outcome Assessment Approaches

There are several approaches to solution assessment:

1. *Interviews, focus groups, and surveys:* Using the approaches in Section 4.4, another approach is to have the participating team interview the community, or some subset of it, about their level of satisfaction with a technological solution, or their views on it, and record their responses (e.g., write down their actual words or video tape them). Of course, focus groups or surveys can also be conducted. These may be especially good approaches if the *same* survey is given before and after a project, if the survey is designed properly. An analysis of the set of responses (as in Section 4.4) can be done to gauge the overall level of community satisfaction and project success. Sometimes the qualitative methods are useful to capture aspects of a technology impact that are difficult to measure with numbers (e.g. holistic, cultural, or emotional aspects). A "phenomenographic approach" to qualitative assessment for humanitarian engineering is discussed in (Vandersteen et al., 2009). Another qualitative evaluation for humanitarian engineering for two case studies, Haiti and Benin, is in (Silliman, 2009).

2. *Statistical assessment and randomized controlled trials (RCTs):* In this class of methods there are metrics defined for success, then the technology solution deployment and use is viewed as an "experiment" as discussed in Banerjee and Duflo's approach to RCTs (Banerjee and Duflo, 2012) in Section 3.2.4 (RCTs are covered in more detail in Section 4.9.4). That method required more than one technology solution implementation, or different configurations of the same technology, or costs to the user (this sets the "experiment"). Often, in humanitarian engineering practice there is just *one* solution implementation. In this case, a typical but often *flawed* approach is to measure the metric before and after technology implementation and then compute the difference (or percentage improvement). Such an approach can be flawed as in the intervening time, it could be that something else changed and improved conditions, not the implemented technology. It is problems such as these that the RCT is designed to avoid.

3. *Computer simulations:* Computer simulation has been used to great benefit in engineering. Often, however, engineers have focused too narrowly and simulated the technology in isolation (e.g., to determine if it will perform properly). In humanitarian engineering there is a significant need to evaluate the impact of a technology on its social context (e.g., people whom are affected by the operation of the technology). I will refer to this as "engineers without blinders" (EWB) in Section 4.12.2 to emphasize that the engineer needs to take into consideration not only the technology in a simulation, but also simulate the group of people that

Assessment methods can be quantitative or qualitative.

it impacts. Computer simulation of a technology embedded in a social context can be used to help design the technology before deployment so it works properly in its destined social context; however, it can also be useful to develop a computer simulation of a technology that has been deployed, and is in operation in a social context in a community, and this is studied in Section 4.12.2. When technologies are implemented in a social context, real data can be gathered during operation of the system that, together with science, can be used to improve the simulation model. Then, such a model provides a way to measure the impact of a technology on a social context, that is, a solution quality assessment method. There are many potential benefits of developing, (pre- and) post-deployment, a computer simulation of the technology in a wide social context. For instance, the impact on economics, wealth distribution, or democracy can be studied as they were earlier in this book. Moreover, simulations can be used to assess a number of issues: (i) long-term effects (e.g., impacts on environment); (ii) non-local effects (downstream pollution); (iii) assessment of non-measurable variables; (iv) exploring "what if scenarios" (e.g., what if the community got bigger/smaller, social interactions changed–strengthened or weakened); and (v) exploring the impact of parametric or structural changes to the technology on social context. For all of these, it is often possible to consider multiple values of parameters in the simulation (e.g., parameters describing components of the technology) and impacts for each case of performance metrics related to performance or social context (e.g., computing averages and standard deviations). A computer simulation approach has several fundamental advantages over the RCT: (i) full consideration of dynamics, feedback, and nonlinearities in outcome assessment; (ii) use as a prediction tool for evaluating success of candidate designs or design modifications; and (iii) evaluation of long-term, non-local, an unmeasurable effects. See Section 4.12.2 for more discussion.

Just like the need to assess humanitarian technology, there is also such a need for STEM educational programs and technologies that are developed with the methods in Section 4.8. Methods from the developed world (Spurlin et al., 2008) for assessment may be useful provided they can be made "culturally sensitive."

### 4.9.4 Randomized Controlled Trials

The basic idea of the randomized controlled trial (RCT) was given in Section 3.2.4, and is further illustrated in Figure 4.12. At the top of Figure 4.12, the population of individuals is shown, but the ones that meet eligibility criteria (e.g., for receiving some development assistance such as a humanitarian technology that will be referred to as the "treatment"). Individuals from the population are recruited, and asked if they agree to join the assessment. For the group that agrees to join, each individual is randomly assigned to be in the treatment group or comparison group (e.g., by flipping a coin). Sometimes, (i)

the comparison group (often called the "control"), receives no treatment; (ii) the comparison group is given no treatment, or a different treatment than the treatment group (e.g., a different version of the technology); and/or (iii) there are several treatment groups. Information is gathered on outcomes for each group, and then compared using statistical methods (e.g., mean, variance, and statistical power). The randomization is of central importance to the procedure. By randomly assigning treatments, each treatment is applied to the same average subpopulation and inter-group differences are eliminated or at least minimized. The result is that you can test two different treatments on what is considered the "same" situation; this leads to the proper conclusions about effects of each treatment with respect to a control, or with respect to each other.
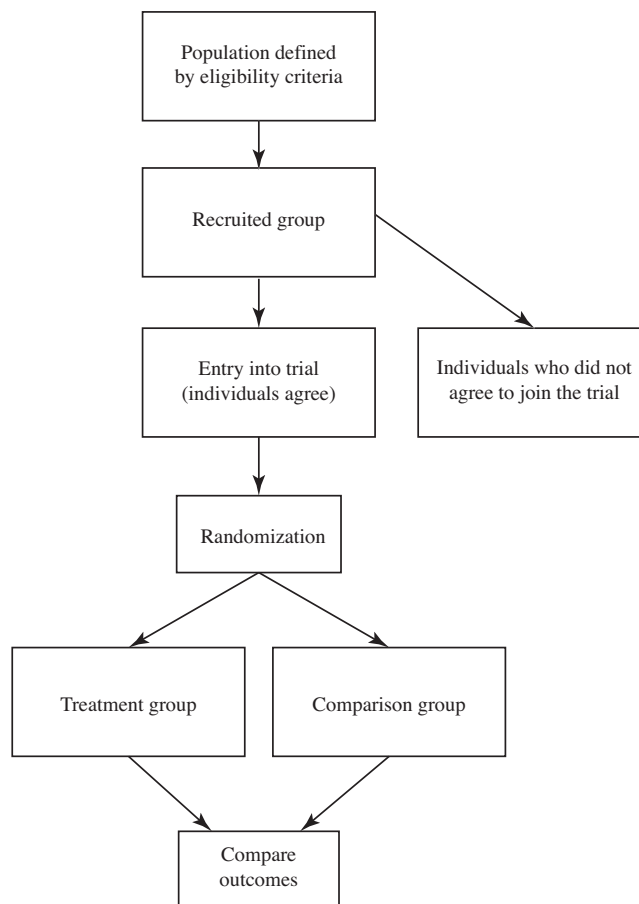


Figure 4.12: Procedure for conducting an RCT. Adapted from Figure 1.1 in (Matthews, 2006). See also, Figure 4.3 in (Glennerster and Takavarasha, 2013) for an illustration of both individual- and group-level randomization.

Here, the brief treatment of RCTs should not be interpreted as meaning that they are not important. Indeed, they are considered the "gold standard" for outcome assessment in development by many people and organizations. Humanitarian engineering as a field needs to know what works and what does not so that we can reduce the number of failures. RCTs provide an excellent way to give the field of humanitarian engineering confidence in its approaches, ways to be confident in claiming success, both of which will then allow us to build on our successes.

The treatment of RCTs here is brief simply because there are many excellent sources on RCTs. First, (Glennerster and Takavarasha, 2013) explains how to use RCTs in the developing world, and has great practical advice. RCTs originated in testing of medicines and in agriculture. For a coverage of the medical approach, that also has a nice treatment of the relevant statistics, see (Matthews, 2006). Background material on statistics is in (Devore, 2004).

## 4.10 Dissemination and Scale Up

In order to prepare to scale up a technological solution for application to a broad area, it is necessary to design a product so that it is easy to manufacture for scale up. Also, the issue of social business arises as it is one way, aside from a pure aid-based approach, to scale up a solution. All these issues are covered next.

### 4.10.1 Design for Manufacturing

There are only certain times when the constraints due to the need to consider manufacturing arise. The most common cases where they must be considered are when multiple copies of a product are needed in a community, the team wants to be able to "scale up" the solution for wider regions, perhaps via aid or a social business approach.

Manufacturing costs are a large driver in product costs and it is best to consider this fact right from the start of the technology product development. Design for manufacturing has a number of features (Ulrich and Eppinger, 2012) as we discuss next. First, manufacturing costs need to be estimated. The "unit manufacturing cost" is the total manufacturing costs for some time period divided by the number of units of product manufactured in that time period. However, it is difficult to estimate this as equipment for manufacturing may last many years, multiple products may be manufactured at one site, and the team may not know how many products will be manufactured (e.g., since this may depend on user acceptance or sales). Aspects of cost also include component costs, assembly costs (equipment and people's work and salaries), and overhead (materials handling, quality assurance, purchasing, shipping, receiving, facilities, equipment maintenance, etc.). Also, there are transportation costs to get the product to the client. There are typically "fixed" and "variable" costs, with fixed costs not changing based on the number of units produced, and vari-

> Design for manufacturing is needed when many copies of technology product are going to be created.

able costs depending on the number of units produced (e.g., if it costs less per component if you purchase many components from a supplier).

The team should try to reduce component costs as they can be the biggest cost drivers, and these should be identified and minimized. Sometimes, component costs are high simply because proper consideration was not given to component costs early in the design process and this may create significant opportunities for redesign to minimize manufacturing costs, without necessarily sacrificing product quality. Sometimes, components may need to be redesigned to reduce the number of manufacturing process steps and thereby drive down costs. Often, components should be available locally as this can drive costs down (and ease the maintenance process as replacement parts will then be easier to find). Typically, unit manufacturing cost goes down as production volume goes up ("economy of scale"); you should try to pick the right economic scale for a product. To drive manufacturing costs down, you should try to standardize components and the process and use "black box" component procurement (only specify input-output functionality to potential suppliers and let them compete with each other to provide functionality at lowest cost).

The team should seek to reduce assembly costs, which can result in reducing component count, manufacturing complexity, and manufacturing support costs. To minimize assembly costs, sometimes it is possible to integrate multiple parts into one and at other times it is possible to make assembly easier (e.g., by allowing parts to be inserted from the top, making parts self-aligning, making it so parts do not need to be oriented, making it possible to assemble with only one hand, making it so no tools are required, simplifying motions needed for assembly, and making sure parts are secured upon initial insertion) (Ulrich and Eppinger, 2012). Other times, it is possible to let the client assemble the parts. Sometimes it is possible to minimize overall manufacturing complexity, make manufacturing error proof, and this can reduce costs of supporting the manufacturing process.

It is important to view product development (covered mainly in Section 4.7) not as a step-by-step procedure but as an integrated activity that involves many influences from different parts. Design for manufacturing impacts many other aspects of the process, including: development time and cost, product quality, and environmental factors such as component reuse and life cycle costs (e.g., service costs).

### 4.10.2   Design for Scale: Opportunities and Challenges

To start, view the talk

<div align="center">Design for Lasting Impact at Scale</div>

given by Eric Reynolds from MIT D-Lab, on April 25, 2014.

You can think of the humanitarian engineering "design for scale" problem as being one of engineering technologies so that many "copies" can be made and put in the hands of people so that a project has the broadest possible positive impact. The question to the humanitarian engineer is: Do you want to

have a positive impact on one person, or $> 10,000$ people? Or more? "Scale" can be defined in different ways, but one logical approach is simply to use $N$ to measure it where $N$ is the number of people "owning," "using," or "being directly impacted by" the technology, at least to some extent. You can think of the differences in appropriate technology between the personal and community technology categories as being a simple example of differences in design for scale; however, there are other important cases. Scale is a significant driver in creating differences in humanitarian engineering projects.

Clearly, all aspects of PTD in Section 4.7, and manufacturing that is discussed in Section 4.10.1, will impact design for scale as you can think of "scale" as being a community need (so long as you assess the needs at scale) where $N$ for the "community" can be very large (e.g., a whole country or more). In such a conceptual approach, all the principles of PTD apply for the large community (e.g., in assessing needs you will need to go to many more communities), though the PTD process breaks down in ways (e.g., close communications and working together).

A frequent and natural approach in humanitarian engineering is to "scale up" via manufacturing and distribution ("dissemination") of many copies of what has been determined to be an effective personal technology, based on multiple individual cases. One approach to do this is social business (see Section 4.10.3) and another is via selling technologies to aid agencies who may then distribute (e.g., at a subsidized rate depending on what is appropriate). This has the potential to positively impact many people, and is thought of by some as a key current challenge for humanitarian engineering. Another way to scale up is to use PTD in several communities for a community technology (one designed for a group) for the same need if multiple communities identify a common need, and if the technology is successful in multiple communities, widen your definition of "community" to be a region, country, or beyond. Then, again, aid agencies or participatory social business (see Section 4.10.3) may handle scale up. Conceptually, the design for scale based on $N = 1$ and $N > 1$ (for a community) are related; however there are some basic differences such as the design for cooperation challenge. The design for large $N$ presents a number of additional challenges.

An example of a university-originated technology that is both innovative and had significant efforts to scale it up is the MIT D-Lab Canecoal project led by Amy Smith (see Problem 4.26). Of course, many NGOs, institutions, and governments are working on various scale-up projects. Some challenges to scale-up are discussed on pp. 68-69, and p. 108, of (Toyama, 2015).

> PTD projects can be scaled up for greater impact via aid or participatory social business.

### 4.10.3 Participatory Social Business

The principles of social business were covered in Section 3.5 via the perspectives of Prahalad, and Polak and Warwick. Some ideas on helping clients be better business people are in (Polak, 2009). Here, a *different* perspective on social business is presented where, as a part of PTD in a community, and should a community want to, a business that includes community participants, and

firmly has community members "in the driver's seat," is started with the intent of selling the technology, for instance, to other nearby communities in the region (or members of the same community). Even though the locals may only seek profit and not social impact for others, it will be called "participatory social business" (PSB) from the perspective that you will be helping create a business that will have social impact on the community that creates it. While this will require some persons with business expertise on the team, there are a number of reasons why a community may want to participate in such a social business:

*Participatory social business can empower and economically enrich a community.*

1. It may create jobs now, and the promise of jobs in the future.

2. It may create profits and local ownership.

3. It may be feasible as if it works well in one community, and there are similar communities in the region (often the case), then it is likely to work well in those communities.

4. It can be strongly empowering, cement community ownership, and be a natural end to the PTD process.

5. It may help with technological solution maintainability and longevity.

To get an idea of how the PSB start-up process might work, view the (17:09) TED talk by Ernesto Sirolli

<div align="center">

Want to Help Someone? Shut Up and Listen!

</div>

that is from Aug. 2012. In Problem 4.36, you will be asked to answer a number of questions about this talk. He says to listen to the people, but not in community meetings; he says that the problem with those is that the entrepreneurs (and the smartest people) never come and they will not publicly say what they want to do with their own money. How do they get to the smartest people? What does privacy have to do with it?

Another good and relevant video on PSB for engineering and technology is in Problem 4.35 where Cat Laine describes her work with the "Appropriate Infrastructure Development Group" in Guatemala. Also, a group that focuses on participation in social business is described at

<div align="center">

eKutir: Opportunity Driven by Knowledge

</div>

It is no small task to create a PSB and it involves many skills that engineers may not have such as marketing, financial management, and business models (for business model creation, see (Osterwalder and Pineur, 2010)). However, pulling necessary expertise into the team is often easy to do, and teaching the principles of the operation of a business to community members is certainly feasible. Indeed, in the spirit of the philosophy of participatory endeavors, expert business people will learn a lot from local community members about business constraints, context, and how the business should function. Also, they will be helpful in making sure that there is on-going maintenance infrastructure

(e.g., technicians) for support of a product. They may help understand what to do if components fail, such as how to find replacement parts locally. They will know how to set up a network of local entrepreneurs, and what are the best ways to incentivize locals' involvement in the PSB. They may be able to help with intellectual property and patent issues if that arises. Clearly, if the team is serious about starting a PSB, it will need to do significant additional study in a number of areas of business, and in particular the cultural context of business in another community (e.g., possibly how to deal with the issue of kickbacks and bribes, or other local business customs, that must be followed in order to be successful).

### 4.10.4 Reverse Innovation

There is sometimes the perception that technological innovation occurs only in the developed world, and that these innovations are transferred to the developing world. "Reverse innovation" refers to the development of technology for the constraints and goals of the developing world, and perhaps sales in their markets, and the transfer of the results to the developed world for profit-seeking in their markets (Govindarajan and Trimble, 2012). There is no reason why, however, a product must be tested in developing-world markets; a successful product that was produced via an aid program of some sort in/for the developing world may also be a good candidate for developed-world markets. Of course, for this case, the lack of testing in a local developing-world market may leave the developers and investors less convinced that it will succeed in a developed-world market. The flow of technological innovations, in both ways, developed to developing, and developing to developed, is studied in (Rogers, 2003) under the umbrella of "diffusion of innovations." See also Problem 4.15.

## 4.11 Humanitarian Engineering Fieldwork

Some principles govern the overall approach to humanitarian engineering projects, and there are practical guidelines for organizing people, selecting a project site, preparation, reflection, and individual/group accountability.

### 4.11.1 Two Governing Principles

There are two principles you should always follow when doing humanitarian work:

1. *Do no harm:* In doing humanitarian work it is crucial that in trying to do good, you do not end up doing harm (you may be reminded of the dictate to medical doctors, "above all, do no harm"). Again, potential risk for harm should be considered at each decision point in doing humanitarianism. You clearly do not want harm to come to the community

or visitors; this often requires attention to safety and health considerations. Also, ensuring you do no harm requires great cultural sensitivity and understanding of the community.

2. *Do what is best for the community:* In deciding how to go about humanitarianism, there are many decisions you will make along the way. It is wise, at each decision point, to ask yourself "what would be best for the people I am going to work with?" This often sharpens thinking, guides you in what to choose, and leads to good decisions. How many persons/engineers should participate/travel? What expertise is needed? What project should the focus be on, and hence get resources, finances, and time? Asking, in each case, "what is best for the community" often helps, and of course, it is crucial that the community themselves firmly enter into the decision making about what is best for them, to the greatest extent possible.

Do no harm and do what is best for the community.

These principles demand a sense of *humility* on the part of the visiting engineer as they create complex and significant challenges that go far beyond technical ones.

One way to help avoid the above problems is if the project team works to build good working relationships in the community, as discussed in the first part of Section 4.2.5; indeed, the whole participatory development approach is oriented toward avoiding a range of pitfalls in the development process. It is often "people problems" rather than technology problems that create the most difficulties on a project; hence, it is important to learn about issues in culture (Section 1.4), social justice (e.g., discrimination and marginalization) (Chapter 2), helping dynamics (Section 4.1), participation (Section 4.2 and Section 4.7), cooperation (Section 4.3.1), teamwork (Section 4.3.2), and the human side to project management (Section 4.3.3). Engineers sometimes dismiss the human side to technology as unimportant, but it is often the key to successfully using technology as a solution to a development problem (see, e.g., (Toyama, 2015)).

### 4.11.2 University Case: Aligning Learning Objectives With Community Benefits

In the case of university students going on project trips, each of the two above governing principles holds, but becomes more complicated:

1. *Potential harm by student novices:* Any engineer, but especially a novice one, can make mistakes and these can have significant adverse impacts on a community (if for nothing else, by destroying people's *hope* due to a project failure). In the university, students are allowed to fail. Is this acceptable when they are working with a community? Or, does a project leader have to step in to make sure everything works for the community, but then give the student a failing grade? Student accountability matters as some students need to feel real pressure to succeed, while others are naturally

very conscientious, but it is often impossible to predict how some students will perform and behave: project success needs to be directly proportional to students' own success, as measured by grades and feedback. This is discussed more below, but also see the discussion on project failures and unintended consequences in Section 4.9.2.

2. *Student learning–community benefits balance or alignment?:* The objectives of a university-run humanitarian engineering project are multidimensional, but two key issues are (i) providing an engineering fieldwork experience that is authentic and promotes significant learning by students; and (ii) simultaneously providing a significant benefit to the community. Student learning objectives need to be *aligned* with creating benefit for the community. Students are supposed to be learning how to develop technologies that help people. It should not be that you are balancing competing objectives of student learning and community benefits; if you are, you need to reconsider how your program is designed. As an example, in a project that is high on humanitarianism content, but very low on engineering content, are engineering student learning objectives being well-served (see Section 1.5.4)? Generally, no. Is it possible that there is lots of engineering content, but little connection to the target community and hence little humanitarian content? Yes. Is the community going to benefit from that? Clearly, the best projects are ones that simultaneously achieve learning and community objectives (i.e., the two objectives are mutually reinforcing); however, sometimes maneuvering a project to achieve this *alignment* is challenging. Most often, the community (or NGO) is not very concerned about student learning objectives so these typically have to be managed by someone from the university (e.g., a professor).

Long-term impact on students must be considered. Many students find even a short-term (e.g., 10-14 days) project to be transformative and say it "changed their lives" or "changed their viewpoints." The whole experience can be "humbling," "eye-opening," help students understand their position of privilege, and appreciate more what they have. It may motivate a life of working for social justice, at home and abroad.

It should not be that the developing world is viewed or treated as a classroom or laboratory where all that happens is that the students gain a good learning experience, a new type of colonialism (Riley, 2007). Some advocate the notion of "fair trade learning" that says that what the project trip members give should be roughly equal to what they get (learn) (Fair-Trade Learning, 2013). In any case, there must be learning about engineering *and* community benefits, or a trip can degrade into "poverty tourism" or a type of "voluntourism" that is heavy on tourism.

Project site choice, partner/community relations, preparation, project management, reflection, and accountability all affect how to cope with the above issues.

### 4.11.3   Getting Organized and Picking a Project Site

Here are a few ways that humanitarian engineering groups form:

1. *Universities:* In universities, there are often student organizations that set up projects, often with the help of a faculty or staff advisor. Other times, such trips are set up as part of a service learning or study abroad program, or both. For graduate students, sometimes project trips are part of a research program that their advisor is running.

2. *Groups from companies or other organizations:* Sometimes, engineers "self-organize" at work (e.g., over lunch) and band together to form a humanitarian engineering group. Other times, such activities can occur as part of a "corporate citizenship" ("social responsibility") program. Sometimes, such groups form as part of a local engineer's group (e.g., local chapter of a national organization) or a church.

Usually, when such groups form, they discuss "where to go and what to do." Choice of a project site is crucial to the overall project success. It impacts the "degree" of humanitarian engineering, the overall project feasibility in terms of engineering challenges, and financial viability of a trip.

   Some example project sites include: (i) a small living community (that is perhaps part of a larger one); (ii) an orphanage; and (iii) a disadvantaged school or university for a STEM education program (see Section 4.8). Which ever site is chosen, some key issues in site selection may include a possible community assessment (or parts of it) as described in Section 4.4 and (some work done toward) project selection as described in Section 4.5. A site selection process would also typically include the following:

1. *Partner:* If you are an outside visitor to a site where you want to do humanitarian engineering work, it is very important to establish a strong partnership with someone who lives at or near the site. They can provide guidance on a whole range of issues. For universities, this may be an Alum as they likely will stand behind your educational mission and know a lot about what to do at a site. For a company, this may be some in-country affiliate of the company.   It could be good to partner with an NGO at the site. They can provide significant help, including helping to define problems (though they should normally not be the only ones specifying problems; the local community should be consulted too via your own visits). Even if you work locally in your own country, it is most often best to work with a local social services organization to do a humanitarian engineering project; respect the value of the "helping professions" and the general lack of knowledge engineers often have about how to directly work with some populations.

   Having a good local partner is often a key driver of project success.

2. *Security and health:* Security is often a significant concern as you certainly do not want any member of your team to get hurt during a trip. It can be difficult to understand the local security situation "on the ground" for

many regions of the world, but one source you can consider that evaluates security at the country level is the

US Dept. State Travel Warnings

Probably the best source for local security conditions can be your partner living there. They know where to go, and not go, to stay secure. Next, availability of local healthcare facilities should be evaluated in case a member of the team gets ill (e.g. is there a clinic or good hospital?), including due to unclean water, food contamination, insect bites, diseases, etc. Sometimes, universities put their students on special "global insurance" to ensure they can get medical care or a life-flight to a top-rate medical institution if they have a major health problem. Of course, this is a good idea for any traveling engineer. You should get evaluated by your doctor for whether you need shots or medicine to avoid diseases.

3. *Food, water, housing, transportation:* Ensuring all these are present for the whole team for the whole trip can be a significant logistical challenge. The difficulties with coordinating all these may make you want to choose a partner who can do at least some, if not all, these things for your team, as some NGOs do.

4. *Good engineering problems:* Typically, one of the criteria for site selection is that there are good challenging engineering problems at the site, some that can be immediately addressed, and others that cannot be immediately solved, but ones that may present challenges over many years. Sometimes, there is a desire to "match" the types of problems with the envisioned group that will travel to help solve them; however, other times the group may not be fully defined before a site is chosen (e.g., sometimes, in the case of a university) and in this case typically you may seek a site that has a wide range of engineering problems, ones appropriate for a range of engineering disciplines. Another issue is assessing how amenable the community is to welcoming visitors and working together with them on an engineering problem.

All these issues affect the final cost of the trip per person. Ways to get these costs down are to travel to somewhere that is closer so that the plane ticket does not cost as much. It may be possible to reduce some of the food and housing costs in some countries, but you may not want to reduce them if it means creating health and security risks. Besides, often these costs can be quite low anyway.

Sometimes, given a good connection to a partner, it is possible to learn about a few of the above issues over the internet; however, before taking a trip (or leading a trip) with a group you will *definitely* want to have 2-3 persons from your group travel to the site in question to assess all the above issues (i.e., an "assessment trip"). Typically, you can learn much more in person than you can via phone calls or the internet. You simply have to see it all. Often, on such

an assessment trip it is a good idea to meet with the partner and community to establish how the reciprocal relationship will work. Who provides food and housing? Transportation? Broadly, what engineering projects will be pursued? Who will take care of maintenance when the group leaves? How are issues of liability dealt with? Who is going to be on the team? How will the project end (Amadei, 2014)?

### 4.11.4 Preparation, Reflection, and Accountability

In a university, there are often courses that are required before travel, such as a "service-learning" course or a capstone design course sequence. Often, students also take courses in other areas like development studies or social work (see a list of relevant areas/courses starting on page 714). Another way to prepare is to read this book and listen to the associated lectures here (e.g., newcomers should study much of this book, but particularly Section 4.2.5 and Section 4.3)! You should also prepare by reading a history of the country you are going to, and learning about many aspects of their culture, economics, and politics. This will enrich your visit experience. It can be especially useful to learn about a country if you can find someone from that country locally (i.e., someone from the country's "diaspora") and get together to discuss the country, or have them come to class to give a presentation.

Group trips often have a "leader," and sometimes for a university trip this is the faculty or staff, but there may be a (designated) student leader also. It is best that the group work together on the engineering design, learn about the country, and have some social events to make sure the group is a well-functioning cooperative unit before travel. The attitude of each member of the team taking the trip matters. You should view taking a trip for a project as an opportunity (privilege) and not a sacrifice. Each member should have a humble attitude in the face of the very difficult challenges presented by doing good humanitarian engineering fieldwork at a remote site (if a team member thinks it is easy, they do not really understand what is going on, or the project is poorly designed). Each individual needs to have an open/learning attitude with respect to culture and the way things are done in the location you are going to (e.g., in some countries there is not much respect for time and schedules and in such cases it is important that everyone is "flexible" and changes expectations on how and when things get done).

"Reflection" means to reconsider what was done or what happened. In the context of a humanitarian engineering project trip there are many approaches to reflection:

1. Written personal (private) diaries made each evening (sometimes called a "journal").

2. Daily discussions on what is happening (e.g., each evening).

3. Written report to be completed by the end of the trip or shortly thereafter.

4. Audio or video diaries made each evening, sometimes by taking turns in a group, where each individual says one to two things that were notable or memorable from the day. Normally, this leads to good discussions after the taping session.

5. Presentation to a group (often, not just the members of the team), the community, or people back home, with question/discussion time allowed. Sometimes, coupled with the above final report, this is a part of a student's (or student group's) grade for the humanitarian engineering project.

One concrete approach to reflection, via the above methods, is to ask the following two questions:

1. "Who is being helped?"

2. "Who is helping whom?"

After the obvious answers, it can be good to ask the group "Who here was helped, and how?"

The importance of accountability in development was discussed in Section 3.2.2. The key issue is that humanitarian engineers must be held accountable to succeed; otherwise, there might be significant consequences for project failure for a community, but no repercussions for the visiting engineers aside from feeling bad. One approach to establishing accountability is to have an agreed-upon accountability to each other, so that people will not want to let other team members down (see Section 4.3). For engineers from industry, one strategy for self-imposed accountability is to make a team agreement that project success, with explicit metrics, is inversely proportional to the amount the team will donate in cash to an agreed-upon charity. In a university-based project, the main quantitative mechanism for generating accountability by students is grading. In a university, the preparation courses and reflection can be graded and become part of the assignment of a total grade for the student's contribution to the humanitarian engineering project. This creates at least some level of accountability for the students. It is best to establish a rubric that is given to the students before the project starts that clearly says how they will be graded. Such a rubric could include an aggregation of the grades for: (i) technical contribution, (ii) cooperation/team work, (iii) engagement with the community, and (iv) cultural, historical, economic, political understanding of the site. To maintain a high level of accountability, high standards of academic excellence must be used for the rubric, no different standards from how other engineering courses are graded (e.g., avoiding grade inflation pressure since "these students are giving of their own time and money in order to make the humanitarian engineering project happen"). I know that is controversial in some few cases. Also, however, would it not make sense to let the client/community grade the students, or let individual clients' or community views at least help determine student grades (e.g., via brief discussions by the faculty with community members)? Or, could a community partner (e.g., NGO) or leader help with grading? Clearly, this might be asking too much, and sometimes simply would

> Mechanisms for accountability of visiting engineers must be agreed upon before a project.

not work. Yet, could agreed-upon performance metrics (measuring quality of the project) be agreed upon by all, including students, faculty/staff, and the community, early in a project, and then make grading proportional to those metrics (e.g., make the grades, or at least part of them, proportional to the level of contamination on the water coming out of a community-implemented water filtration system)?

I feel that a professional humanitarian engineer in training would agree to some sort of accountability if they are truly concerned about clients and communities. Likely it is best to use a dual approach: Can rewards or awards be given for the highest student performance on a team, or the best student humanitarian engineering project each year for a whole humanitarian engineering program? What should the metrics be to judge such awards? Client/community satisfaction or level of educational attainment by students? Both?

## 4.12 Models, Dynamics, and Analysis of Sociotechnological Systems

A "sociotechnological" system is a dynamical system that includes technologies and humans in a close interaction. Some sociotechnological systems are "socioecotechnological systems," ones that also include the environment in an intimate way. Here, cooperative management of community technology is studied as one example of a sociotechnological system. Following that, modeling and analysis of the impact of technologies on a community is studied where sustainability is considered, that is, a socioecotechnological system. Finally, general characteristics of the emerging field of "computational humanitarianism" are outlined by summarizing such approaches studied in this book, and pointing out future directions in this area.

### 4.12.1 Cooperative Management of Community Technology

Continuing with the line of reasoning in Section 4.3.1 on cooperation, and Section 4.6.3 on technology for cooperation, here we study approaches to cooperative management of community technology, that is, how people and technology can work together to manage the operation, maintenance, and replacement of technologies that are shared by a community. Several related topics and ideas have been covered already. In Section 1.6.7, and also Section 2.4.5, modeling and analysis of the dynamics of the tragedy of the commons and environmental justice were studied. In Section 2.2.2 the related issue of the "common good" was discussed; indeed, in a number of ways, cooperative management of community technology is one specific application of the idea of the common good. In Section 3.6.6 the control of an environmental justice policy was used to regulate the dynamics of the commons so that a tragedy was avoided. Management of community technology is clearly related to the management of "common pool

resources" as discussed in Section 4.2.11, and also in (Ostrom, 1990; Meinhardt, 2002; Mansuri and Rao, 2013). On the other hand, while community technology can be thought of as a common resource, and indeed community technologies are often used to provide resources or services (e.g., a water pump), community technology is different from the resources in these earlier sections that have *continuous* renewal and growth. Technology degradation due to use and aging could perhaps be broadly thought of as a type of resource use in the earlier sections, and repair and replacement as a type of resource renewal. Often, however, such a broad analogy may not be useful due to the very different dynamics (e.g., probabilistic and discrete) associated with shared technology, compared to shared natural resources (e.g., a forest or fishery) that are studied for the tragedy of the commons.

Before reading this section, first view the movie "The Water of Ayolé" in Section 4.7.1 that you can find on the internet and that is considered in Problem 4.20. While this Ayolé project only considered one community technology, it is still quite relevant to the key issues discussed in this section, especially the issue of whether it is better to have humans manage a community technology, a technology that fully automates the management, or a combination of the two, which is the approach below ("semi-automated").

### The Community Technology Management Problem

Suppose a community technology is installed. Examples could include some energy source (e.g., biodigester), water pump, sanitation service (e.g., toilets), or a cell phone charging station. Community technology management involves:

1. *Operation:* The technology, especially if it is complex, must be operated so services or goods are provided properly (e.g., in adequate quantity and quality), and equitably among users, where "equitable" should be defined by the community. While there may be some cases where virtually any user can operate the technology (e.g., some pumps), in other cases someone may need to attend to the technology's operation and typically this person would have to be paid in some way.

2. *Maintenance:* Technology, especially under heavy use and aging, breaks down. This can require repairs or replacement, both of which most often cost money, and at least someone knowledgeable in how to repair the technology.

Here, "management" includes operation and maintenance. Management costs money, community member time, and/or may require local community talents. A simple case for community technology use is depicted in Figure 4.13. The boxes represent technology resources, a water pump, toilets/sanitation, and a cell phone charging station, and the circles represent users/persons. In this case, each person uses each community technology resource, but the pattern and frequency of use is not shown.

In general, suppose the technology resources are numbered by $j$, $j = 1, ..., M$, and the users are numbered by $i$, $i = 1, ..., N$. Let $r_{ij}(k)$, $r_{ij}(k) \geq 0$, denote the

*Management involves operation and maintenance.*
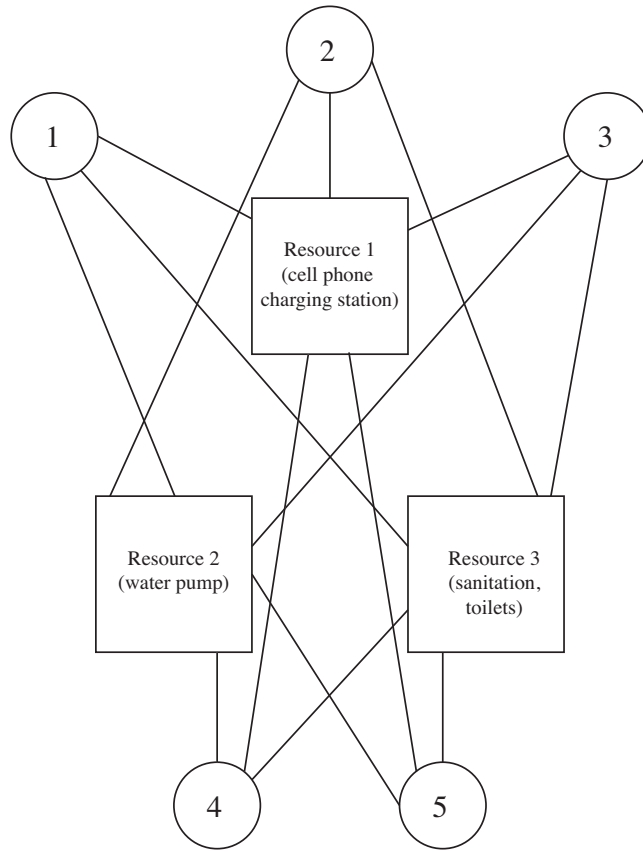
Figure 4.13: Example of community technologies.

amount of good or service from technology resource $j$ obtained by user $i$ at time step $k \geq 0$. In some cases, it is possible for multiple users to obtain a service simultaneously (e.g., for a cell phone charging station with multiple outlets), while in other cases this might not be possible (e.g., a pump that can only accommodate giving water to one person at a time). In some cases, $r_{ij}(k)$ may be discrete (e.g., one use of a toilet), but in others it could be continuous (e.g., obtaining more or less water from a pump or varying amounts of charge on a cell phone). Some users may not use every resource, and the time sequence that they use resources may vary. In some cases it may be possible for a single user to simultaneously access multiple resources (e.g., charge a phone while pumping water). In some communities, the value of $N$ may vary over time. All these issues can significantly impact technology management.

Assume that users must pay for technology services so that money can be collected for management. Let $p_{ij}(k)$, $p_{ij}(k) \geq 0$, denote the per-unit price of goods or services from technology resource $j$ obtained by user $i$ at time step

$k \geq 0$. If user $i$ buys $r_{ij}(k)$, the user pays $p_{ij}(k)r_{ij}(k)$, $k \geq 0$, so that the more they purchase, the more they pay. Strategies to set prices will be discussed below.

Collected money is used for operation and maintenance of the technologies. The problem of determining the amount of money needed for technology management is most often nontrivial, but falls within the scope of typical engineering practice. Determining operation costs can depend on whether people need to be paid to operate the technology or attend to it. This is discussed in the next section. Maintenance costs, that include repairs and replacement, often depend on an analysis of the "mean time between failures" (MTBF) for a technology. Such analysis typically must consider a wide range of factors, including how heavily the technology is used; effects of temperature, humidity, and other factors; failure rates of components of the technology that may depend on strengths of materials and other factors; and other issues. Such analysis can be very different for different technologies. Of course, the costs also depend on what is locally available and whether prices are projected to increase or decrease. If you have multiple technologies that are being managed as in Figure 4.13, it may be that you can pool the money from all technologies and then perform repairs on specific technologies as they fail. However, in some cases this may not be possible as individuals may "own" a technology and only allow funds collected for it to be used for their technology. In this section, such issues are generally ignored and it is assumed that the whole community owns all the technologies.

**Management of Community Technology by People**

Suppose that for Figure 4.13, the technologies used are operated and maintained by people in the following ways:

- People are stationed at each technology as long as needed each day to provide services to others (for some technologies, that can be locked down, this may involve only making the technology available for certain time periods). For instance, someone may sit at the cell phone charging station and help people charge their phones and at the same time ensure the security of the technology against theft or abuse. Similarly, someone could help operate a water pump or sanitation facility.

- The people at the stations charge people for services, collect and account for money that they would transfer later to a "community bank," whatever form that may come in. It may be that some community leader or committee sets the pricing, likely using guidelines on MTBFs discussed above.

- People tending to technologies could help ensure their fair use (e.g., via lines) by community members. They could report the need for maintenance as it arises.

- Likely, the prices of services would have to be raised so that the individuals tending to the technologies can be paid. Alternatively, in some contexts

> it may be possible to expect a person to tend a technology in exchange for their own use of services.

"Jobs" of attending technologies may have significant value for some community members.

There are a number of problems that can arise in having people manage technologies:

1. *Reliability:* Will the people *always* be there, or will they be tardy or absent at critical times? Will they leave a technology unattended for long time periods, thereby enabling free use or abuse of the technology? In such situations, will the person be paid anyway?

2. *Corruption:* There are a number of problems that can arise: (i) Theft of payments, or "skimming off the top," (ii) Giving away services to family and friends, (iii) Setting unfair pricing (e.g., for someone the person does not like, or due to discrimination).

3. *Pricing sophistication:* Can a person, even supported by inputs from a community committee, set prices appropriately to ensure that there is enough money for repairs and replacement? Repairs and the need for replacement come at random and unpredictable times, and sufficient reserves may not be collected to ensure success of the system (collecting too much money is clearly not good either as it drains people's resources). If this results in regular breakdowns and loss of services for long time periods, this can result in hurting the confidence of the community in the system, destroy hope, and even lead to project failure.

On the other hand, there can be some unexpected benefits from having humans cooperate to manage a community technology. This is clearly shown in the movie "The Water of Ayolé" in Section 4.7.1 where as the result of the project: (i) women were empowered in decision making in the community as they had authority when it came to water as water-gathering was traditionally their job; and (ii) by learning about cooperation for the pump, the community began to cooperate on other projects that would benefit the community. Benefits of this type may not come from the automated management approach discussed next.

### Automated/Semi-Automated Management of Community Technology

Another approach to the management of community technology is to automate the process to the greatest extent possible. This is not an unusual proposal. Much of the developed world takes this approach with shared technology resources. For instance, consider the case of utilities providing electricity, sanitation, and water. People pay their bills (often generated with information technology, and sometimes automated payments are used with deductions from your bank), and then gain access to the benefits of the technology. From the

*There are advantages and disadvantages to having people manage community technology.*

funds, people are paid to operate and maintain the technology. Here, the only real differences are (i) one of scale, where we envision possibly small numbers of people being served by the community technologies; and (ii) the fact that we envision very low-income individuals being the clients so that setting low prices is crucial, even in the face of trying to keep the technology properly maintained.

To automate, suppose that there is an electro-mechanical device at each technology:

1. Suppose it displays prices and enables the gathering of money. One approach would be a coin-operated system, bill-operated system, or a system where cards/tokens are sold by a committee and swiped/collected. An electrical system may be problematic in some situations where a battery is not sufficient and there is no electricity.

2. It is best if the system can log in payments and keep track of timing, amounts of services, and payment amounts over time. Such data can be very useful for assessments of the effectiveness of technologies, and to make sure that there is continuous operation in providing services. For some cases, it may be possible to transmit information like this to a remote site and it could then be used in assisting the community with repairs or replacement.

3. It may be useful to have the technologies on a wired or wireless network so that pricing can be coordinated across the whole system. For instance, if one technology is only rarely being used, the price could be lowered on it to encourage use, and raised on another technology to cover costs.

4. Automation costs money, such as for electro-mechanical devices, but these costs may primary be up-front costs, not on-going costs (aside from maintenance). Also, such costs may be offset by not needing to pay human operators. On the other hand, by automating, you eliminate the possibility of creating jobs for individuals to tend to technologies.

Even if an automation approach is rejected, studying how to automate it, especially the setting of resource prices, can be highly valuable for teaching a community how to manage technologies (e.g., it may lead to a practical set of guidelines for management that takes into account many complicated issues like MTBF and the value of dynamic pricing as discussed below).

After evaluating the people vs. full-automation options, it may be that a "middle of the road" solution is desirable where a mix of automation and people are used. For instance:

*Automation or semi-automation of community technology should be considered.*

1. It could be good to have people collect money, input via a keypad the amounts, and get paid as employees.

2. However, the prices $p_{ij}(k)$ could be set and changed by a computer, possibly over a network of technology resources. Then, the price would be displayed to the user and the person tending the technology (to help avoid corruption), and payments would be made.

3. If electrical power is lost, the system would revert to manual operation, using an agreed-upon set of prices.

4. If a person leaves their station, or does not show up for their job, then there can be a way to go to a fully-automated mode so that there is not an interruption in services.

It may be that, in addition to the above functionalities, there are explicit ways to deal with problems of inequality in a community:

- In an automated approach, money could be taken out of the pool of gathered money and used to "pay" (internally) for services for an individual user, or perhaps to subsidize their use by reducing their prices. Criteria for such help could be based on their usage/payment patterns as determined by the records in the system. This would amount to a type of wealth redistribution (e.g., as studied in Section 2.4.3) as helping someone pay by reducing their prices, even partially, will essentially come at the expense of the whole community of users who are contributing to the pool of maintenance money.

- There could be community-based voting on how generous the system should be to individuals. Such a strategy is easy to automate (e.g., see relevant ideas in Section 2.4.4) and such a solution can provide a type of privacy for those receiving benefits that may be valuable. Alternatively, a community committee could vote on reducing prices for less-well-off individuals. Such price reductions may be input into the automated system, or handed to persons operating a technology. A solution via people, however, may cause problems for some people who may feel that such preferential treatment of some individuals is not fair.

It may also be possible to study usage patterns to assess if some community members are being discriminated against.

A key question, prompted by the movie "The Water of Ayolé" in Section 4.7.1, is whether the appropriate parts of the problem can be left to the people of the community (not automated) so as to promote empowerment of marginalized individuals and community cooperation on other important matters? There may be no one single answer to such a question. High levels of automation may be appropriate for some communities, but for others any type of automation may be bad.

### Feedback Control for Community Technology Management

Consider one technology resource, $M = 1$, and three people, $N = 3$. Assume that all three individuals can be serviced by the technology simultaneously (e.g., a cell phone charging station). Assume a discrete time formulation with time steps $k \geq 0$ (e.g,. corresponding to days or weeks). Since there is only one resource, simplify the notation to $r_i(k)$ for the amount of service from the technology by user $i$ at time step $k$, and $p_i(k)$ the price for user $i$ at time $k$. Here, the

> There are ways to address inequalities in a community when considering management of community technology.

$r_i(k)$ are set to be constants of 5, 7, and 8 but with uniformly distributed noise added on from the range $[-2, 2]$. This represents that users demand different levels of resource services at different times, and use levels that are somewhat unpredictable.

Let $c_m(k)$ denote the amount of maintenance costs at time $k$. Let $m(k)$ be the total amount of money available for maintenance at time $k$. Let $m_d(k)$ be the amount of money that should be on-hand for maintenance at time $k$. Then the amount of money available for maintenance at the next time step, $m(k+1)$, is

$$m(k + 1) = \max \left\{ \left( m(k) - c_m(k) + \beta \sum_{i=1}^{N} p_i(k) r_i(k) \right), 0 \right\}$$

The "max" keeps the money value positive or zero. Here, if $\beta = 1$, $m(k+1)$ is the amount available at the current time step ($m(k)$), minus maintenance costs at that time, plus the total income at that time. If $0 \leq \beta < 1$, then the amount earned at time $k$ is reduced by

$$(1 - \beta) \sum_{i=1}^{N} p_i(k) r_i(k)$$

which is paid to people helping operate the system. Here, for simplicity, we let $\beta = 1$. Of course, values for $c_m(k)$ would normally be set so that $m(k) \geq 0$. Let

$$e(k) = m_d(k) - m(k)$$

be the "error." Here, $m_d(k)$ is set to ramp up initially to a value (so that in the initial period prices are not too high) and then is held constant. Also, at $k = 200$, we assume that a repair is needed such that $c_m(200) = 50$. It is relatively easy to use different $c_m(k)$ profiles. One that may make sense is to set the timing of the occurrence of costs via $c_m(k)$ to be inversely proportional to the MTBF for a technology.

Let the "pricing signal" $p(k)$, be

$$p(k) = \min \left\{ \max \left\{ 0, Ke(k) \right\}, \gamma \right\} \tag{4.18}$$

where $K > 0$. This ensures that $p(k) \in [0, \gamma]$ so that prices never go negative and never become larger than $\gamma > 0$. Here, $\gamma = 0.3$. Note that this corresponds to using a nonlinear "proportional" feedback control with a gain $K$ that can be adjusted. Here, we let $K = 0.02$.

The objective of the feedback system is to adjust the prices $p_i(k)$ so that $m(k) \to m_d(k)$ as $k \to \infty$ and indeed if $K$ is adjusted properly the transient response will be such that $m(k)$ will quickly become identical to $m_d(k)$. Also, note that this strategy ensures that there is no problem with *random* occurrences over time of failures/repairs. When such failures occur, money is available for fixing the problem, and then the feedback controller will react to increase prices to replenish funds for future repairs. All that remains is to define how user prices $p_i(k)$ are set based on the pricing signal $p(k)$.

Feedback control offers one approach to manage the gathering of funds for maintenance.

Suppose that prices for each user are set according to

$$p_i(k) = g_i p(k)$$

where the parameters $g_i$, $g_i \geq 0$, $i = 1, ..., N$, are such that

$$\sum_{i=1}^{N} g_i = 1$$

Hence, you can think of $p(k)$ as the total price and $p_i(k)$ as individual prices and taking the sum on both sides of this equation we know that

$$\sum_{i=1}^{N} p_i(k) = \sum_{i=1}^{N} g_i p(k) = p(k)$$

The prices set for individual users add up to the total pricing signal. The $g_i$ set the percentage of the total price that each user is responsible for. Below, we will adjust the values of the $g_i$ to study their effects. Normally, these $g_i$ gains would be set by the community committee mentioned above. How? For instance, they could be set as follows:

- *Equality:* Let $g_i = g_j = \frac{1}{N}$ for all $i, j = 1, ..., N$, so that everyone's prices are set the same.

- *Inequality:* Skew the values of $g_i$ so that some are low and some are high, but so that they still sum to one. In this case, persons with the high $g_i$ values will be given higher prices and persons with low $g_i$ values will pay less.

> It is possible to incorporate ways to address community inequalities within a pricing strategy.

Both these cases will be considered in simulations below.

An alternative strategy to the one in Equation (4.18) would be to use

$$p(k) = \min\left\{\max\left\{0, \frac{Ke(k)}{r(k) + \epsilon}\right\}, \gamma\right\} \tag{4.19}$$

where $\epsilon > 0$ is a small number to keep the denominator from being equal to zero. Since (i) $p(k)r(k)$ is the total money obtained from services sold; (ii) $Ke(k)$ is the percentage reduction in the error $e(k)$ by all users; and (iii) ignoring the min-max part of the above formula, and $\epsilon$, the price is set via the formula $p(k)r(k) = Ke(k)$, via which solving for $p(k)$, we get the $\frac{Ke(k)}{r(k)}$, and then modifying it via $\epsilon$, we get the formula above. This strategy for setting prices takes into account usage levels by all users. For example, if usage is high (low), prices are set lower (higher, respectively). We will *not* use this strategy in the next section, but it does appear in Problem 4.61.

To cope with the $M > 1$ and $N \gg 1$ cases, and the possibility of networking the $M$ resources, will require additional pricing strategies, possibly based on summing up the money collected for each technology. Moreover, other constraints are likely to become relevant such as a requirement that prices not fluctuate too much, become zero, or go above some preset level. The acceptability of price fluctuations and maximum allowable prices could be set by the community.

**Computational Analysis of Community Technology Management**

In this section, we use Equation (4.18) to set prices. Let $g_i = \frac{1}{3}$, $i = 1, 2, 3$. The results are shown in Figure 4.14. The resource use patterns for $r_i(k)$, $i = 1, 2, 3$, over one year, 365 time steps, are shown in the upper-left plot. The prices, $p_i(k)$ and pricing signal $p(k)$ are shown in the upper-right plot. Here, it can be seen that the pricing for each user is the same due to the choice of the $g_i$. The actual amounts of money collected from each user, and the total amount of money collected, each time step, are shown in the bottom-left plot. The action of the feedback loop is best seen by considering the bottom-right plot along with the others. Here, in the bottom-right plot, the red line is $m_d(k)$ and the blue one is $m(k)$. The values of maintenance costs are shown via the small black circles. Notice that they are all at zero except at $k = 200$ where $c_m(200) = 50$, the single black circle in the middle of the bottom-right plot. Notice that initially, funds are built up, then when the maintenance costs at $k = 200$ are incurred, the funds are depleted some to pay for repairs. Notice that in the initial phase, prices are set higher (upper-right plot) and more money is collected (bottom-left plot) so that the $m(k)$ value moves up to be able to meet maintenance cost demands. Later, when maintenance costs are incurred at $k = 200$ there is a similar pattern by the feedback controller where prices are raised until enough money is collected to pay future maintenance costs. Adjusting the value of $K$ to a lower number like $K = 0.01$ results in an overall slower response, where prices are not increased as fast (do not fluctuate as fast) and funds are not collected as fast, but then $m(k)$ is not as well-regulated to $m_d(k)$. Clearly, the meaning of a time step (duration) affects whether price fluctuations are fast or not.

Let $g_1 = 0.5$, $g_2 = 0.3$, and $g_3 = 0.2$. This is a case where a community committee decided that user 1 would be charged the most, user 2 charged less, and user 3 charged the least. The results are shown in Figure 4.15. Notice that there are differences compared to Figure 4.14. In particular, the upper-right plot of Figure 4.15 shows that the users are given different prices due to the $g_i$ values being different. Also, the amounts of money collected for the individuals are different as shown in the plot in the bottom-left. The bottom-right plot shows that in spite of charging different users different amounts, the amount of money available for maintenance is similar to the equal case in Figure 4.14. This is simply because while some are charged less, others are charged more to compensate.

## 4.12.2 Dynamics and Analysis of Technologies in Sustainable Community Development

It is important for an engineer working with a community to develop a technology to think more broadly about the impact of that technology on the community. In particular, it is useful to view the community as a dynamical system that includes people, technologies, the environment, etc. Here, a model of a community is developed (a socioecotechnological system), simulated, and used to study the impact of technology on sustainable community development. Such
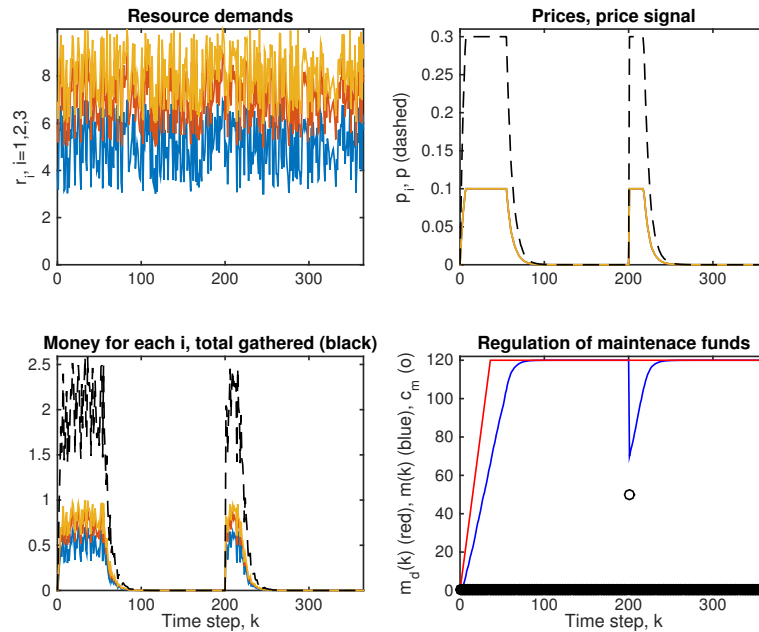
Figure 4.14: Cooperative management of community technology, case where there is equality among users.

a tool can be useful in design of a technology, and outcome assessment for a technology.

### Engineers Without Blinders: Considering the Social Context of Technology

As pointed out in Section 4.9.3, a proper assessment of a technology embedded in a community can only be properly completed by taking into account technology-community dynamical interactions. Engineers often use mathematics, science, and computational approaches to develop and evaluate the performance of a technology (e.g., a product). Considering that humanitarian engineering demands also the use of the social sciences, it is natural to simulate the technology along with the social context within which it is used (e.g., community) in order to evaluate its influence on multiple people, and use that information to redesign the technology to make sure it meets the needs of a community. Here, this is referred to as "engineers without blinders" (EWB), to highlight the need for engineers to think of the broader context of what they are doing. Simulations of technology-community dynamics is one approach to understand the impact of technology on community and community on technology. Simulations are never perfectly accurate, of course, but even the act

Engineers without blinders understand the impact of technology on a community.
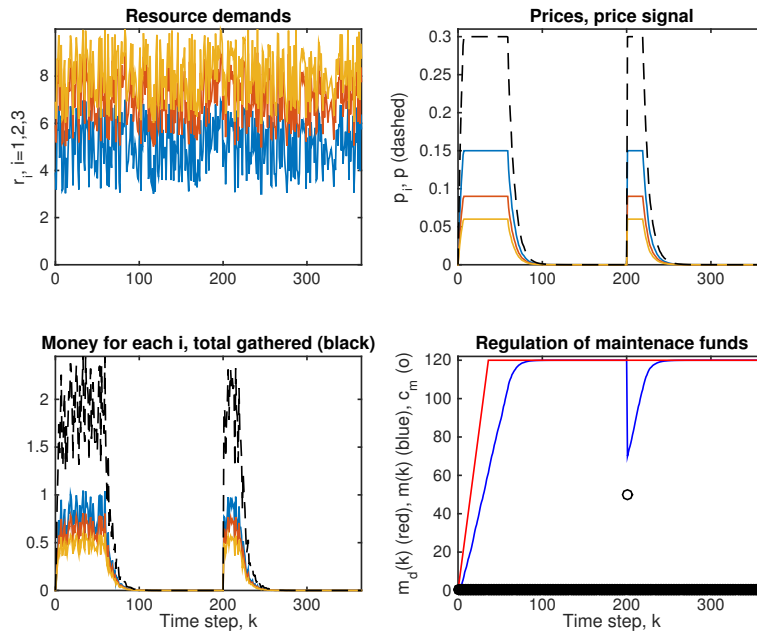
Figure 4.15: Cooperative management of community technology, case where there is inequality among users.

of creating a simulation is very instructive since it forces the engineer to take off their blinders and move past the boundaries of the technological product itself (e.g., the choice of components like resistors or capacitors), and consider its broader impact. Of course, "broader impact" can mean more than just the humans that are present, it can also mean the environment, later generations, and nearby villages in the region. An additional benefit is that simulating the technology embedded in its social context can tend to make the engineer more realistic about the impact of her humanitarian engineering work, and make clear the importance of the humans involved. Clearly, to do a good job at simulating the social context it will be necessary to talk to people in the community to get the dynamics of the social context right. Consideration of the social context of a technology is not a new field. Social context is considered quite carefully in a whole range of technologies, including cell phones, IT services, etc.

**The Community Modeling Challenge**

Creating a mathematical or computational model of a dynamical system requires different information sources, such as:

- *Science:* In traditional engineering this may include physics, chemistry, and biology. In humanitarian engineering, these are clearly important, but the social sciences also become relevant. Typically, science provides "first principles" for modeling, including in the social sciences case.

- *Data:* Experimental science often uses data from experiments to help construct models, sometimes to validate theory, and other times to provide ideas on how to extend theory. Experiments are done in virtually all areas of engineering. Conducting experiments in humanitarian engineering can be especially challenging as large and complex sociotechnological systems are typically considered (e.g., technologies embedded in a community).

No model is perfect. A model is an approximate representation of some piece of reality: the mathematics or computer simulation is not the real system. It can be difficult to (i) judge how good a model is, (ii) know how to adjust a model so that it better fits reality, and (iii) know how good is "good enough." Consider the following quote by Albert Einstein:

> So far as the laws of mathematics refer to reality, they are not certain. And so far as they are certain, they do not refer to reality.

Einstein also made a related statement: "Everything should be made as simple as possible, but not simpler." There is always a remaining inaccuracy in a model when the modeling task is considered complete. They key point is that every model serves a purpose, and should be accurate enough to serve that purpose.

Here, the purpose of the community model is only to gain a *qualitative* understanding of the impact of technology on sustainable community development. We seek to understand (i) trends like whether a higher quality technology will help, and (ii) the impact of technology failures. The approach taken here is to use ideas from economics, health, education, and ecology to construct a mathematical and computational model of a community. This model is *not* validated with data from any community, that is, data has not been gathered and used to adjust the model to fit an actual community. On some parts of the model, however, significant experience in modeling real data is implicitly incorporated via using the standard choices for parameters. Moreover, the *elements* of the model have been used extensively in the economics (e.g., the production function) and ecology literature (e.g., the resource dynamics model).

A key feature of coping with the uncertainty in how to specify a model of a community is that here the *uncertainty in knowing aspects of a community is itself represented.* Rather than claiming, for instance, that a mathematical representation is a specific experimentally-validated model of an individual, we admit that it would be very difficult to know this, especially for all $N$ persons in a community as they are likely all different (which would require significant experimentation). Hence, we generate *random individuals* with features that are within the range of what science (and simple common sense) would tell us is true. Even when we do this for a large community, it is unlikely that one modeled individual matches a real individual in a community; however, it is

more likely that if we consider *many* such individuals and communities in our analysis, that the overall trends will be qualitatively accurate.

**Modeling Community Dynamics**

Suppose that there are $N$ individuals in a community and below we will consider $N_c$ different communities. Here, we let $N = 100$. Let $w^i(k)$, $w^i(k) \geq 0$, be the "wealth" of individual $i$, $i = 1, ..., N$, at step $k \geq 0$ (e.g., day $k$), in the community. Here, for simplicity, wealth represents cash in hand, savings, and capital. It is assumed that there are no loans, credit, or insurance. Let $h^i(k)$, $h^i(k) \in [0, 1]$, represent the health of individual $i$, $i = 1, ..., N$, at step $k \geq 0$. If $h^i(k) = 0$, they are very unhealthy and if $h^i(k) = 1$ they are perfectly healthy. Let $e^i(k)$, $e^i(k) \in [0, 1]$, represent the education level of individual $i$, $i = 1, ..., N$, at step $k \geq 0$. If $e^i(k) = 0$, they have no education, experience, or skills, and if $e^i(k) = 1$ they have these in abundance. The variable $r(k)$ denotes a resource amount, of a shared resource of the community, like the one studied in, for instance, Section 1.6.7.

A model of community dynamics must at least include the variables needed to assess outcomes.

Let $v_w^i(k) \geq 0$ be the *variable income* of individual $i$, $i = 1, ..., N$, at step $k \geq 0$ (e.g., due to day labor, possibly a random sequence of income amounts per day). Let $v_h^i(k)$ be the variable health influence on individual $i$, $i = 1, ..., N$, at step $k \geq 0$. This could be due to disease, poor water, poor sanitation, etc., or could, via patterns of the variable, represent health recovery rates. Let $v_e^i(k) \geq 0$ be the variable education influence on individual $i$, $i = 1, ..., N$, at step $k \geq 0$. This could be due to the adverse effects of poor health on school attendance.

Let $v_w^i(k)$, $s_w^i(k) \geq 0$, be the total amount of spending by individual $i$, $i = 1, ..., N$, at step $k \geq 0$. Let $s_s^i(k)$, $s_s^i(k) \geq 0$, be the total amount of spending by individual $i$ on themselves or their household (e.g., eating), $i = 1, ..., N$, at step $k \geq 0$. Let $s_h^i(k)$, $s_h^i(k) \geq 0$, be the spending on health by individual $i$, $i = 1, ..., N$, at step $k \geq 0$ (e.g., healthcare and small items for hygiene). Let $s_e^i(k)$, $s_e^i(k) \geq 0$, be the spending on education by individual $i$, $i = 1, ..., N$, at step $k \geq 0$. Then,

$$s_w^i(k) = s_s^i(k) + s_h^i(k) + s_e^i(k)$$

**Wealth Dynamics:** The community dynamics are given in terms of the above variables. First, wealth dynamics are given by

$$w^i(k+1) = \max\left\{0, (1 - \delta_w^i)w^i(k) + pf_w f_h f_e f_u + v_w^i(k) - s_w^i(k)\right\} \quad (4.20)$$

Here, $pf_w f_h f_e f_u$ is defined by $f_w = f_w(w^i(k), \alpha_w^i)$, $f_h = f_h(h^i(k), a_h^i, \alpha_h^i)$, $f_e = f_e(e^i(k), a_e^i, \alpha_e^i)$, and $f_u = f_u(\min\{r_l, r(k)\}, a_u^i, \alpha_u^i)$. Also, $\delta_w^i$ represents depreciation (e.g., capital depreciation), and we use $\delta_w^i = 0.001$. We let $w^i(0) = 1$ for all $i$, $i = 1, ..., N$. The term $v_w^i(k)$ is a random variable uniformly distributed on $[0, 2]$ to represent an average of \$1/day. The total spending $s_w^i(k)$ will be explained below. The term

$$pf_w(w^i(k), \alpha_w^i)f_h(h^i(k), a_h^i, \alpha_h^i)f_e(e^i(k), a_e^i, \alpha_e^i)f_u(\min\{r_l, r(k)\}, a_u^i, \alpha_u^i)$$
$$(4.21)$$

is a "production function" that depends on technology ($p \geq 0$ is proportional to technology quality), wealth, health, education, and resources. Here, for simplicity, we only use one scaling parameter $p \geq$ on the production function and assume that other effects on the components of the production function are represented with those function parameters.

The individual functions that make up the production function are:

1. *Effect of wealth on ability to produce income:* If wealth includes capital, then generally speaking, having more capital makes it easier to produce wealth. A traditional choice for this component is

$$f_w(w^i(k), \alpha_w^i) = (w^i(k))^{\alpha_w^i}$$

Typical choices are to have $\alpha_w^i \in [0.1, 0.5]$ and this is what will be used here. This function represents that as wealth increases, $f_w$ increases, that is, more is earned when you have more wealth (e.g., having more capital generally makes it easier to earn more money).

2. *Effect of health on ability to produce income:* If you are unhealthy, you cannot work, and if you are only partly healthy you may not be able to work as much (e.g., doing day-laborer work), but if you are completely healthy you can often earn more (e.g., if you do piece-work). A way to represent this is to use

$$f_h(h^i(k), a_h^i, \alpha_h^i) = 1 - \frac{1}{a_h^i(h^i(k))^{\alpha_h^i} + 1}$$

Here, we use $a_h^i \in [1, 1.25]$ and $\alpha_h^i \in [0.5, 1.5]$. This is an s-shaped function that has a derivative at zero of zero, increases, then reaches a maximum value of one. This represents that if you have very low health you cannot earn any income, but that as your health increases, you can make more. This is the function that was used in Section 3.6 in the study of poverty traps.

3. *Effect of education on ability to produce income:* Generally, more education, knowledge, skills, or experience makes it more likely (given available work) that you will earn more income. This idea was studied by Mincer, and he used a function of the form

$$f_e(e^i(k), a_e^i, \alpha_e^i) = \exp(a_e^i e^i(k)) + \alpha_e^i$$

Here, $a_e^i \in [0, 1]$ and $\alpha_e^i \in [0.1, 0.2]$. The term $\alpha_e^i$ represents experience or skills without education. The parameter $a_e^i$ helps quantify how much additional money can be earned for an increase in education.

4. *Effects of availability of resources on ability to produce income:* Without resources, in some cases, it is not possible to produce income (e.g., in some

agricultural cases). Having more resources makes it possible to produce more income. This is quantified with

$$f_u(\min\{r_l, r(k)\}, a_u^i, \alpha_u^i) = a_u^i(\min\{r_l, r(k)\}) + \alpha_u^i$$

Here, $r_l = 500$ sets the lower resource limit to be able to get income, the one assumed people will have. The parameter $a_u^i \in [0.00001, 0.00001 + 0.000001]$ and $\alpha_u^i \in [0.0000001, 0.0000001 + 0.0000001]$ (these values were obtained after a bit of tuning via the simulator discussed below).

Notice that the production function, $pf_w f_h f_e f_u$, is a *product* which represents a *conjunction:* technology, wealth, health, education, and resources must *all* be present to earn money. If one component function is zero, then no income is produced by the production function. Having all components present in greater amounts results in more income. However, if three of the four are present, but one is very low, then income cannot be earned (e.g., having very low $h^i$ results in a very low $f_h$ and since it is used in the product, the overall production function value will be low if the person has bad health).

Here, we will make random draws of the above parameters in the ranges given. This will result in each community member being different from every other community member with respect to the form of their ability to earn income as represented by $pf_w f_h f_e f_u$. In particular, for one random draw, the components of the production function in Equation (4.21) are shown in Figure 4.16 for a community of $N = 100$ people. Notice that there is significant variability between individuals' abilities to earn income.

**Spending Dynamics, Money Allocation, and Money Storage:** To define how an individual spends from their wealth, there are two cases:

- *Choice of spending when have sufficient wealth:* It is assumed that, if the individual has sufficient wealth, they will spend at least $s_{min}$ on themselves each day. If $w^i(k) \geq s_{min}$,

$$s_w^i(k) = \min\{w^i(k), \max\{s_{min}, s_{min} - K_p(w_d(k) - w^i(k)) \quad (4.22)$$
$$-K_{int} \sum_{j=0}^{k}(w_d(j) - w^i(j))\}\}$$

so that spending is no more than what is available and no less than $s_{min}$. This formula represents a decision-making strategy on funding that the user employs, one that we assume is used. The issue of the effects of deviations from such a strategy is discussed in Section 1.6.4. We let $w_d(k)$, the desired wealth, be $w_d(k) = 25$ for all $k \geq 0$, representing that each person wants to have \$25 available every day in case of emergencies. The term $-K_p(w_d(k) - w^i(k))$ results in more spending, the higher the wealth is above the desired wealth (it is the proportional term of the feedback controller as in Section 1.6.4). The term $-K_{int} \sum_{j=0}^{k}(w_d(j) - w^i(j))$ is the integral term for the feedback controller similar to what we used in Section 1.6.4. Here, we use $K_p = 2$ and $K_{int} = 0.001$.
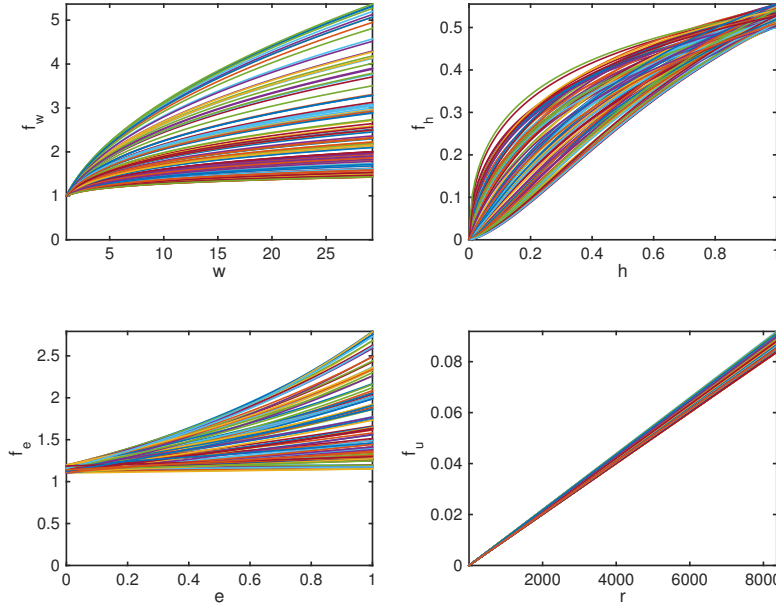
Figure 4.16: Plots of the components of the production function $pf_w f_h f_e f_u$ for a random draw for $N = 100$ community members.

- *Choice of spending when have insufficient wealth:* If $w^i(k) < s_{min}$, so that the person has very little money,

$$s_w^i(k) = \max\left\{0, w^i(k)\right\}$$

so that all wealth is spent in this case.

Let $g_s \geq 0$, $g_h \geq 0$, and $g_e \geq 0$ represent the relative weights on how the total spending $s_w^i(k)$ is allocated, where

$$g_s + g_h + g_e = 1$$

Here, we pick $g_s = 0.8$, $g_h = 0.1$, and $g_e = 0.1$. The spending on themselves (e.g., eating), and spending on health and education, are

$$g_s s_w^i(k)$$
$$g_h s_w^i(k)$$
$$g_e s_w^i(k)$$

so that

$$s_w^i(k) = g_s s_w^i(k) + g_h s_w^i(k) + g_e s_w^i(k)$$

and the $g_s$, $g_h$, and $g_e$ represent how the individual allocates funds to spending on themselves, health, and education. It is assumed that the $g_s s_w^i(k)$ amount is *immediately* spent that day. However, we imagine that the person proportions the spending on health and education by putting that money in two "banks" (e.g., not necessarily a traditional bank, but hidden somewhere) that they draw from as needed. In particular, the two bank variables, for health and education, are (respectively) $h_b^i(k)$ and $e_b^i(k)$. Spending from the banks are

$$s_h^i(k) = \min\left\{h_b^i(k), K_h(1 - h^i(k))\right\}$$

and

$$s_e^i(k) = \min\left\{h_e^i(k), K_e(1 - e^i(k))\right\}$$

Here, we use $K_h = 5$ and $K_e = 1$, and again this represents a decision-making strategy by the individual. If their health is further below one, they will spend more to get it fixed, and similarly for education. Here, a PI feedback control strategy may also be used for both cases, though this is not studied here. Then, the proportions of money spent in the current day on health and education, along with the spending on these, are used to update the two banks

$$h_b^i(k + 1) = g_h s_w^i(k) - s_h^i(k) + h_b^i(k)$$

and

$$e_b^i(k + 1) = g_e s_w^i(k) - s_e^i(k) + e_b^i(k)$$

If spending is not needed on health and education, then the corresponding banks will simply accumulate wealth. This wealth could be thought of as "intended" for health and education spending; however, in an emergency, the individual could use this money for other purposes, if it is available (but that case is not considered here). Hence, we define total wealth $w_t^i(k)$ of individual $i$ as

$$w_t^i(k) = w^i(k) + h_b^i(k) + e_b^i(k)$$

This variable will serve as a basis to evaluate how individuals in a community are doing in terms of stored wealth.

**Health, Education, and Resource Dynamics:**  To represent the dynamics of health let

$$h^i(k + 1) = \min\left\{1, \max\left\{0, (1 - \delta_h^i)h^i(k) - v_h^i(k) + \beta_h s_h^i(k)\right\}\right\} \qquad (4.23)$$

so that health is measured on a numeric scale between zero and one (clearly a gross simplification). We let $h^i(0) = 1$ for all $i$, $i = 1, ..., N$, to represent that all individuals start in perfect health. The term that has the parameter $\delta_h^i = 0.001$ represents natural health degradation over time as a person ages. The term $\beta_h s_h^i(k)$ represents the improvement to health due to spending $s_h^i(k)$ (e.g., for medicine or at a health clinic). The term $v_h^i(k)$ represents health degradations due to disease, infection, etc., and here we choose it to be uniformly distributed

on $[0, 0.005]$. Also, however, at $k = 400$ we let $v_h^i(k) = 0.3 + x$ where $x$ is uniformly distributed on $[0, 0.1]$ and at $k = 800$ we let $v_h^i(k) = 0.5 + x$ where $x$ is uniformly distributed on $[0, 0.1]$; these represent two times where all individuals get sick (e.g., via a community-wide disease). Of course, you could also make these variables depend on $i$ so that different people get sick at different times.

To represent the dynamics of education let

$$e^i(k+1) = \min\left\{1, \max\left\{0, (1 - \delta_e^i)e^i(k) - v_e^i(k) + \beta_e s_e^i(k)\right\}\right\}$$

so that education is measured on a numeric scale between zero and one that represents level of education, skill level, and/or amount of knowledge. The term that has the parameter $\delta_e^i$ represents degradation of knowledge due to forgetting over time, but here we pick $\delta_e^i = 0$ for all $i$. We let $e^i(0) = 0.01$ for all $i$, $i = 1, ..., N$, to represent that all individuals start with very little knowledge. The term $\beta_e s_e^i(k)$ represents the improvement to education due to spending $s_e^i(k)$ (e.g., for books or instruction at school). The term $v_e^i(k)$ could represent effects of poor health on getting less education (e.g., if it affects school attendance), but here we let $v_e^i(k) = 0$ for all $i$ and $k \geq 0$.

To represent a resource shared by the community, let the individual utilization of the resource be

$$u^i(k+1) = \beta_u s_w^i(k)$$

for $i = 1, ..., N$. The resource dynamics due to everyone in the community using it are

$$r(k+1) = \max\left\{0, r(k)\left(\exp\left(a_r\left(1 - \frac{r(k)}{\alpha_r}\right)\right) - \sum_{i=1}^{N} u^i(k)\right)\right\}$$

where $a_r = 1$, $\alpha_r = 10000$ (the carrying capacity as in Section 1.6.7), and $r(0) = 500$. Hence, it is assumed that the more that is spent by individuals in the community, the more the community uses the resource, per the term $\sum_{i=1}^{N} u^i(k)$. Spending is related to lifestyle and as spending goes up, lifestyle generally improves but use of resources also goes up. This is a shared resource, so increased use by one individual will *decrease* what is available for other users, and simultaneously via the production function will decrease how much income everyone else in the community will earn off the resource. The resource creates a coupling (interaction) between all members of the community.

### Representing Technologies

Humanitarian technologies can be complex and it is difficult to incorporate all their relevant features and dynamics in a community model. Here, a very simple approach to representing a technology is used. It is represented by a parameter (or parameters) that will be adjusted to study its impact on a community. In particular, the following types of technologies will be considered:

- *Technologies that impact the ability to make money:* The parameter $p$ in the production function $p f_w f_h f_e f_u$ can be zero (representing a technology

that failed or one that is not present), and is proportional to the quality of the technology. For example, such technologies could include tools for work, equipment for manufacturing, or fertilizer for agriculture.

- *Technologies that impact improving health:* The parameter $\beta_h$ is used to represent the conversion from spending on health to health improvements and could represent medicines or monitoring/diagnostic technology for health.

- *Technologies that impact improving education:* The parameter $\beta_e$ is used to represent instructional technology or hands-on technology for STEM education.

- *Technologies improving sustainability by more efficient use of a common resource:* The parameter $\beta_u$ is used to represent how spending by an individual degrades resources; hence, an example technology could be one that makes sure that energy use (which costs money) is efficient (as in a fuel-efficient cookstove) or one that efficiently utilizes agricultural products. In this case, better technologies are represented with *lower* $\beta_u$ values (that is, an inversely proportional relationship), compared to the three cases where technology quality is proportional to each parameter.

The effects of each of these parameters on community dynamics will be considered below; however, first, to give an idea of what community dynamics look like, two examples are provided in the next subsection for two values of $p$.

**Examples of Community Dynamics: Low and High Technology Cases**

Assume $p = 10$ (low technology case), $\beta_h = 2$, $\beta_e = 0.01$, $\beta_u = 0.002$, and $N = 100$. Figure 4.17 shows the community dynamics. Notice that in the upper-left plot, the person regulates their wealth to their desired wealth. The right-top plot shows that each person in the community spends a different amount on themselves, with low spending initially as they are trying to build their wealth to $w_d$. In the plot for health, there are two health degradations at $k = 400$ and $k = 800$ and these are "fixed" by the health spending shown on the right. Via education spending, the individuals in the community educate themselves at different rates as they have different education spending amounts. The resources for the community degrade a little, but remain relatively constant as the mean spending amounts for each individual eventually become relatively constant. Since there are not too many costly health degradations, money accumulates in the health bank (bottom-left plot), and once people are fully educated, spending on education stops and money accumulates in the education bank (bottom-right plot).

For the same parameters as above, but with $p = 200$ (high technology case), a higher quality technology than above, the results in Figure 4.18 are obtained. Compared with Figure 4.17, notice that the wealth is regulated better to the desired wealth, and there is both higher self-spending and higher total spending.
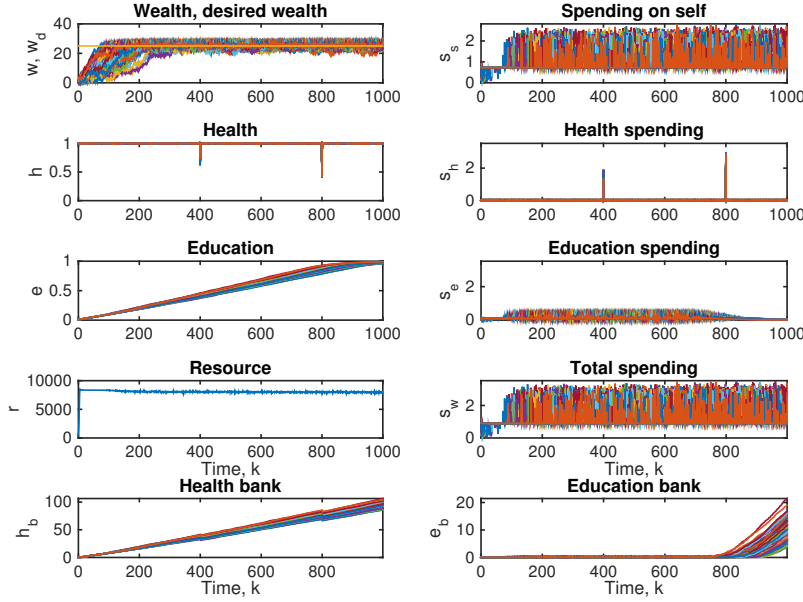
Figure 4.17: Community dynamics for one community, low technology case, $p = 10$.

People are educated faster as they have more money to spend on education. This comes, however, at the cost of using more resources. Below, the effects of changing $p$ will be considered in more detail.

**Sustainable Community Development Index (SCDI)**

Here, three types of "sustainable community development indices" are introduced. For the first one, the key variables used are $w_t^i(k)$, $h^i(k)$, $e^i(k)$, for $i = 1, ..., N$, and $r(k)$. In the analysis below, these variables are computed for $N_s = 1000$ steps, for a total of $N_s + 1 = 1001$ values including the initial conditions. Also, we will consider $N_c = 50$ communities of $N = 100$ individuals each over $N_s$ steps. Means and standard deviations are computed.

**Variables Measuring Community Features:**   Compute

$$\bar{w}_t = \frac{1}{N_s + 1} \sum_{j=1}^{N_s+1} w_t^i(j)$$

for each individual in each community ($i$ notation is not added to $\bar{w}_t$ to keep the notation simpler). This $\bar{w}_t$ is a random variable in the sense that it generally

*A sustainable community development index measures human development for a community.*
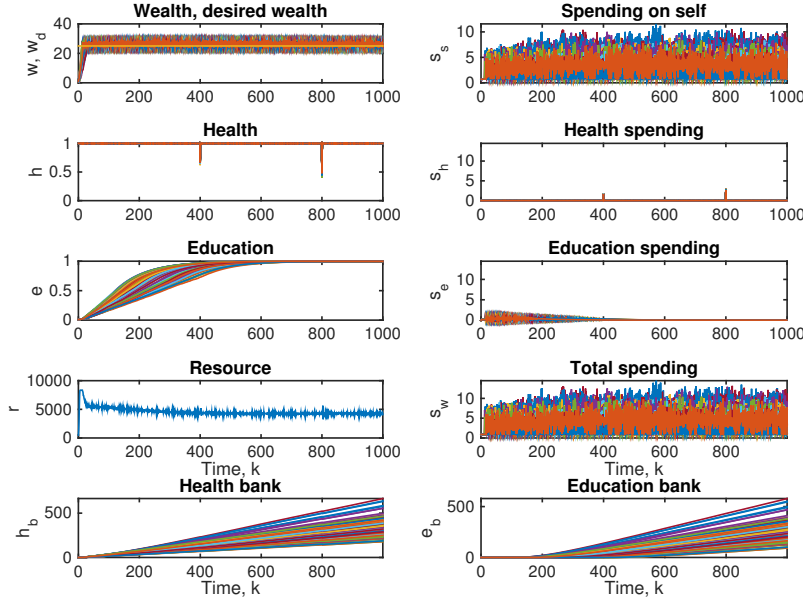
Figure 4.18: Community dynamics for one community, high technology case, $p = 200$.

takes on different values for different individuals (and if you repeat the simulation it will generally change for each run due to the random income sequence). Let

$$\bar{\bar{w}}_t = \frac{1}{N} \sum_{m=1}^{N} \left( \frac{1}{N_s + 1} \sum_{j=1}^{N_s+1} w_t^m(j) \right)$$

be the mean of the mean wealths of all people in one community. However, if you consider a random set of communities, as we do here, $\bar{\bar{w}}_t$ is also a random variable that can take on different values for each community considered of the $N_c$ communities. Let $\bar{\bar{\bar{w}}}_t$ denote the mean over all $N_c$ communities of their $\bar{\bar{w}}_t$ values. Similarly, let $\hat{\bar{\bar{w}}}_t$ denote the standard deviation over all $N_c$ communities of their $\bar{\bar{w}}_t$ values. The values of $\bar{\bar{\bar{w}}}_t$ and $\hat{\bar{\bar{w}}}_t$ will be plotted versus parameters representing technologies in the community (e.g., $p$) and also used in the computation of the $SCDI$ below (e.g., see Figure 4.21).

The values of $\bar{\bar{h}}$ and $\bar{\bar{e}}$ represent the mean computed over the $N_s + 1$ values and then the mean of that mean over the $N$ individuals, the same approach to computing $\bar{\bar{w}}_t$. Let $\bar{r}$ be the mean computed over the $N_s + 1$ values of $r(k)$. Similar to $\bar{\bar{w}}_t$, $\bar{\bar{h}}$ and $\bar{\bar{e}}$ represent the means computed over the $N_s + 1$ values,

and then over the $N$ individuals, and then over $N_c$ communities. The standard deviations, $\hat{\bar{\bar{h}}}$ and $\hat{\bar{\bar{e}}}$, are also computed. Also, let $\bar{\bar{r}}$ be the mean computed over the $N_s + 1$ values of $r(k)$ and then the mean of the result computed over $N_c$ communities. Let $\hat{\bar{r}}$ be the standard deviation of the mean that is computed over the $N_s + 1$ values of $r(k)$ and then the standard deviation of the result computed over $N_c$ communities (i.e., the standard deviation of the means).

**Variables to Dimensions:** A sustainable community development index (SCDI) will be specified based on these variables. We will use money in the SCDI in different ways (total wealth, spending, and income). The value of income in terms of development is normally not considered to be equal to the monetary value of income. In the IHDI in Equation (1.5), where income is used, since each dimension (income, health, and education variables, are converted to the "dimensions") represents "capabilities" (per the definition by Amartya Sen in Section 2.3.2), the function that transforms income into capabilities is assumed to be concave (Anand and Sen, 2000). For this reason, to compute the IHDI, the natural logarithm ($\ln(\cdot)$) is taken of the income variable and then used in the formula (of course the argument of $\ln(\cdot)$ will not be allowed to be less than one, but greater than zero, as this results in negative values). The effect is that an increment that raises income from a very low value has value in terms of development, but when income is high the same size increment has little value in terms of development. Here, we assume that this basic idea also applies to total wealth, spending, and income. However, to avoid the problem of $\ln(\cdot)$ becoming negative, here we use the square root $\sqrt{\cdot}$, which is also concave and hence serves the same purpose.

Let

$$X_w = \frac{\sqrt{\bar{\bar{\bar{w}}}_t} - \sqrt{w_{min}}}{\sqrt{w_{max}} - \sqrt{w_{min}}} \tag{4.24}$$

where $w_{min} = 0$ is the minimum value of wealth and $w_{max} = 500$ is the maximum value wealth will achieve (chosen after running a number of simulations). Here, $X_w \in [0,1]$ represents a measure along the wealth dimension of enabling capability relative to the minimum and maximum wealth that enable capabilities. Also, $\bar{\bar{\bar{w}}}_t$ is the variable, and $X_w$ is the dimension corresponding to that variable. Let

$$X_h = \frac{\bar{\bar{\bar{h}}} - h_{min}}{h_{max} - h_{min}}$$

where $h_{min} = 0$ is the minimum value that wealth can take on and $h_{max} = 1$ is the maximum value wealth will achieve. Here, $X_h \in [0,1]$ represents the level of health for the communities. Let

$$X_e = \frac{\bar{\bar{\bar{e}}} - e_{min}}{e_{max} - e_{min}}$$

where $e_{min} = 0$ is the minimum value that education can take on and $e_{max} = 1$ is the maximum value education will achieve. Here, $X_h \in [0,1]$ represents the

level of education for the communities. Let

$$X_r = \frac{\bar{\bar{r}} - r_{min}}{r_{max} - r_{min}}$$

where $r_{min} = 0$ is the minimum value that resources can take on and $r_{max} = \alpha_r$ is the maximum value resource value that can be achieved. Here, $X_r \in [0,1]$ represents the level of resources for the communities.

**The Atkinson Inequality Index:** The SCDI will be formulated using ideas from the definition of the IHDI (see Section 1.1.2 and Equation (1.5)) where it incorporates an inequality measure (another inequality measure is the Gini index discussed in Section 1.1.2). The Atkinson inequality index (Atkinson, 1970) for a variable $x$, with values $X_1, ..., X_n$, is $A_x$,

$$A_x = 1 - \frac{\left(\prod_{i=1}^{n} X_i\right)^{\frac{1}{n}}}{\frac{1}{n}\sum_{i=1}^{n} X_i} \tag{4.25}$$

which is one minus the geometric mean divided by the arithmetic mean; rearranging the equation you can see that $1 - A_x$ reduces/scales the value of the arithmetic mean, $\frac{1}{n}\sum_{i=1}^{n} X_i$ to obtain the geometric mean. It must be that $\frac{1}{n}\sum_{i=1}^{n} X_i \neq 0$ for $A_x$ to be well-defined. If $X_1 = \cdots = X_n = 0$, then $\frac{1}{n}\sum_{i=1}^{n} X_i = 0$ so it must be that for some $i$, $X_i > 0$. Assume that the $X_i \geq 0$, $i = 1, ..., n$; however, notice that if for some $i$, $X_i = 0$, then $\prod_{i=1}^{n} X_i = 0$ so that no matter what the $X_j \geq 0$, $j \neq i$, values are, the $\prod_{i=1}^{n} X_i = 0$ so $A_x = 1$. So, the measure of inequality is not proper for this condition as it does not consider inequality in the data for $X_j \geq 0$, $j \neq i$. For this reason, it must be assumed that $X_i > 0$, for all $i = 1, ..., n$, and hence $A_x \in [0,1)$ (that is, it is never the case that $A_x = 1$). On the other hand, if it is only assumed that for all $i = 1, ..., n$, $X_i \geq 0$, and for some $j$, $X_j = 0$ (or many such $j$), so that $A_x = 0$, then the Atkinson inequality index can be viewed as valid but it says that if any one value is zero, there is complete inequality independent of all other values. Applied to the case of incomes, this would mean that there is complete inequality if even one person in a group of many people has no income, independent of the incomes of all other people (even if they are all very low incomes so that all incomes are nearly equal). Of course, this is a valid way to measure inequality, depending on your purpose.

The Atkinson index is a measure of inequality of the $X_1, ..., X_n$ values, $X_i > 0$, for all $i = 1, ..., n$. If in Equation (4.25) there is perfect equality, $X_1 = \cdots = X_n = X^*$, then $\frac{1}{n}\sum_{i=1}^{n} X_i = X^*$ and $\prod_{i=1}^{n} X_i = ((X^*)^n)^{\frac{1}{n}} = X^*$; hence, $A_x = 0$ representing equality. If the $X_1, ..., X_n$ values are all the same value, $X_1 = \cdots = X_n = \epsilon > 0$, where $\epsilon$ is a very small number, except one, call it $X^d$, then as $\epsilon \to 0$, $\frac{1}{n}\sum_{i=1}^{n} X_i = \frac{1}{n}((n-1)\epsilon + X^d) \to \frac{1}{n}X^d$ (a constant) and $\prod_{i=1}^{n} \epsilon^{(n-1)}X^d \to 0$ so $A_x \to 1$ representing perfect inequality. Hence, $A_x \in [0,1)$.

As an example, consider $n = 2$, and how $A_x$ changes as a function of $X_1, X_2$,

$$A_x(X_1, X_2) = 1 - \frac{(X_1 X_2)^{\frac{1}{2}}}{\frac{1}{2}(X_1 + X_2)}$$

in order to see how differences between $X_1$ and $X_2$ are measured by the Atkinson inequality index. A plot of $A_x(X_1, X_2)$ for $X_1, X_2 \in [0, 10]$ is shown in Figure 4.19. Notice that along the line $X_1 = X_2$, $A_x = 0$, and this is the darker region in the plot. As the values of $X_1$ and $X_2$ become different, the $A_x$ values increase until when they are at maximum difference for this example (e.g., $X_1 = 0$ and $X_2 = 10$, the upper right corner of the surface) when $A_x$ is maximized. The $(X_1, X_2)$ plane in Figure 4.19 shows a contour plot, and with the color bar on the right, you can see lines of constant inequality corresponding to constant $A_x$. Underneath the surface there is a line of constant equality corresponding to $X_1 = X_2$. Note that in Figure 4.19 if you let $X_1 = 10$, and decrease $X_2$ from 10 to zero, representing increasing inequality, then $A_x$ increases to one. Moreover, for small variations in the $X_2$ value along this range, the change in $A_x$ is larger as $X_1 - X_2$ increases. When $X_1$ is fixed at $X_1 = 10$, then if $X_2 = 9$ and that $X_2$ value is perturbed, the value of $A_x$ changes only a little bit; however, if $X_2 = 1$, and it changes a little, the value of $A_x$ changes much more. Hence, the Atkinson inequality index is more sensitive to inequality variations if inequality is higher. All these ideas can be quantified via a mathematical approach to sensitivity analysis that studies the impact of variations of the $X_1, ..., X_n$, on $A_x$ and the sustainable community development indices defined below. See Problem 4.65.

For the case here,

$$A_w = 1 - \frac{\left(\prod_{i=1}^{N_c} \bar{\bar{w}}_t\right)^{\frac{1}{N_c}}}{\frac{1}{n} \sum_{i=1}^{N_c} \bar{\bar{w}}_t}$$

where $n = N_c$ and $\bar{\bar{w}}_t$ has values for each of the $N_c$ communities. Here, $\prod_{i=1}^{N_c} \bar{\bar{w}}_t$ denotes a product of all the $\bar{\bar{w}}_t$, where there is one of these for each community. Also, $\frac{1}{n} \sum_{i=1}^{N_c} \bar{\bar{w}}_t$ denotes the mean of the $N_c$ possibly different $\bar{\bar{w}}_t$ values. Values of $A_h$, $A_e$, and $A_r$ are computed similarly.

**Sustainable Community Development Indices:** The sustainable community development index, *SCDI*, is defined for wealth as

$$SCDI_w = ((1 - A_w)X_w(1 - A_h)X_h(1 - A_e)X_e(1 - A_r)X_r)^{\frac{1}{4}}$$

In the case where there are no inequalities on any dimension $A_w = A_h = A_e = A_r = 0$ so

$$SCDI_w = (X_w X_h X_e X_r)^{\frac{1}{4}}$$

so we see that inequalities as measured by the Atkinson index, on any dimension, reduce the variables and this in turn reduces the $SCDI_w$ (i.e., true development must also include a measure of inequality). Also, a reduction (increase) in any
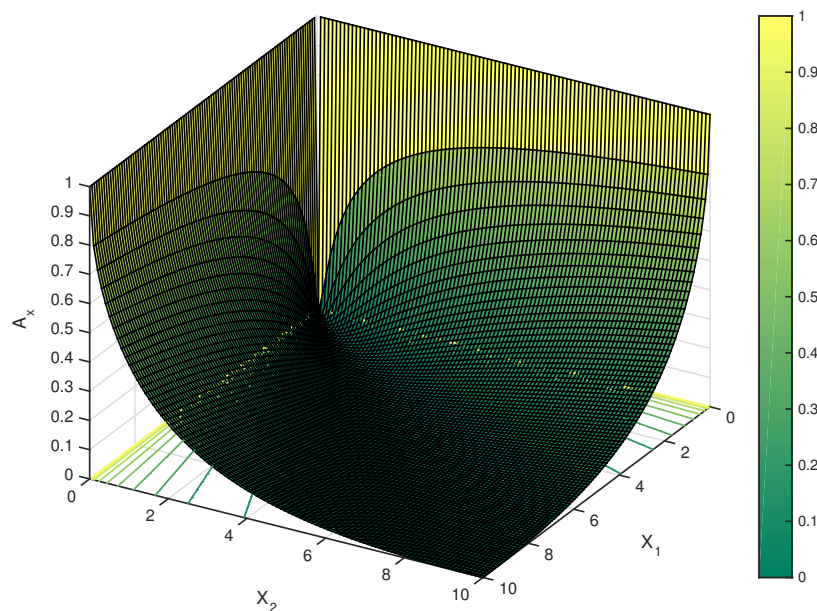
Figure 4.19: Atkinson inequality index $A_x(X_1, X_2)$, as a function of $X_1$ and $X_2$.

dimension (e.g., $X_h$) will reduce (increase, respectively) the $SCDI_w$. Inequality matters in development and the $SCDI_w$ captures inequalities both within and between dimensions.

As an example of how this measures development consider Figure 4.20 that is a plot of the geometric mean of $x$ and $y$,

$$S = (xy)^{\frac{1}{2}}$$

where $x$ and $y$ are two dimensions used in some SCDI, that we call $S$ here (e.g., it could be any two of the wealth, health, or education dimensions used above or the spending or income dimensions considered below). Notice that $S$ peaks when $x = y = 1$, the maximum values along those two dimensions. Of course when either $x$ or $y$ is zero, $S = 0$. As the values of $x$ and $y$ increase so does $S$. Consider the contour plot that is in the $(x, y)$ plane on beneath the surface, along with the color bar on the right. The lines there are curves of constant $S$, going from a color of yellow near $S = 1$, to dark green for $S = 0$. Consider the values of $S$ along the line $x = y$, which in the plot is the top of the hill along this line. Notice that if $(x, y)$ is perturbed off this line, along the contour lines, there is no change in $S$, but that for all other perturbations off this line, the value of $S$ will *decrease*. It is in this sense that $S$ "penalizes" (measures) differences

*between the dimensions.* If you consider the inclusion of an Atkinson inequality index that scales each of the two dimensions, you can see that inequalities *within dimensions* as measured by the Atkinson inequality index will result in decreasing $S$. For example, for $SCDI_w$, $(1 - A_w)$ is the measure of inequality within dimension $X_w$ so that $(1 - A_w)X_w$ is a measure of the level of $X_w$ *and* inequality within dimension $X_w$; when you also consider the health and education variables, you see that $SCDI_w$ measures inequalities in each dimension and inequalities between *all* dimensions for wealth, health, and education, and discounts $SCDI_w$ based on all inequalities. In this sense, $SCDI_w$ puts the same priority on wealth (modified via the square root in Equation (4.24)), health, and education. All these ideas can be quantified via a mathematical approach to sensitivity analysis that studies the impact of inter-dimension variations on the sustainable community development index.
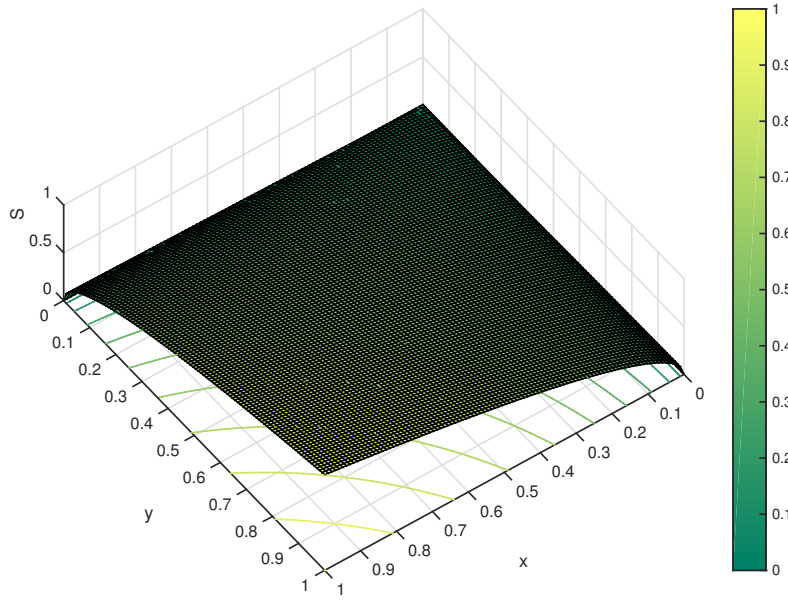


Figure 4.20: An example of the nonlinear mapping produced by part of the computations made for an SCDI.

As an alternative measure of sustainable development, consider

$$SCDI_s = ((1 - A_s)X_s(1 - A_h)X_h(1 - A_e)X_e(1 - A_r)X_r)^{\frac{1}{4}}$$

where the $X_s$ and $A_s$ variables are based on the spending variable $s_s^i(k)$. This uses self-spending rather than total wealth as sometimes self-spending is thought of as setting a standard of living (here, we do not include spending on health

and education in the category of self-spending, but of course they easily could be). Here, minimum self-spending is set to zero and maximum spending to five. For another measure of sustainable development, consider income by adding together the values from the production function and the variable income, that is the term $pf_w f_h f_e f_u + v_w^i(k)$ in Equation (4.20), and use it instead of total wealth or self-spending to define an income-based $SCDI$ that we call $SCDI_i$ via $X_i$ (not to be confused with a single data point in the definition of the Atkinson index above) and $A_i$. We have

$$SCDI_i = ((1 - A_i)X_i(1 - A_h)X_h(1 - A_e)X_e(1 - A_r)X_r)^{\frac{1}{4}}$$

Here, the minimum income is set to zero and maximum income is set to five as with $SCDI_s$.

**Individual-Community Based SCDI:** Finally, note that the $SCDI$ measures above are at the "community level." This means that they measure community development for $N$ people, and consider inequalities in development between communities (not individuals). This can ignore the variations in individual human development in communities. Of course, you can let $N = 1$ and then the comparisons will be between $N_c$ individuals, but that ignores shared aspects of development in a community. A different measure is needed to consider in the $SCDI$ the effects of inequalities among the $N$ individuals in each of the $N_c$ communities. This is not difficult to formulate. One approach is to proceed as follows:

1. *Individual-level development:* Use $N_c$ measures like the $SCDI$, call them $SCDI_j$, $j = 1, ..., N_c$, that consider the $N$ individuals in the $j^{th}$ community, with appropriately-defined variables and dimensions (perhaps that include means and standard deviations for a number of simulations for each individual), and quantify inequalities between the individuals and dimensions; and

2. *Community-level development:* Then another $SCDI$-type measure can be used that combines the $SCDI_j$, $j = 1, ..., N_c$, to measure community development considering inequalities between communities along dimensions that quantify community-level features (as above).

Call an SCDI defined in this way, an $SCDI_{ci}$, as it takes into account community and individual differences. See Problem 4.64. The assessment of individual development in 1. must be interpreted properly. For it, the resource that is common to the community the person lives in is also a dimension that contributes to the individual's development. Hence, the assessment is for a person that is living in a specific community, not just any community.

**Impact of Technology Quality and Technology Failures on a Community**

Consider the impacts of the four parameters that represent the technologies discussed above. Impact is assessed in several ways, including changes in total

> A $SCDI$ can be defined that takes into account individual and community differences in development.

wealth, spending, income, health, education, and resources. Also, the impact on $SCDI_w$, $SCDI_s$, and $SCDI_i$ are considered.

Let $\beta_h = 2$, $\beta_e = 0.01$, and $\beta_u = 0.002$. Figure 4.21 shows the effects of the technology parameter $p \in [0, 200]$. First, the $p = 0$ case represents that there is no technology or that the technology fails in the whole community. For the $p = 0$ case, total wealth, total spending, income, self-spending, education, $SCDI_w$, $SCDI_s$, and $SCDI_i$ are the lowest (there is little impact on health). Notice that total spending and income are close to each other as once wealth is regulated, this condition generally holds. Yet, since $p = 0$ results in less total spending, due to less total wealth, there are more resources available (center plot, right column of plots). All the measures, $SCDI_w$, $SCDI_s$, and $SCDI_i$, suggest that technology quality should be as high as possible, but there are not many gains past about $p = 75$.

A community dynamics model can be used to assess the impact of technologies on a community.
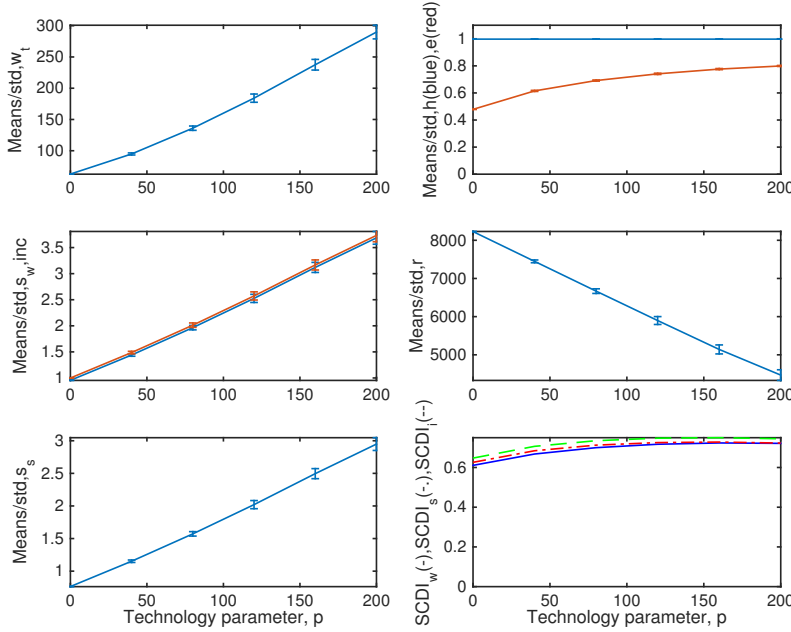


Figure 4.21: Effects of varying the technology parameter $p \in [0, 200]$ on total wealth, total spending, income, self-spending, health, education, resources, $SCDI_w$, $SCDI_s$, and $SCDI_i$. On the vertical axes for the top four plots and the bottom-left plot, the word "means" is interpreted per the variable being labeled. For instance, in the total wealth case there are three means taken: ones over time, community members, and community. The "std" refers, for the total wealth case, to the standard deviation of two means: ones over time and community member.

Let $p = 100$, $\beta_e = 0.01$, and $\beta_u = 0.002$. Figure 4.22 shows the effects of the health parameter $\beta_h \in [0, 5]$ (zero corresponds to a failure). For the $\beta_h = 0$ case, total wealth, total spending, income, self-spending, health, education, $SCDI_w$, $SCDI_s$, and $SCDI_i$ are the lowest; as $\beta_h$ increases, each of these increases. But, as $\beta_h$ increases, resources decrease due to total spending going up. The change from the $\beta_h = 0$ case (representing no technology or a failed technology) to higher values indicates the importance of health technologies for development.
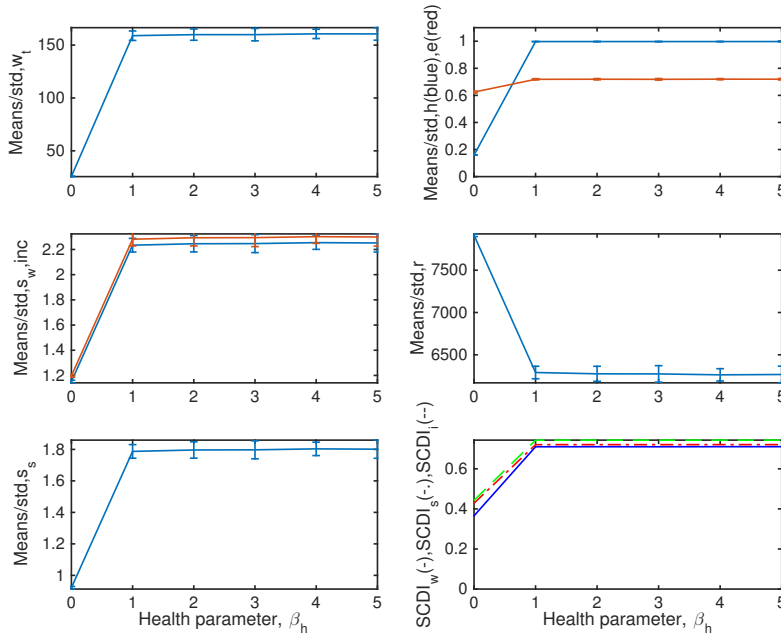


Figure 4.22: Effects of varying the health parameter $\beta_h \in [0, 5]$. See caption of Figure 4.21 for explanation of plot variables.

Let $p = 100$, $\beta_h = 2$, and $\beta_u = 0.002$. Figure 4.23 shows the effects of the education parameter $\beta_e \in [0, 0.1]$ (zero corresponds to a failure). For the $\beta_e = 0$ case, total wealth, total spending, income, self-spending, education, $SCDI_w$, $SCDI_s$, and $SCDI_i$ are the lowest (health is not affected); as $\beta_e$ increases, each of these increases (indicating the importance of health technologies for development), but resources decrease as expected.

Let $p = 100$, $\beta_h = 2$, and $\beta_e = 0.01$. Figure 4.24 shows the effects of the utilization parameter $\beta_u \in [0.00001, 0.02]$ (the maximum value can be thought of as corresponding to a failure as better technologies are ones that have lower $\beta_u$ values). Increasing $\beta_u$, corresponding to increasingly *worse* technologies, results in less total wealth, total spending, income, self-spending, education, resources,
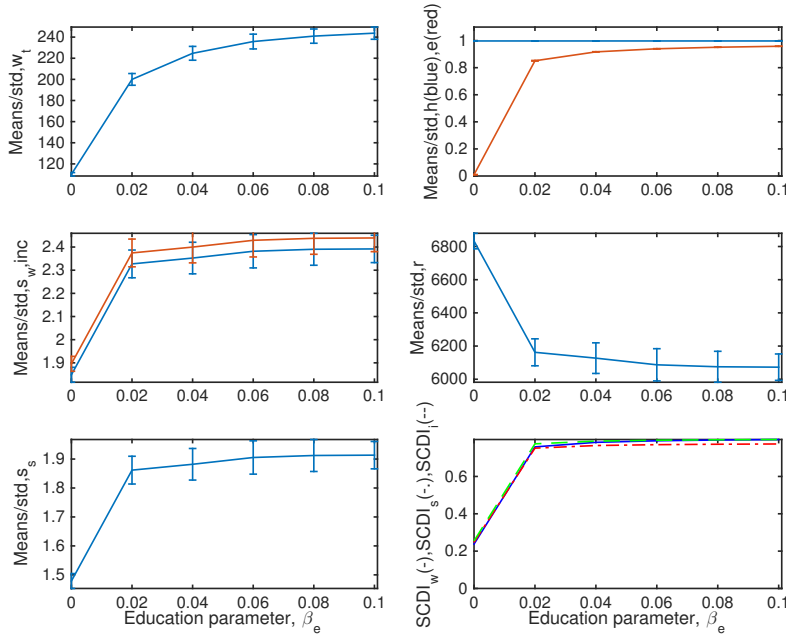
Figure 4.23: Effects of varying the education parameter $\beta_e \in [0, 0.1]$. See caption of Figure 4.21 for explanation of plot variables.

$SCDI_w$, $SCDI_s$, and $SCDI_i$. Heath stays relatively constant. The reductions in $SCDI_w$, $SCDI_s$, and $SCDI_i$ indicate the importance of technologies for sustainability, that is, ones that result in less use of resources by individuals in the community for more spending.

**Model Inaccuracies and Technology for Development as a Feedback Process**

There are, of course, many ways in which the community model in this section is inaccurate. First, combining capital, cash in hand, etc. into "wealth" is a gross simplification. However, using standard models and ideas from economics (e.g., from (Acemoglu, 2009)), it is easy to expand the model to conform to existing economic models. For health, it is clearly a gross simplification to use one number to represent the level of health of a human, but it is a start in the right direction. For education, while the model is based on Mincer's ideas, there are other ways to integrate the education model into the community model (e.g., some ideas are in (Acemoglu, 2009)). The coupling of the model to a shared resource and its dynamics certainly needs improvement.

There are many other aspects of the community model that could be stud-
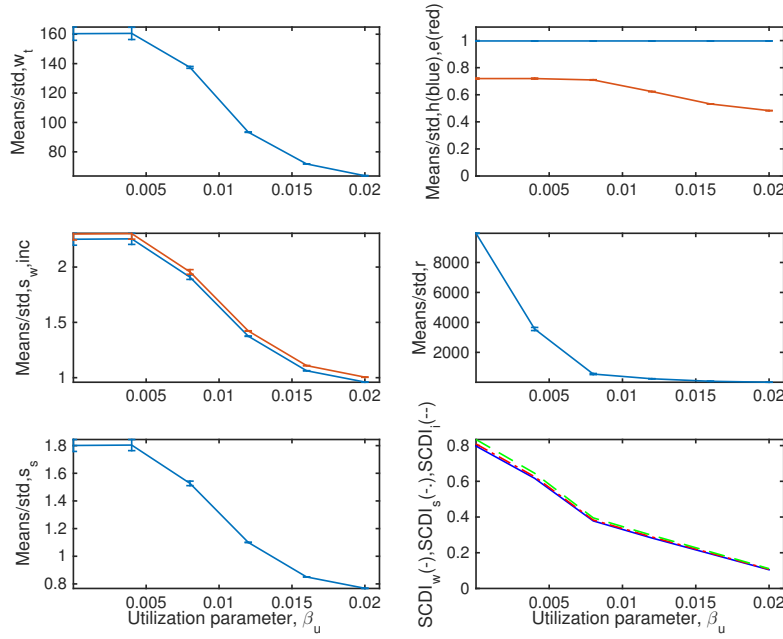
Figure 4.24: Effects of varying the utilization parameter $\beta_u \in [0.00001, 0.02]$. See caption of Figure 4.21 for explanation of plot variables.

ied that were ignored in this section. The effects of the parameters of the production functions of each individual could be modified and the effects on the $SCDI$ could be studied. The impact of the parameters for the controllers that set spending could be adjusted, or changed in form (e.g., using PI controllers for health and education spending), and the effects of deviations off spending strategies used here could be studied. Also, for the spending strategy, the allocation parameters for self-spending and spending on health and education could be adjusted (or a more sophisticated feedback controller could be used). The impact of the resource dynamics could be studied by changing the parameters there and considering the impact on variables. The effects of the size of the community $N$ are studied in Problem 4.62.

There were other features of a typical community that were ignored. It could be useful to represent the social network, economy, governance of a community. This could include buying/selling, the market, barter, trade, investments, loans, insurance, etc. It could include the role of school or a health clinic. It could represent management strategies for community technologies (see Section 4.12.1) or common-pool resources (Section 4.2.11). Moreover, the wealth distribution policy of Section 2.4.3 could be used, possibly with a democracy as studied in

Section 2.4.4. Indeed, that approach to modeling democracy could be used to adjust other parameters in the community (e.g., allocation of the use of resources or the individuals' allocation of spending). See Problem 4.66.

Technology for development, that is humanitarian engineering, is itself a feedback control process. To see this, note that there could be an feedback control loop introduced where $SCDI$ is sensed, fed back, compared to goals, and a controller that specifies technology modifications/introductions (i.e., specifies technology designs) can be used to steer the community (plant) to higher and higher values of $SCDI$. Clearly, community assessment is used to process other community information to be used in technology design, project options can be considered and selected, and outcomes assessed for later learning and planning. This feedback loop would operate on the 1-3 year time scale, and if it converges would result in successive improvements to technologies, or technology introductions, to provide a high $SCDI$ value, and good community capacity so that the community can become relatively autonomous in pursuing its own goals. If you fill in all the details from other parts of this book, such a feedback system is similar to the one in Figure 4.1, and particularly, the one in Figure 4.2. Additional systems-theoretic perspectives on humanitarian engineering for development are provided next and in Section 4.12.3.

### Other Community Mechanisms for Community Development

It is possible to use the model of this section to study other mechanisms that promote community development. For instance, the following approaches could be used:

1. The financial advisors in Section 1.6.3 could be extended to include financial variables of other individuals and vendors; this would link the community together and enable the study of community development as a function of finance management strategies.

2. The wealth distribution strategy in Section 2.4.3 could be used to financially link the members of the community and its effects could be studied on an appropriately-defined community development index. It would, then, be logical to compare the approach to other group financial management strategies (e.g., microfinance).

3. The democracy in Section 2.4.4 could be added to the wealth distribution strategy to see if it resulted in better community development, or if some other participation strategy would be better.

4. The EJP from Section 2.4.5, and resource utilization control approach in Section 3.6.6, could be added to any of these cases to study its impact.

The possibilities for simulations studies are clearly numerous.

### 4.12.3 Computational Humanitarianism

The sections in each chapter, "models, dynamics, and analysis of..." provide a basis for an area I call "computational humanitarianism" for the study of poverty and sustainability (Section 1.6), social justice (Section 2.4), development and development strategies (Section 3.6), and human-technology interactions in a community (Section 4.12). We are in the infancy of this area, but quite a few people recognize the importance of dynamics in humans, communities, public health, business, economic, political, and environmental systems and their coupled composition, and some recognize the value of mathematical and computational modeling and analysis of these. For example, see (Meadows et al., 1972, 2004; Sterman, 2000; Acemoglu, 2009; Amadei, 2014; Ramalingam, 2013; Spaiser et al., 2014; Amadei, 2015; Burns and Worsley, 2016), Chapter 1, Section I of (Sachs, 2014), and other sources that focus on the human dimensions (Miller and Page, 2007; Homan, 2011; Dale and Smith, 2013; Hovmand, 2013; Forsyth, 2014), to mention a few (relevant work also exists in agent-based simulation). Many of the tools are in place to advance this field, including modeling of many types of systems, large scale distributed and interconnected systems, feedback control theory, complex (adaptive) systems, hybrid systems, large scale simulation, and others. Many disciplines are relevant, and areas of humanitarian engineering like digital humanitarianism (Meier, 2015). In this section, some broad outlines for a path forward for computational humanitarianism are outlined.

#### Simulation as a Policy Evaluation and Intervention Decision-Making Tool

Is it possible to incrementally build a large-scale computer simulation of that that includes many humans, their social interactions as couples, in families, groups, organizations, communities, and workplaces, along with health, economic, political, and environmental aspects? Of course, the key to such model development is to use the right levels of granularity and abstractness or there will be no hope of success. Such a simulation would move far past statistical models (e.g., at the UN and World Bank web sites) to include nonlinear dynamics, (cross-level) interactions, and feedback loops. The complex simulations of the global climate used to predict climate change provide some hope that such a project is feasible in the long-term. Such a simulation would be a dynamical repository for all expert information about poverty and development, and would have the nice feature of forcing people to understand cross-country and cross-level (e.g., people-government) interactions and dynamics. Some computational model validation would be possible via existing and future UN and World Bank data (e.g., changes in world poverty rates over time for a country or region). The hope would be that we can start with pieces of the problem, smaller groups (e.g., first a dyad, a family, a village, etc.), and models that are not at a fine level of granularity, and then as simulation complexity and accuracy are improved by experts over time (possibly updated via real-time acquisition

of country data), the simulation would be useful in setting regional, national, or international policies and in evaluating proposed development solutions (e.g., by adding into the simulation various solutions and using the simulation to predict effects). Work along these lines that uses country-level data (e.g., from the UN and WVS) is in (Spaiser et al., 2014) and other relevant work is in (Meadows et al., 1972, 2004; Ramalingam, 2013).

The simulation could serve as a very useful tool in a number of respects. For instance, development policies could be included and parameters of the simulation could be perturbed (e.g., sensitivity analysis as in Section 3.6.2, Section 3.6.2, Section 3.6.2, Section 3.6.2, and Section 4.6.5) and Monte Carlo simulations used to help pick the best policy. This would take into account dynamics, nonlinearities, noise, etc. and could assist UN and World Bank officials in making aid decisions. Alternatively, a more modest simulation could be developed at the community level, parameterized so it could fit many communities, and then policy and development intervention solutions could be studied computationally. Initial work along these lines for technology interventions is in Section 4.12.2, and ideas on use of optimization for economic models is in Section 3.6.3.

### The Automation of Helping People

Once a model is developed for these very complex processes, it is natural to ask if inputs (e.g., aid injection or other interventions) can be generated by observing outputs (e.g., IHDI, MPI, SCDI, and ecological indicators), that will drive the system in the direction of meeting social justice goals.

**Feedback Control for Complex Systems:** In such a feedback control approach, it is possible to use internet-enabled wide-area distributed feedback control to automate the helping of people. Such an automation system has condition monitoring, and implementation of feedback control strategies to actively help large-$N$ sized groups of people. Of course, as is standard in automation, you rarely achieve full automation at the start of a project. You begin with a semi-automated approach with humans integrally involved ("in the loop," helping with decisions and monitoring), a type of technology for assisting humans. Then, as the technology matures and becomes trusted because it performs well, additional pieces of the decision-making done by the humans are automated. It is an incremental approach to automation. It could also be incremental with respect to group size $N$, by starting with a few people, then scaling up.

For instance, the $N = 1$ case (self-help, perhaps with technology as in the financial advisor in Section 1.6), $N = 2$ case (helping as in Section 4.1 and (Passino and Antsaklis, 1989)), or $N < 10$ case (family or group therapy), are very difficult problems even if the technologies are only assistive. For $N$ values corresponding to communities (or larger), consider the approaches used in Section 2.4, Section 3.6, and also Section 3.6 for the cases of the wealth distribution policy or democracy (both distributed feedback controllers). Of course, the automation of the management of environmental policies in Section 3.6 is

another example of broad-area feedback control for sustainable development. The cooperative management of community technology case in Section 4.12 is also an example of large-scale feedback control for people.

Some specific examples of high-$N$ problems that could be addressed include: (i) Columbus, Ohio: Social condition monitoring, social support system integration, and automation of some support services (e.g., logistics of providing beds in shelters and food, and schedulers for medicine to help with compliance) for an $N < 10000$ challenge; and (ii) State of Ohio, Dept. Public Health: Monitoring health data (doctor diagnoses and sales of medicines are monitored and are on-line) and sending signals to people (e.g., health alerts via text messages, not currently done) for an $N \approx 11.5$ million. Clearly, the right way to start is to develop modest versions of such applications, and then learn and build on successes.

**Model-Free vs. Model-Based Control Design and Evaluation:** All the ideas and approaches from the field of systems and control theory and engineering apply to the development and analysis of such automation systems. For example, for the "model-free case" (i.e., when the feedback controller is developed without the use of a model beyond a "mental model") it is possible to use a wide range of "heuristic" approaches to specify a feedback controller (e.g., ones based on incorporating expert knowledge into the computer decision making system) (Passino, 2005). However, in this case the only way to evaluate the solution is implementation "in the field" where it can be tested. For some applications, this would be considered to be dangerous; however for others, where the process is slow or humans can monitor and intervene if the computer starts doing something wrong, it can be a satisfactory approach (e.g., the public health example above). Indeed, it can be a highly desirable approach since you can get an implementation relatively fast (once the sensor, actuators, and computational infrastructure is put in place). This is standard practice in engineering for some very sophisticated and important controllers for complex systems.

Generally speaking, higher performance operation can be achieved if a quantitative model (e.g., computational or mathematical as discussed above) can be used to develop and evaluate the feedback controller. Indeed, if you have a computational model, you can test a controller on it before you implement it; often, this can give you (i) good ways to "tune" (adjust) the controller before it is deployed, and (ii) a way to evaluate the performance of the feedback control system before it is implemented to raise your confidence that it will work properly the first time. Of course, all the quality of performance achieved in tuning/evaluations is limited by the quality of the model that is used. Generally, however, experience has shown that as the quality of the model improves, confidence in success, and performance improvements, generally improve also.

## 4.13   Conclusions

The broad conclusions for each section of this chapter are:

1. Humanitarian engineering is a helping profession; hence, it is necessary to understand the basic theory of how to help people. Learning how to help one person provides many ideas about how to help multiple people in a community.

2. There are a range of challenges in community development (e.g., oppression), and perspectives on how to approach community development. Here, participatory community development is proposed as an approach that will help with many of the difficulties in humanitarian engineering, including identifying needs, getting the job done in a way that fits the community's desires, empowering people, promoting ownership, and making sure that there are people in place for technology operation and maintenance.

3. Teamwork involving visitors and community members can be enhanced by following some basic principles (e.g., good and frequent communications). Effective project management can make a project run smoothly and help avoid the risks of failure.

4. The aim of community assessment is to learn about a community. It proceeds via research, interviews, focus groups, and/or surveys, along with a technical assessment of constraints, technological solution feasibility, and risks.

5. A project is selected that best fits community needs and assets, along with the visitors' constraints and technical assessment. A "robust" choice is one that is still good in light of changes in the parameters of the project selection problem.

6. Humanitarian technologies, of which appropriate technologies are a special case, seek to address all constraints and trade-offs and provide high performance, which in this case means human development and inclusion.

7. Participatory technology development is a type of community development, one where engineers work with a community to develop a technology. It is product development with community involvement.

8. Humanitarian STEM education seeks to build technological capacity to empower independently-developed solutions to community development challenges.

9. The quality of outcomes from the participatory development process must be assessed so we know what succeeds, what does not, and why.

10. For high quality local solutions, one can consider whether to scale-up to a region, country, or beyond (e.g., via a social business approach).

11. Humanitarian engineering fieldwork is challenging and it is good to consider some "best practices" before attempting it.

12. In the analytical approaches, it is shown that cooperative management of community technology can occur via people, technology, or both (i.e., semi-automated). A community can be modeled and simulated to evaluate the impact of technology on sustainable community development.

## 4.14 Homework Problems

**Problem 4.1 (Egan: The Skilled Helper):** Read Section 4.1.2.

(a) Present and defend your position on whether humanitarian engineering is a helping profession.

(b) For the statement: Helpers should put the client in the "driver's seat" to achieve change. What does this mean?

(c) What does it mean to "empower" someone? Why is it important? How is it relevant to humanitarian engineering? Does involving someone in an engineering project empower them?

(d) For the statement: "Helping is a two-person collaborative exercise in creativity" (Egan, 2014). Explain what this means for humanitarian engineering.

(e) Name four foundations of a working alliance between a helper and a client.

(f) Name three good ways to listen, and three poor listening habits.

(g) Name the key components of the "standard problem management framework."

(h) Name three reasons why you may never start helping a client, or stop helping a client.

(i) Read Section 4.1.2 if you have not already done so. Suppose that per (b) above, you view helping someone to be analogous to helping them drive a car. Draw a diagram like in Figure 4.1 that is labeled with the specific case of helping someone to drive a car. Label inputs and outputs of all the blocks/subblocks and explain what execution monitoring, situation assessment, a set of plans, picking the best plan, and executing the plan mean for the helping-someone-drive-a-car example. Also, be sure to explain what the helper model and helper guidance generation is.

**Problem 4.2 (Schein: Helping and Humble Inquiry):** Read Section 4.1.3.

(a) What does he mean by "economics" in helping? Explain his term.

(b) Name two helper traps and two client traps and explain in each case why he considers these to be traps.

(c) Name two things that the helper does not know at the start of the helping process, and two things the client does not know at the start.

(d) What are the three role choices for the engineer? Explain each one briefly.

(e) Would you ever start at the very beginning by assuming a doctor-engineer role?

(f) Define humble inquiry and give examples of it.

(g) Explain the difference between pure and diagnostic inquiry.

**Problem 4.3 (Edgar Schein on Helping: How to Offer, Give, and Receive Help):** View the (23:19) YouTube talk

Edgar Schein on Helping: How to Offer, Give, and Receive Help

that was published on March 10, 2011. Why must leaders be givers and receivers of help? For leadership, what is the relevance of technical complexity, globalism, multiculturalism, communications, networks, lack of face-to-face meetings, and social responsibility? What should leaders do about these? For solutions, what do his approaches help address (e.g., speed of response to a problem)? What does he say is the problem with asking for help? What does "one down" mean? Why is it good to make yourself vulnerable to your subordinates if you are a leader? What must be taught to both subordinate and boss? What is a "cultural island," and including in a hierarchical and global/multicultural context? Why does he say that this may require going "off site"? Why does he use the imagery of "sitting around the campfire"? How does he say that people ought to talk round the campfire? Why does he think it would be successful? How does he summarize his main points?

**Problem 4.4 (Edgar Schein on Helping):** View the (14:35) YouTube talk

Edgar Schein - Helping

that was published on Nov. 3, 2010. Why are new approaches needed in leadership? Name three reasons that he identifies. Explain. Does a leader have to give help? Accept help? Why? What is his definition of "help"? Why is helping difficult? Why is helping complicated? What are the two perspectives he uses to address the issue of complexity. How should you figure out how to be helpful? What is "humble inquiry"? Give an example. What are "diagnostic" questions? What is a "confrontive" question? When someone else asks for help, you respond at a "level." What are the three levels he discusses? What is the role of trust in a helping relationship? Why is it important? How can a client avoid a "trap"? The trap for the helper is to bypass humble inquiry and try to help before you really know what the problem is. In safety situations, he found problems; what are they? What is the solution to these problems between a subordinate and a leader?

**Problem 4.5 (Community Development):** Read <span style="color:red">Section 4.2</span>.

(a) What are the main challenges for community development? Explain each one in about 3-5 sentences each.

(b) Describe in 3-4 sentences on each of the main theoretical perspectives on community development.

(c) What is praxiology? What is appreciative inquiry? Describe each in less than 5 sentences.

(d) What are the seven community capitals? What is the difference between bonding and bridging social capital?

(e) In Homan's opinion, what is the difference between development and service?

**Problem 4.6 (Rao on Participatory Development):** Read <span style="color:red">Section 4.2</span>. Participatory development is discussed in the (1:22:30) video, released on Nov. 16, 2013,

<div align="center"><span style="color:blue">Localizing Development: Does Participation Work?</span></div>

by Vijayendra Rao who helped write (<span style="color:green">Mansuri and Rao, 2013</span>). Summarize and critique the video.

**Problem 4.7 (Participatory Development, Participatory Action Research, and Participatory Technology Development):** Read <span style="color:red">Section 4.2</span>, and also <span style="color:red">Section 4.7</span>.

(a) Summarize what participatory development (PD) is, and what are the reasons for taking this approach. Make your description less than 200 words.

(b) Summarize what PAR is, and what are the reasons for taking this approach. Make your description less than 100 words.

(c) Summarize the steps in PTD, and justify why each step is taken. Make your description less than 200 words.

**Problem 4.8 (Initiatives of Low-Income People):** View the (15:17) TED-Women video by Mia Birdsong

<div align="center"><span style="color:blue">The Story We Tell About Poverty Isn't True</span></div>

from May 2015.

(a) Summarize the main points of the video.

(b) What does she say about the ideas, innovations, and initiatives of low-income people?

(c) Critique the video. Do you agree or disagree with her? In what ways?

**Problem 4.9 (Management of Common Pool Resources):** Read Section 4.2.11 on management of common pool resources. Explain the relationships between management of common pool resources, "the common good" as it is discussed in Section 2.2.2, and the tragedy of the commons as discussed in Section 1.3.6.

**Problem 4.10 (Critiques of Participatory Development):** Read Section 4.2. Read each of the following papers that critique participatory development. Summarize the main points of each paper. Do they have valid concerns? Explain.

(a) "Participatory Development and Empowerment: The Dangers of Localism" (Mohan and Stokke, 2000).

(b) "Rethinking Participatory Development: From Critique to Better Practice" (de Gramont, 2013).

(c) "Tyranny/Transformation: Power and Paradox in Participatory Development" (Christens and Speer, 2006).

Optional: If you have further interest in critique of participatory methods, see (Cooke and Kothari, 2001).

**Problem 4.11 (Cooperation):** Read Section 4.3.1 or (Rand and Nowak, 2013).

(a) Give examples of where you have seen cooperation between family members.

(b) Give examples of cooperation between unrelated people, based on direct reciprocity and indirect reciprocity.

**Problem 4.12 (The Logical Framework Approach (LFA)):** Read Section 4.3.3 and (PCI, 1979).

(a) Summarize the LFA approach. In particular, answer the following questions: What is a "goal"? What is a "purpose"? "Inputs"? "Outputs"? "Narrative summary"? What is a "hypothesis"? An "indicator"? What is "manageable interest"? "Verification"? What is the role of uncertainty and "assumptions" and how they are coped with? What does "building the project design" mean?

(b) Does Section 4.3.3 that is based on (Project Management Institute, 2013) cover the key features of the LFA approach? For example, explain how the approach in Section 4.3.3 deals with uncertainty and risk.

**Problem 4.13 (PTD for a Personal Spending Advisor):** To understand what a personal spending advisor is, read Section 1.6.3 and especially focus on Section 1.6.4, and also Section 1.6.6. Read Section 4.7.

(a) Identify and explain the steps of the PTD process for an app on a smart phone or standard cell phone for a personal spending advisor.

(b) Identify and explain the steps of the PTD process for computer that implements a personal spending advisor. Suppose that the computer is located at a local microfinance institution.

**Problem 4.14 (Human-Centered Design):** View the TED talk (17:01) by David Kelley

### Human-Centered Design

from Feb. 2002. Summarize the main points of the video and critique it.

**Problem 4.15 (Jugaad (Frugal) Innovation):** View the (16:25) TED talk by Navi Radjou

### Creative Problem-Solving in the Face of Extreme Limits

from Oct. 14, 2014.

(a) Define Jugaad innovation for technology. Give four examples of Jugaad innovation that he provides.

(b) Why does he say "more for more" is not working? What is "more for less"? What impact is it having on the developed world? Is frugal innovation low-tech? Explain. Give an example to justify your answer.

(c) Give three examples of "start-ups" based on Jugaad innovation.

(d) What does he mean by "co-creation"? Give an example from his talk.

(e) What is the UCLA "global lab for innovation"? Explain in less than five sentences.

(f) Radjou identifies principles of Jugaad innovation: (i) Keep it simple, (ii) Do not reinvent the wheel, and (iii) Think and act horizontally. Explain his justifications for these three principles.

(g) What is the relationship between ideas in his talk and reverse innovation that is discussed in Section 4.10.4?

**Problem 4.16 (Sustainable Design Methodology):** For a view of the impact of engineering on the environment, view the (20:05) TED talk by William McDonough

Cradle to Cradle Design

that is from Feb. 2005. Summarize the film and critique.

**Problem 4.17 (Design for Lasting Impact at Scale):** View the talk entitled

Design for Lasting Impact at Scale

given by (OSU Alumni) Eric Reynolds from MIT D-Lab, on April 25, 2014 at OSU. Summarize the main points of his talk and critique it.

**Problem 4.18 (Barefoot Engineers):**

(a) View the (19:07) TED talk by Sanjit (Bunker) Roy

Learning from a Barefoot Movement

from July 2011.

(b) Study the web site of the Barefoot College.

(c) View the (8:34) PBS video Barefoot College in India that was made March 13, 2009.

(d) Summarize the activities of the barefoot movement. What are the distinctive features of their philosophy? Define the meaning of a "barefoot engineer."

**Problem 4.19 (India's Hidden Hotbeds of Innovation):** View the (22:51) TED talk by Anil Gupta

India's Hidden Hotbeds of Innovation

from Nov. 2009. He discusses exploiting other's ideas, getting ideas, sharing with those who he gets them from, and others. He also discusses other ideas of exploitation. He discusses the Honey Bee Network. Explain the basic idea behind this network. Give examples of technologies he highlights that people with a low income have invented. Explain the relevance of his ideas to humanitarian engineering, especially with respect to local solutions and local talent.

**Problem 4.20 (The Water of Ayolé):** View the video of The Water of Ayolé that you can find on the internet (it is about 27 minutes long) Summarize the film and discuss relationships to the ideas of participatory technology development in the chapter. How did the people participate? Initially? Later? How did the community transform? What would you recommend on how this project should be run the next time?

**Problem 4.21 (LifePumps):** View the talk

<div align="center">

Creating a New Handpump Solution in Africa

</div>

by Greg Bixler. Summarize the main points of the talk, critique it, and compare it to issues seen in Problem 4.20.

**Problem 4.22 (Water Harvesting):** View the (17:14) TED talk by Anupam Mishra

<div align="center">

The Ancient Ingenuity of Water Harvesting

</div>

which is from Nov. 2009. Summarize and critique the film.

**Problem 4.23 (Baby Sleeping Bag for Incubator):** Watch the TED talk by Jane Chen (4:46) entitled

<div align="center">

A Warm Embrace That Saves Lives

</div>

summarize her main points, and critique the film. The film is from Nov. 2009.

**Problem 4.24 (Bicycle Machines of Guatemala):** Watch the (4:44) YouTube talk from Makeshift entitled

<div align="center">

The Bicycle Machines of Guatemala

</div>

The video was posted Feb. 23, 2015. What types of "bicimaquinas" do they design and use? Make a list. Explain why each one is useful.

**Problem 4.25 (Bioreactor: A System That Turns Waste Into Energy):**
View the (3:43) YouTube talk from Makeshift

<div align="center">

17-year-old Kenyan Creates Energy from Human Waste
</div>

The video was posted Feb. 23, 2015. Explain the steps in their process for making energy from waste.

**Problem 4.26 (Amy Smith and MIT D-Lab):** To learn about design implementation and iteration in humanitarian engineering view the (15:00) TED talk by Amy Smith

<div align="center">

Simple Designs to Save a Life
</div>

from Feb. 2006. Summarize the film and critique.

**Problem 4.27 (Lighting Design):** View the (10:36) YouTube video

<div align="center">

Human Powered Domestic Lighting in Rural India
</div>

from Jan. 11, 2008. Summarize the film and critique it.

**Problem 4.28 (Cultural Impact on Cell Phones):** To study the cultural impact on technology design, view the (16:06) TED talk, Jan Chipchase,

<div align="center">

The Anthropology of Mobile Phones
</div>

from March 2007. Summarize the film and critique. For more information, see (Chipchase and Steinhardt, 2013).

**Problem 4.29 (Fun and Games: Technologies for Lower Priority Human Rights?):** There are cases where traditional humanitarian engineers might *not* consider helping someone meet their human rights. For instance, normally, it is considered a human right to have rest and leisure (see the UN Universal Declaration on Human Rights, (Nussbaum and Glover, 1995), or Section 2.2.2).

(a) Should a humanitarian engineer pursue assisting with the fulfillment of this right for a client or community?

(b) Would that be a low "degree" of humanitarian engineering?

(c) Via what technologies? Electronic video games? Puzzles?

(d) Is the human right to rest and leisure of lower priority than other rights?

(e) Who sets priorities? You? Who defines needs?

    (f) Is entertainment more important that clean water? What if basic needs of children are ignored by parents in favor of their own entertainment. Would you help that happen?

In answering these questions, recall the discussion in (Banerjee and Duflo, 2012) where a man bought a television at the expense of his own suffering due to the lack of his ability then to meet his own basic needs. Also, consider the following story, from Andrew Fenner, an OSU student (quoted exactly, with his approval):

> In July of 2013 I was living with the Samburu, a relative people of the Maasai, in Kenya. I was with about 20 other college students spread across three different bomas (Samburu villages). We were part of their families, helping tend their cattle and sleeping in the same homes. I had brought my tablet with me to play some games with the children and on the first night I decided to give it a go. I let the children in the boma play some racing games as well as a multiplayer "air hockey" game. Keep in mind this is an area where the closest light bulb is a couple miles away at a shop on the main road, technology like my tablet is completely unheard of. The situation quickly grew from a fun idea to something special. The children were having so much fun and making so much noise that the adults began to congregate around all of us; my father, named Lekoitip, was especially curious. He surprisingly asked me if he could play and of course I said yes. We played the hockey game against each other; he had no idea how to play but was having a blast. He started laughing and clapping every time I would score and then all of a sudden he left. I was worried he was mad at me but it turned out he was embarrassed to have laughed in front of the children! It had brought out too much of his youth.

Is it so bad to have fun via technology? Do such stories teach us about humanity? Do they make people real?

    (g) Do cooperative games help develop solidarity? Are electronic games "humanitarian technology"? What about TV, considering its impact on news and its potential effects on participation via democracy and creating an informed electorate?

    (h) Or, suppose you were a comedian and did a humanitarian trip where all you did was tell jokes and hang out and socialize during your visit (search the internet for "humanitarian comedian" as it is interesting)? Would you get invited back? If such human entertainment has such value, why not electronic entertainment? How enthusiastic would a community be about that? I know, some of you would be concerned the types of games introduced, and certainly such concerns can be valid, as they are in the developed world also.

For more discussion on this issue, that might be called "humanitarian technology for fun," see Section 3.2.4 that is based on the discussion in (Banerjee and

Duflo, 2012) about having a TV, and (Vandersteen et al., 2009), p. 39, where the priority of having a cell phone and DVD player is set higher than getting children shoes.

**Problem 4.30 (Community and Architecture):** View the (15:49) TED talk by Alejandro Aravena

My Architectural Philosophy? Bring the Community Into the Process

which is from Oct. 2014. Summarize and critique the film.

**Problem 4.31 (Ingenious Homes Around the World):** View the (16:59) TED talk by Iwan Baan

Ingenious Homes in Unexpected Places

that is from Sept. 2013. Discuss the features of the various cases (Venezuela, Nigeria, Egypt, and China), then Google "Tower of David" in Caracas, Venezuela, read about it, and see the pictures at Google Images, and videos at YouTube. Are their approaches simply a way to avoid homelessness? Present your position on the following statement: "To solve the homeless problem in Columbus, Ohio, US, we should build a Tower of David in downtown Columbus." Finally, Baan quotes a friend at the end saying that "There is plague of saneness that is killing human joy;" why did he say that?

**Problem 4.32 (Technology Crafts):** View the (14:05) TED talk by Vinjay Venkatraman,

'Technology Crafts' for the Digitally Underserved

from April, 2012. Summarize the main points of the film and critique.

**Problem 4.33 (Wiring the Web for Global Good):** View the (16:43) TED video by Gordon Brown

Wiring the Web for Global Good

from July 2009. Summarize the main points of the talk. Do you agree with him? On what? What do you disagree with him on? Anything?

**Problem 4.34 (Inventing is the Easy Part):** View the TED talk (5:42) by Daniel Schnitzer

Inventing is the Easy Part

from Nov. 2011. Explain the main points of his story and discuss its relevance to humanitarian engineering.

**Problem 4.35 (Cat Laine at Business Innovation Factory-4):** View the (15:20) YouTube talk by Cat Laine

BIF-4: Cat Laine–Keeping Things Gritty

that was posted Feb. 26, 2013. See also the *same* (15:20) talk under a different title at

Cat Laine: Engineering a Better Life for All

from Oct. 2009 and the BIF in Oct. 2008. What does her group focus on? She highlights the lack of affordable products for people with a low income. What products does she think would be important? What does she say about infrastructure? What does she say about lack of locally produced alternatives? What is the role of engineering in her group? Give an example of when solving an engineering problem for the developing world could have a significant impact in the developed world (name a technology that she discusses that could do this).

**Problem 4.36 (Participatory Social Business):** View the (17:09) TED talk by Ernesto Sirolli

Want to Help Someone? Shut Up and Listen!

that is from Aug. 2012. Define "patronize" and "paternalize" in his words. What is the first principle of aid? Second? He says "Become a servant of local passion." What does that mean? He says that you should not arrive with ideas, that you should sit with local people (e.g., in a kitchen or cafe), become friends, and find out what they want to do. Why does he say that? He says "The passion they have for their own growth is the most important thing." Why does he say that and what does he say to do about it? He says to listen to the people, but not in community meetings; he says that the problem with those is that the entrepreneurs (and the smartest people) never come and they will not publicly say what they want to do with their own money. How do they get to the smartest people? What does privacy have to do with it?

**Problem 4.37 (The Business of Sustainability):** Summarize and critique (15:48) TED talk by Ray Anderson

The Business Logic of Sustainability

that is from Feb. 2009. Summarize the film and critique.

**Problem 4.38 (Parsons: Engineering in Context: Engineering in Developing Countries):** Read the paper (Parsons, 1996), "Engineering in Context: Engineering in Developing Countries", Journal of Professional Issues in Engineering and Practice, October. Summarize its main points and critique it. What does she mean by "context"? What lessons did she learn?

**Problem 4.39 (Amadei/Wallace: Engineering for Humanitarian Development):** Read the paper (Amadei and Wallace, 2009), "Engineering for Humanitarian Development: A Socio-Technical Approach", IEEE Technology and Society Magazine, Vol. 28, No. 4, pp. 6-15. Summarize its main points and critique it. Why are engineers indispensable to international development? What is EDC and what does it do?

**Problem 4.40 (Silliman: Assessing Experiences of International Students in Haiti and Benin):** Read the paper (Silliman, 2009), "Assessing Experiences of International Students in Haiti and Benin", IEEE Technology and Society Magazine, Vol. 28, No. 4, pp. 16-24. Summarize its main points and critique it. Identify the main categories of stakeholders (students from US, students from Benin, etc.) and discuss their roles. Discuss the differences in the roles of undergraduates and graduate students.

**Problem 4.41 (Vandersteen/Baillie/Hall: International Humanitarian Engineering: Who Benefits and Who Pays?):** Read the paper (Vandersteen et al., 2009) "International Humanitarian Engineering: Who Benefits and Who Pays?," IEEE Technology and Society Magazine, Vol. 28, No. 4, pp. 32-41. Summarize its main points and critique it.

**Problem 4.42 (Technology for People Who are Homeless in the US):** Read Section 4.6.4.

(a) Name six technologies that may help people who are homeless. Explain why each one might be useful in less than three sentences.

(b) Define the mission and rationale of Tech$_4$Community as it pertains to homelessness.

**Problem 4.43 (Community Assessment and Robust Technology Selection: Smart Phones):** Read Section 4.4, Section 4.5.2, and Section 4.6.5.

(a) Give the "problem statement" for evaluating and comparing two different smart phones, ones made by different companies (e.g., iPhone and Android). You are evaluating these for yourself.

(b) Explain the general methodology to compare the smart phones.

(c) Do a quantitative assessment of the two phones. Pick features common to both phones. Use at least four features. Evaluate and produce numeric assessments. Pick numbers to represent the importance of each feature. Compute the "quality" (preference) for each case and make a recommendation on what to buy.

(d) Determine the uncertainty ranges on the assessments and importances.

(e) For the program `RobustMCDM.m` input the data from (c) and (d), run the program, provide the three plots, and explain which phone you would pick and why, taking into account the uncertainties you have in assessments of features. In what sense is your selection "robust"?

(f) Design a set of questions for an interview or focus group, or a survey, and conduct it (use at least three other people) for the problem of selecting a phone. Compute statistics. Repeat (c), (d), and (e), but using the information from multiple people. What is different compared to the case above where you were the only one assessing the technology? Did the way you incorporated uncertainty change? How? Were the results for running the program `RobustMCDM.m` different? How?

**Problem 4.44 (Uncertainties in Preferences in Multicriteria Decision Making):** Consider Equation (4.11). Add this approach to quantifying the effects of another kind of uncertainty into the program `RobustMCM.m`. Do *not* scale this uncertainty with the parameter $\alpha_u \in [0, 1]$ as was done for the other parameters $f_{ij}$ and $w_j$; just consider the $\epsilon_i$ to lie on the fixed range in Equation (4.12). In the plots that are output from `RobustMCM.m` you obtain the upward/downward sloping blue/red lines around the horizontal black dots, where the blue/red lines meet at the dots when $\alpha_u = 0$. When you add in $\epsilon_i$, this will be different. You should provide a plot that demonstrates that your program is working properly, in particular, the plots output from the program should be different from those for `RobustMCM.m`, and clearly show the impact of the $\epsilon_i$ uncertainty *combined with* the other uncertainties. *Hint:* The $\epsilon_i$ uncertainty creates a "band" (region) around $P_i^{nom}$, that must be "added" on to the consideration of the other uncertainties.

**Problem 4.45 (Humanitarian STEM Education):** Read Section 3.4 and then Section 4.8.

(a) Describe the difference between utilitarian and transformational approaches to education as they relate to STEM. Does engineering tend to be more of one than the other? Which? Why?

(b) For Section 4.8.2, identify at least three targets for STEM education that were identified in the chapters.

(c) Explain the steps to design a STEM program for a developing school. Use less than 200 words.

(d) Give at least one example of an SJ-STEM experiment, one different from the "juggler" discussed in the chapter.

**Problem 4.46 (Taking OLPC to Colombia):** View the (6:48) TED talk by Nicholas Negroponte

<div align="center">Taking OLPC to Colombia</div>

(one lap-top per child) which is from Dec. 2008.

(a) Summarize the main points of the program.

(b) Search the web for key OLPC sites (e.g., a Wiki) and find the criticisms of the program and summarize those. Include in your discussion the critique in (Toyama, 2015).

**Problem 4.47 (PlayPower Affordable Fun Learning Games):** Visit the PlayPower web site here and summarize their objectives and activities in ¡200 words.

**Problem 4.48 (Toys from Trash and STEM Education):** View the (15:30) TED talk by Arvind Gupta

<div align="center">Turning Trash Into Toys for Learning</div>

from Dec. 2010. Summarize and critique the film. Name at least three projects he presents and explain in each case the scientific or engineering idea that the "toy" teaches.

**Problem 4.49 (Teaching Design for Change):** View the (16:43) TED talk by Emily Pilloton

<div align="center">Teaching Design for Change</div>

that is from July 2010.

(a) Summarize what she feels are the main problems with rural communities in the US

(b) Summarize some key points of her design approach, and also for her case of where she focuses on her "design for education."

(c) She cites a number of reasons for living where she is working (helping). Cite some of her reasons.

    (d) What does she mean by "co-creation"? "Design with"? Discuss relationships with humanitarian engineering.

**Problem 4.50 (Digital Humanitarianism):** View the (10:57) TED talk by Paul Conneally

<div align="center">

Digital Humanitarianism
</div>

from Nov. 2011. Summarize the main points of the talk. Name two more forms of digital humanitarianism. Explain. Visit the Digital Humanitarians web site, and summarize their activities in less than 200 words. For more information on this subject, see (Meier, 2015).

**Problem 4.51 (Sweatshops and Engineers):** Read Section 4.6.6.

    (a) View the (20:29) YouTube video

<div align="center">

Nike Sweatshops: Behind the Swoosh
</div>

       from July 28, 2001. Summarize and critique the video. (Optional parts: For more information on the Nike case, see pp. 125-126 in (Rivoli, 2009): (i) Is Nike responsible for the conditions at supplier facilities? and (ii) How have Nike's practices in this regard changed?)

    (b) View the (17:00) YouTube video The Apparel Truth from Jan. 7, 3013. Summarize and critique the video.

    (c) Explain the following: fair wage issue, issues with health and safety standards, working conditions, pollution from the sweatshop, and worker rights, including freedom of association with unions, and strikes.

    (d) Explain what you could do as an engineer to improve the conditions at a sweatshop, but without raising costs and thereby putting the sweatshop out of business as you can assume that the jobs there are very important for the local people.

    (e) See the Alta Garcia site:

<div align="center">

Alta Garcia
</div>

       Explain the philosophy of Alta Garcia, and in particular their notions of fair trade and a fair wage.

For more information on sweatshops, see (Rivoli, 2009; Powell, 2014).

**Problem 4.52 (Supply Chains and Global Labor):** View the (17:46) TED talk by Auret Van Heerden

<div align="center">

Making Global Labor Fair

</div>

from July 2010. Summarize and critique the talk. For more information on supply chains and human rights see (Shift, 2012).

**Problem 4.53 (Transparency International):** Read Section 1.1.2. Summarize and critique the (16:13) TED talk by Peter Eigen

<div align="center">

How to Expose the Corrupt

</div>

that is from Nov. 2009. Describe what he means by a "prisoner's dilemma." He is with Transparency International; study their web site and explain their mission in less than 50 words.

**Problem 4.54 (Fighting Corruption With Technology):** Read Section 1.1.2.

(a) Summarize and critique the (14:27) TED talk by Charmain Gooch

<div align="center">

Meet Global Corruption's Hidden Players

</div>

that is from June 2013. What does she say makes global corruption possible? She is with Global Witness; study their web site and explain their mission in less than 100 words. For more information on the subject of corruption, see (Risman and Miguel, 2008). Are there technological approaches to fight corruption? Name at least one based on the discussion in the chapter.

(b) View the (12:28) TED talk by Shaffi Mather

<div align="center">

A New Way to Fight Corruption

</div>

Summarize and critique his talk. What is the role of technology in his approach to stopping corruption?

**Problem 4.55 (Child Trafficking and Slavery):** Read Section 1.1.2.

(a) View the talk by Joe Chongsiriwatana

<div align="center">

Child Trafficking

</div>

from July 2010. Summarize and critique the talk. There is potential for technology to assist in the fight against child (and human) trafficking, e.g., via global information systems (GIS) for tracking perpetrators and helping in rescuing children (Chongsiriwatana, 2013).

(b) View the (12:42) TED talk from Nov. 2009 by Sunitha Krishnan

<div align="center">The Fight Against Sex Slavery</div>

Summarize and critique the talk.

(c) View the (18:29) TED talk by (Nobel Laureate) Kailash Satyarthi

<div align="center">How to Make Peace? Get Angry</div>

from March 2015. Summarize and critique the talk. What profession does he belong to?

See also Problem 2.21.

**Problem 4.56 (Engineers' Involvement in Weapons Development and Law Enforcement):** Read (Forge, 2004) and Section 1.1.2.

(a) In (Forge, 2004), the author says:

> It is argued that the engineer has responsibility for the uses to which the tools that he designs can be put, and that responsibility extends to the use of weapons.

Explain in more detail the meaning and implications of the author's argument. Do you agree?

(b) In (Forge, 2004), the author says:

> ...there must be a strong assurance that the results will only be used as a just means in a just cause.

Is such an assurance possible? Explain.

(c) See also Problem 2.21, and particular, view the TED talk there. Can you think of a humanitarian technology that will help address the problems with violence that he raises?

For related information, see Chapters 13 and 14 in (Volti, 2006).

**Problem 4.57 (Military Humanitarian Intervention):** Read Chapter 11 of (Fisher, 2011). In (Fisher, 2011), the author says:

> Does a government have a right, even a duty, to save the lives, not just of its own citizens, but also the citizens of other states? Are we obliged to save the lives of strangers? If we are, what means are we entitled to employ to achieve this?... Is there a right of humanitarian intervention, even when it is non-consensual?

(a) Answer these four questions.

(b) Critique the ideas in (Fisher, 2011) using your own perspectives on the issues, and especially incorporating your views on social justice with background from Chapter 2.

More information on just and unjust wars is in (Walzer, 2006; McMahan, 2009)

**Problem 4.58 (Engineering for Change (E4C)):** Go to the E4C web site and:

(a) Summarize their mission and activities in a less than 200 words.

(b) View one of their webinars (your choice), summarize its main points, and critique it.

**Problem 4.59 (Humanitarian Science and Engineering Organizations):** Summarize the mission and activities of each of the following organizations in one less than 100 word paragraph each:

(a) Practical Action

(b) Engineers Against Poverty

(c) Engineers for a Sustainable World

(d) Engineers Without Borders

(e) Engineering World Health

(f) TechChange: The Institute for Technology and Social Change

(g) Scientists Without Borders

(h) SciDevNet "Bringing science and development together through original news and analysis."

(i) UCLA Institute for Innovation in Health

(j) If you are a student at OSU, see Humanitarian Engineering Center to see the humanitarian engineering student organizations at OSU (write less than 5 sentences on each). If you are at a different university, write a brief paragraph on each humanitarian engineering student organization at your university.

**Problem 4.60 (Cooperative Management of Community Technology):** Read Section 4.12.1 and for this problem you will use

```
CoopManageCommTech.slx
```

and

CoopManageCommTechPlotter.m

(a) Set $K = 0.01$ and equal $g_i$ values. Run the simulation and compare the plot to the ones obtained in Section 4.12.1. In particular, how have the plots changed? Explain why.

(b) Set $K = 0.005$ and repeat (a) for this new value.

(c) Set $g_1 = 0.5$, $g_2 = 0.4$, and $g_3 = 0.1$. Explain what this case represents in terms of inequality per the discussion in Section 4.12.1. Repeat (a) for this case with different $g_i$ values than (a). Explain the differences from the results in Section 4.12.1.

(d) Building on Problem 4.20, present and defend your view on whether an automation approach for pricing of water such as the one in Section 4.12.1 would have been good for "The Water of Ayolé" project to ensure that funds were available for maintenance.

**Problem 4.61 (Alternative Pricing for Cooperative Management of Community Technology):** Read Section 4.12.1. Modify

CoopManageCommTech.slx

and

CoopManageCommTechPlotter.m

to implement Equation (4.19) which defines an alternative way to set prices.

(a) Consider equal $g_i$ values. Find values of $\epsilon$, $\gamma$, and $K$ that result in adequate performance (e.g., in making the amount of saved money quickly converge to the desired amount of money for maintenance). Compare your best achievable performance to the results and approach in Section 4.12.1.

(b) Repeat (a) for $g_1 = 0.5$, $g_2 = 0.4$, and $g_3 = 0.1$. Compare to (a) and explain the differences from the results in Section 4.12.1.

**Problem 4.62 (Impact of Community Size on Sustainable Community Development):** Read Section 4.12.2 where the community size was $N = 100$ people. Use the program

CommunityDynamics.m

to study the impact of community size on sustainable community development for the case where $p \in [0, 200]$. Read the first lines of program that explain how to run it for different cases.

(a) Consider a smaller community size, $N = 50$ by changing this parameter in the program (called N) and running the program for the case where $p \in [0, 200]$ (in the program set `Ncomm=50` and `Nparam=6`); note that it can take several minutes to run this simulation. Provide a plot showing the impact of changing $p$ on variables, one like Figure 4.21 (several are provided by the program, but use "`figure(1)`"). Why does the simulation take a while to run? Answer this question by explaining how many people, over what time period, how many communities, and how many parameter cases are considered in the simulation. Compared to Figure 4.21, what has changed in the $N = 50$ case? Are some of the variables higher/lower? Shapes of plots changed? Why? Explain in terms of the plots and model in Section 4.12.2.

(b) Repeat (a), but for $N = 150$. Also, compare the results to (a) and Figure 4.21 in the discussion.

**Problem 4.63 (The Impact of Education on Health and its Effect on Community Dynamics):** Level of education can impact whether someone is healthy or not (Hurd and Kapteyn, 2003; Grossman, 1972), with more educated people being generally healthier. Modify $v_h^i(k)$ or $\beta_h s_h^i(k)$ (one only, your choice) in Equation (4.23) to incorporate this effect. Your modification of the term you choose will incorporate a function of $e^i(k)$ that represents the effect (you pick the form of that function and how it is incorporated into the term), and this will create a modified version of Equation (4.23)). This will change the dynamics of each individual in the community and hence the community dynamics. Modify

<div align="center">

`CommunityDynamics.m`

</div>

to incorporate your change. Run the new code to produce all the plots corresponding to those in Section 4.12.2. You should view these simulations (and any particular runs for a single community) as a test of whether you have done a good job of modeling the effect. Once your simulations seem to represent the community-level effects, you should compare your plots to the ones in Section 4.12.2 and explain differences. Use the $SCDI$ and $SCDI_s$ and $N = 100$ people in the community.

**Problem 4.64 (Sustainable Community Development Index for Individual and Community Differences):** Read Section 4.12.2. Mathematically define an SCDI index that will account for variations in individuals and communities, $SCDI_{ci}$. Modify

<div align="center">

`CommunityDynamics.m`

</div>

to incorporate your change. Run the new code for $N = 100$ to produce all the plots corresponding to those in Section 4.12.2, provide the plots, and explain the similarities and differences between the two cases. Also, explain why the similarities and differences exist.

**Problem 4.65 (Properties and Measures of Inequality):** Read Section 4.12.2, and consider $X_i$ numbers, $i = 1, ..., N$.

(a) *Variance:* This measure is defined in Equation (1.2). For $N = 2$, the variance $\sigma^2 = (X_1 - \bar{X})^2 + (X_2 - \bar{X})^2$ where the mean is $\bar{X} = \frac{1}{2}(X_1 + X_2)$. What is the domain and range of $\sigma^2$ for this case? Write a Matlab program, for example, by modifying `SCDIplotter.m`, that produces a plot analogous to the one in Figure 4.19 that shows how $\sigma^2$ changes in terms of $X_1$ and $X_2$. Explain how variance quantifies inequality.

(b) *Gini index:* This index is defined in Equation (1.3). For $N = 2$ write a Matlab program, for example, by modifying `SCDIplotter.m`, that produces a plot analogous to the one in Figure 4.19 that shows how $G_{index}$ changes in terms of $X_1$ and $X_2$. Explain how $G_{index}$ quantifies inequality. Compare and contrast with the Atkinson inequality index in Equation (4.25). Note that if you split a population into distinct subgroups, and compute the Gini index for each subgroup, it is not generally the case that the addition of the subgroup Gini indices will equal the Gini index computed for the whole group at once (it is not additive across subgroups). Explain, using the mathematical definition of the Gini in Equation (1.3), or via an an example, why this is the case.

(c) *Atkinson index:* This entropy-based index is defined in Equation (4.25). Use a mathematical approach to sensitivity analysis to prove the following statement: "As inequality increases, greater changes to inequality occur for variations to data values corresponding to the ones that are most unequal relative to others." To start, see the discussion on the shape of $A_x$ in Figure 4.19. Optional: (i) Repeat such an analysis for the Gini index above, and the Theil index below; and (ii) What is the "inequality aversion parameter," say $\epsilon$, that can be used for a more general mathematical formula for the Atkinson index? State the more general formula, and the meaning of the parameter. Provide a plot analogous to the one in Figure 4.19 but for two cases, $\epsilon = 2$, and $\epsilon = 10$. Compare the two cases, and explain the effect of the size of $\epsilon$.

(d) *Theil index:* This entropy-based index, for a mean $\bar{X} = \frac{1}{N}\sum_{i=1}^{N} X_i$, is defined by (normalized version)

$$T_{index} = \frac{1}{N \ln(N)} \sum_{i=1}^{N} \left( \frac{X_i}{\bar{X}} \ln \left( \frac{X_i}{\bar{X}} \right) \right)$$

What restrictions do there need to be on the $X_i$, $i = 1, ..., N$? Here, $T_{index} = 0$ corresponds to perfect equality and $T_{index} = 1$ corresponds to complete inequality. For $N = 2$ write a Matlab program, for example, by modifying `SCDIplotter.m`, that produces a plot analogous to the

one in Figure 4.19 that shows how $T_{index}$ changes in terms of $X_1$ and $X_2$. Explain how $T_{index}$ quantifies inequality. Compare and contrast with the Gini index in Equation (1.3) and the Atkinson inequality index in Equation (4.25). What is the "decomposability property" (additivity across subgroups) of the Theil index and why could it be useful? Does the Atkinson index also have a decomposability property? What are the relationships between the Atkinson index, Theil index, relative entropy function, and Kullback-Liebler distance?

(e) *Decile dispersion ratio:* This indicator is the ratio of the average income (or consumption) of the top $r\%$ of the people divided by the average income of those earners with income in the lowest $r\%$. For instance, it could be that $r = 10$ or $r = 5$. This way, the interpretation is "the income of the rich is some multiple of low-income earners." Write down a mathematical formula for the decile dispersion ratio. For $r = 5$, if there are only transfers between the middle earners (between 95% and 5%), then does this indicator change? Can you name two types of transfers that will result in a change in this indicator? Which direction does the indicator move, up or down, for the types of transfers you identify?

(f) *Share of income/consumption:* A problem with, for instance the Gini and Theil indices, is that they change when the values of the $X_i$ , $i = 1, ..., N$, change, no matter whether the change occurs among top, middle, or bottom earners (e.g., transfers among top earners will change the values of the indices). If the focus is on the share of earner's income for persons with low income, a better indicator may be the share of the income that is earned by those persons earning less than 10% (or 20%). Notice that with such an approach, if there are transfers between the top 80% of the earners, this indicator will not change. Write down a mathematical formula describing this indicator.

(g) *Relative inequality:* Suppose that we consider a focal individual $i^*$. From this person's perspective, how do they view their own standing with respect to the other $N$ individuals? This depends on what information $i^*$ has about other individuals, $j \neq i^*$. Provide a mathematical definition of relative inequality, by modifying the Gini index. Next, generalize the mathematical definition to obtain an inequality measure of one group (subset) of people relative to another group (subset) of the $N$ people. Optional: Can you define relative inequality by starting from a one of the other above inequality measures? Explain.

(h) *Transfer principle:* What is the "transfer principle" related to inequality measures? Define it. Can you name an inequality measure that possesses the transfer principle? Explain by proving it mathematically or showing an example via a computational approach.

(i) *Mean independence and uniform raises:* Pick one of the following inequality measures: Gini or Atkinson. For your chosen measure: (i) Mean inde-

pendence: If $X_i$, $i = 1, ..., N$, suppose you form $X_i^{'} = aX_i$, $i = 1, ..., N$, for some $a > 0$ (e.g., each income value is multiplied by a positive constant). Is $A_x$ computed for $X_i$, $i = 1, ..., N$ the same as $A_x$ computed for $X_i^{'}$, $i = 1, ..., N$? and (ii) Effect of uniform raises: If $X_i$, $i = 1, ..., N$, suppose you form $X_i^{'} = a + X_i$, $i = 1, ..., N$, for some $a > 0$ (e.g., a "raise" in income of the same value is added to each individual's income). Is $A_x$ computed for $X_i$, $i = 1, ..., N$ the same as $A_x$ computed for $X_i^{'}$, $i = 1, ..., N$? For both of these, explain your answers by proving it mathematically or showing an example via a computational approach.

**Problem 4.66 (Impact of Democracy on Sustainable Community Development):** Read Section 4.12.2 and in particular focus on Section 4.12.2. In this open-ended problem, you should implement a democracy for voting on some aspect of the community rules. Demonstrate the performance of your strategy in the manner that has been done in both Section 2.4.3 and Section 2.4.4. Include Monte Carlo simulations in your analysis.

**Problem 4.67 (Volunteer, Job, and Career Opportunities in Humanitarian Engineering):** Search the internet and make a list of volunteer and career (job) opportunities in humanitarian engineering. Include, for instance, the Peace Corps, and NGOs that need engineers. Does USAID, UN, or the World Bank hire engineers (or, without specifically requesting engineers, people with the same type of skill set in science, math, and design)? Also, consider

<div align="center">Monster</div>

<div align="center">Corporation for National and Community Service</div>

and

<div align="center">Idealist</div>

For each case, provide the web link or source, and explain what type of volunteer activity or job is available. You may also be interested in (Gedde and Green, 2015), and (Mehta, 2015) which has a wide array of relevant information on careers in social innovation/entrepreneurship (e.g., organization descriptions, job descriptions, career trajectories, organizations, preparation, advice, etc.). For instance, career advice is given on pp. 38-42 of (Mehta, 2015).

## 4.15 Annotated Bibliography

**Helping:** The first section on helping is based on (Egan, 2014), and the feedback control perspective is from (Passino and Antsaklis, 1989). The second section on helping is based on (Schein, 2011), with some material on "humble inquiry" from (Schein, 2013).

**Participatory Community Development:** The first part of the participatory community development section is primarily based on (Homan, 2011), but (Healy and Link, 2012) was also used. One reference used in the participatory development section was (Freire, 1993). The community capitals part is based on (Homan, 2011; Flora et al., 2004; Flora and Flora, 2013). A good source for information on participatory development, from the Institute for Development Studies, is

<div align="center">Participatory Methods</div>

This web site is like a book and has several useful resources. For online information on all aspects of community development, see

<div align="center">The Community Toolbox</div>

The sections on participatory development are based on (Tufte and Mefalopulos, 2009), and for impact studies on (Guijt, 2014). The participatory approach to development is discussed in great detail in (Mansuri and Rao, 2013) and this source was instrumental in creating the corresponding section in this chapter (see also the earlier (Bank, 1996)). The feedback control perspective is a multi-person extension of the ideas in (Passino and Antsaklis, 1989). A source for participatory action research is

<div align="center">Participatory Action Research, Planning and Evaluation</div>

In other related work, Agunga (Agunga, 1997) emphasizes the importance of communication in development, participation, and a useful systems-theoretic viewpoint. The "results framework" is described in (USAID, 2010), where participation is broadly defined to include government, USAID, and others. Other frameworks, including (Caldwell, 2002), also emphasizes the feedback nature of development processes, and a framework for engineering for sustainable development projects is given in (Amadei, 2014). The UNDP approach to planning, monitoring, and evaluation is in (UNDP, 2009). An example of the importance of people knowing how an agricultural technology works so that they receive its full benefits can be found on p. 71 of (Rivoli, 2009).

**Teamwork and Project Management:** The section on teamwork is based on (Katzenbach and Smith, 1993; Pentland, 2012), with some overview material from (Maxwell, 2001; Ulrich and Eppinger, 2012). For more information on how to deal with people and work effectively on teams, or in organizations, you may want to consider (Carnegie, 1936) and (Covey, 2004). There are several books on project management, including one based on an order of topics along the project time line (Schwalbe, 2012), or separate key concepts, each along the time line, then integrated (Project Management Institute, 2013). Here, ideas on general project management came primarily from (Project Management Institute, 2013), and a few ideas from the logical framework approach in (PCI, 1979).

**Community Assessment and Project Selection:** The part on needs assessment, in the section on community assessment, is based on (Watkins et al., 2012). For more on needs assessment see Chapter 7 of (Altschuld and Watkins, 2014) and (Eade and Williams, 1995). See also

NeedsAssessment.org

The section on monitoring, evaluation, and impact analysis is partly based on (Bank, 2004).

A special case of the multicriteria decision making approach in the chapter is used in (Ulrich and Eppinger, 2012) (e.g., the "scoring methods") in the product development process. For more on the subject of theoretical work on sensitivity analysis in multi-criteria decision making, see (Triantaphyllou, 2000). Dynamical approaches to multicriteria decision making are found in nature, for humans, and also insect societies such as the honey bees in (Passino and Seeley, 2006).

**Humanitarian Engineering and Technology:** Humanitarian engineering is set in a historical context in (Mitcham and Munoz, 2010). General treatments of humanitarian engineering and service-learning in engineering are in (Colledge, 2012) and (Tsang, 2000; Lima and Oakes, 2014; Lucena et al., 2010) and also see (Schneider et al., 2008) and (Douglas and Papadopoulos, 2010). A relevant general article is in (Amadei and Wallace, 2009). A book on engineering for sustainable human development in communities is in (Amadei, 2014); for it, there is a significant coverage of disasters, project management, community resilience, and civil engineering applications (e.g., water, sanitation, and hygiene (WASH) that address key root causes of health issues as discussed in Section 3.3). The authors in (Mihelcic et al., 2009) present an environmental engineering approach to water, sanitation, and indoor air. For information on "digital humanitarianism" see (Meier, 2015). The use of engineering in emergencies is covered in (Davis and Lambert, 2002). Toyama emphasizes the role of the human in trying to use technology for social change (Toyama, 2015). For instance, Toyama discusses, in Part 2 of (Toyama, 2015), the role of "heart, mind, and will" and "good intention, discernment, and self-control" and "intrinsic growth" which is progress on these, for both individuals and groups (communities or nations), and highlights these as important for human development in all cases, and in particular the case of trying to use technology to help with development. Studies on global competency of engineers are in (Downey and Lucena, 2006; DeBoer et al., 2013; Jesiek et al., 2014). Cross-cultural engineering is discussed in (Caspersen, 2002). A phased approach for an academic program for humanitarian engineering is in (Greene, 2013). The problems of failures and unintended consequences in humanitarian engineering are spread throughout the literature; however, there is a more significant focus on these issues in the following which also contributed to the discussion in this chapter (Parsons, 1996; Vandersteen et al., 2009) (see also, (Schneider et al., 2009)). One nice case study in humanitarian engineering is in (Silliman, 2009). The project

concept of an "engineering clinic," that was named the "community technology clinic," but is now called "Tech$_4$Community," is based on (Passino, 2009) and more information is at Tech$_4$Community. Some of the "best practices" for engineering humanitarian project (trips) are based on my own experiences, the experiences of some colleagues I have had discussions with (Bixler et al., 2014), and in a few cases are also based on (Oakes, 2012; O'Neill et al., 2012a; Vandersteen et al., 2009). The notion of "fair trade learning" says that what the project trip members give should be roughly equal to what they get (learn) (Fair-Trade Learning, 2013) (click here).

Early work that has had a significant influence on appropriate technology is in (Schumacher, 1975). Sources for ideas on humanitarian technology, appropriate technology, or the related philosophy include the web sites in the chapter and (Hazeltine and Bull, 2003; Bowman and Crews, 2009; Patel et al., 2014), the "design for the other 90%" movement (Smith, 2007, 2011) (which are appropriate technologies), and in architecture you can consider (Architecture for Humanity et al., 2006). See also (Cahill, 2005). For mathematical modeling and analytical studies of the impact of appropriate and "inappropriate" technologies on economic growth see (Acemoglu, 2009). Clearly, appropriate technology should not be low quality (e.g., see discussion on pp. 89-90 in (Kidder, 2009)). For more information on sweatshops, see (Rivoli, 2009; Powell, 2014). The impact of technology on the transformation of work is discussed in Chapters 8-10 in (Volti, 2006). Development of technologies to fight corruption seems to be an under-studied field of humanitarian engineering. For information on corruption, see (Risman and Miguel, 2008). Sources on issues in human trafficking and corruption for the chapter are based on (Finke, 2013; Chongsiriwatana, 2013). See also (Kristoff and WuDunn, 2010) for discussions on a range of issues associated with sex trafficking, and other women's issues. For specific technologies and tools for empowerment of girls and women see (Teutsch, 2015).

**Participatory Technology Development:** The participatory technology development section is based on integrating participatory development and community needs and resource assessment from (Homan, 2011), and more generally the area of participatory development, into a conventional approach to product design and development (Ulrich and Eppinger, 2012) combined with a human-centered design approach (IDEO, 2014) (see also here where there is "The Field Guide to Human-Centered Design," 2015, (IDEO, 2015)) with consideration of cultural issues (per Chapter 1) and anthropology for product development (Chipchase and Steinhardt, 2013) (see also, (Watson, 2011)). For product development you may also want to consider (Cagan and Vogel, 2013). For another approach to design, one that has some features that fit with humanitarian engineering (e.g., client empathy), you could consider (Curedale, 2013). For more details on the environment and sustainable design, see (Allenby, 2012). For technology commercialization in the developed world that, of course, has implications for the developing world, you may want to consider (Overholt, 2013). Section 4.10.4 discusses "reverse innovation" as covered in (Govindarajan and

Trimble, 2012), where products are developed in or for the developing world then transferred to the developed world.

**Humanitarian STEM Education:** For the H-STEM education section, in addition to (Sachs, 2006) where the author expresses his views on the importance of technological capacity for development, the chapter used a number of ideas on education and development from (Maclure et al., 2012); this source also has a number of references, books and web sites, on international and comparative education. Quite a few of the ideas in the H-STEM education section came from my collaborator (Anderson, 2013); this included the projects/experiments based approach, teacher programs (i.e., teach the teachers), "STEM without words" ideas for an international context, and specifications on what is a feasible STEM experiment for K-12 education. Often at the K-12 level it is useful to also create a "lesson plan" for a teacher to use and for this see (Wilson, 2015). The participatory approach to educational program design is discussed more in Section 4.2.11, (Mansuri and Rao, 2013), and pp. 231-234 of (Bank, 1996). A critique, and ideas for, the use of technology in education in the developing world is provided in (Toyama, 2015). There are a number of types of STEM programs that may be of interest; to get ideas on broadening a STEM program to be inclusive of other subjects see Changemakers which discusses entrepreneurial STEM, or E-STEM. The H-STEM education "suitcase" idea is from (Pappano, 2013). Some of the ideas on the university-level low-cost engineering laboratory project, part of the iSTEM program, called "weLab" are in (Quijano et al., 2008) and see iSTEM for current information on the weLab program (that includes several other publications, for example, on particular experiments). The idea of extending the motor experiment to a feedback controller is from (Pavlic, 2013). A perspective on higher education development in Latin America is in (Castro and Levy, 2000). General information on international STEM is in (Marginson et al., 2013). Information on differences between boys and girls in STEM education is given in (PISA, 2015). The role of universities in sustainability is discussed in (Weber and Duderstadt, 2012), and of course the issue of sustainability is an important one for STEM education at all levels, including in the iSTEM program where that topic is treated via experiments (e.g., on recycling). A statement of the sustainable development goals for children is in (Bardales and Arenas, 2014). A good book on teaching and learning is (Ambrose et al., 2010) While there are many books on aspects of educational theory and assessment, a useful resource on engineering education assessment is (Spurlin et al., 2008). Other work on connecting engineering to social justice, including engineering education, is in (Catalano, 2006; Baillie, 2006; Riley, 2008; Baillie and Catalano, 2009; Baillie et al., 2012; Lucena, 2013).

**Assessment of Outcomes:** The use of RCTs in the developing world us explained in (Glennerster and Takavarasha, 2013), and has great practical advice. For a coverage of the medical perspective on RCTs, that also has a nice treatment of the relevant statistics, see (Matthews, 2006). Background material on

statistics is in (Devore, 2004).

**Modeling and Analysis of Sociotechnological Systems:** Ideas on management of common pool resources are in (Hardin and Baden, 1977; Ostrom, 1990; Mansuri and Rao, 2013). The use of cooperative decision making for common pool management is discussed in (Meinhardt, 2002). The model of community dynamics was developed using standard ideas from economic models (Acemoglu, 2009) (e.g., the Cobb-Douglas model (Cobb and Douglas, 1928)), from (Bloom and Canning, 2005) for using a production function with components that include education, (Hurd and Kapteyn, 2003; Grossman, 1972) for integration of health into the model, (Dasgupta and Ray, 1986) for how health affects the production function, (Heckman et al., 2006) for the ideas of Mincer (Mincer, 1974) on relating education to income, and (Hai and Heckman, 2014) for integrating income, health, and education. More ideas on how to model a community's financial and educational/skills aspects can be found in (Acemoglu, 2009). The sustainable community development indices are based on the IHDI that is explained in (HDR, 2013) and that is based on the Atkinson inequality measure (Atkinson, 1970). Unlike the Gini index in Equation (1.3), the Atkinson inequality index is an entropy measure of inequality. Other entropy measures of inequality include the "Theil index" which has been used to measure both economic inequality and lack of racial diversity and the "relative entropy function," also called the Kullback-Liebler distance, though technically it is not a distance. The SCDI here is a simple approach to include some sustainability aspect in an IHDI-type measure of development. Clearly, many other features would have to be included for a full quantification of the coupled interactions between the environment and development (e.g., pollution of land, water, and air along with use of many different coupled resources), and in a number of ways it does not even make sense to start with the IHDI due to its limitations (e.g., the MPI (HDR, 2013) may be a better starting point). Work on how to define a sustainable development index includes (Neumayer, 2001; Barrera-Roldan and Saldivar-Valdes, 2002; UN, 2007; Bravo, 2014; SDSN, 2015). For work in the direction of "computational humanitarianism," see (Meadows et al., 1972, 2004; Sterman, 2000; Amadei, 2014; Ramalingam, 2013; Spaiser et al., 2014; Amadei, 2015), Chapter 1, Section I of (Sachs, 2014), and other sources that focus on human dimensions (Miller and Page, 2007; Homan, 2011; Dale and Smith, 2013; Hovmand, 2013; Forsyth, 2014), to mention a few. Finally, this chapter was influenced by the following books on social systems theory and the social psychology perspective on group dynamics (Dale and Smith, 2013; Forsyth, 2014).

# Supplements

## Supplements Contents

*Step into my shoes and walk the life I'm living and if you get as far as I am, just maybe you will see how strong I really am.*

*Unknown*

*Never mind walking a mile in my shoes. Try thinking a day in my head.*

*Unknown*

# The 10 Principles of Humanitarian Engineering

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### The 10 Principles of Humanitarian Engineering

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### 1. Focus on People

- Individuals are unique and infinitely valuable, talk to them, respect them, have solidarity with them

- Try to understand suffering, have empathy and compassion

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### 2. Relate, Listen, Ask, Cooperate, Empower

- Build relationships, trust, community participation, inclusiveness, multi-disciplinary teams, and cooperation

- Do needs, resources, capacity, and aspirations assessment via active listening

- Empower people

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### 3. Understand Social and Physical Context

- Understand people, communities, culture, and history

- Understand built and natural environment, resources, and institutions

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### 4. Be a Professional Humanitarian Engineer

- Have competence and good conduct

- Create the best design that meets all constraints (performance, reliability, cost, environmental, social, use of local materials, etc.) in the social and physical context and keeping the people firmly in mind

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### 5. Build Technological Capacity

- Empower the community to create its own solutions, and be a mentor

- Science, technology, engineering, and mathematics education empowers students and communities

### 6. Ensure Long-Term Positive Impact

- Design for reliability in extreme conditions

- Build technological capacity for operation and maintenance

### 7. Understand Impact on/from Social Context

- Understand people and power relations

- Understand role of education, health, and economic development

### 8. Design for Sustainability

- Minimize resource use and pollution impacts

- Focus on life-cycle design and design for the environment

### 9. Assess Outcomes

- Determine deployed technology effectiveness and side-effects

- Establish basis for later improvement or scale-up

### 10. Promote Human Dignity, Rights, and Fulfillment

- Focus on human dignity, rights, and fulfillment, along with other ideas from social justice

- Try to reduce inequalities in technological capacity, promote inclusiveness, and eliminate marginalization of people

# Questions for Discussion

The questions below are intended to be used in a group setting, such as a classroom or project meeting. Typically, there would be a group leader who would ask the questions and guide the discussion, trying to evoke responses from everyone and fully explore the subject.

## Suffering

Suffering has been defined in the New Oxford American Dictionary as

> "the state of undergoing pain, distress, or hardship"

and in their thesaurus of synonyms and related concepts, the following words are used:

> "hardship, distress, misery, wretchedness, adversity, tribulation, pain, agony, anguish, trauma, torment, torture, hurt, affliction, sadness, unhappiness, sorrow, grief, woe, angst, heartache, heartbreak, stress"

Consider the following questions:

1. What are the different types of suffering? Give examples.

2. What is the worse type of suffering?

3. Are there types of suffering that are particular to certain groups? What groups? What types of suffering?

4. Can we know if others are suffering? For what types of suffering?

Next, from the New Oxford American Dictionary, consider the following definitions:

> Sympathy: "feelings of pity and sorrow for someone else's misfortune"

> Compassion: "sympathetic pity and concern for the sufferings or misfortunes of others"

> Empathy: "the ability to understand and share the feelings of another"

Notice that sympathy and compassion are closely related. However, empathy is a deeper, closer connection.

There is an old saying (unknown source)

> "Walk a mile in my shoes..."

that has different variations, ones that focus on understanding and judgement, such as the following (unknown sources):

1. "Walk a mile in my shoes... See what I see, Hear what I hear, Feel what I feel... Then maybe you'll understand Why I do what I do... till then don't judge me."

2. "Step into my shoes and walk the life I'm living and if you get as far as I am, just maybe you will see how strong I really am."

3. "Never mind walking a mile in my shoes. Try thinking a day in my head."

Consider the following questions:

1. How well can you understand someone else's suffering?

2. How does the suffering of others affect you? What types of suffering affect you in what ways?

3. When do you ignore it? Why?

4. When do you try to do something about it?

## Privilege

Privilege has been defined in the New Oxford American Dictionary as

> "a special right, advantage, or immunity granted or available only to a particular person or group of people"

> "something regarded as a rare opportunity and bringing particular pleasure"

The following are three quotes that help define privilege in a more concrete manner (sources unknown):

1. "If you don't have to think about it, it's a privilege."

2. "Privilege is when you think something is not a problem because it's not a problem to you personally."

3. "I have the privilege of being totally unaware of my own privilege."

Consider the following questions:

1. In what ways are people privileged? Give examples.

2. What is the highest form of privilege?

3. Are you privileged?

4. Are certain groups privileged? Which ones?

5. Can you know if someone is privileged? How?

6. How do others' privileges affect you?

and consider relationships between privilege and suffering:

1. Can you be suffering and privileged at the same time? Give examples.

2. Can you use your privileges to end your suffering or others' suffering? Can your suffering eliminate your privilege?

3. Can good things come from suffering? Privilege?

## Gratitude

Watch the (9:47) TED talk by Loui Schwartzberg

<div align="center">

Nature, Beauty, Gratitude
</div>

that was published June, 2011. The audio after (4:10) is by David Steindl-Rast, and you can start at that point for the discussion questions below. Although not essential for the discussion questions, you could also consider the (14:30) TED talk by David Steindl-Rast

<div align="center">

Want to be happy? Be grateful
</div>

that was filmed in June, 2013. David Steindl-Rast has also published books that you can get information about on the internet.

Steindl-Rast emphasizes the importance of noticing your surroundings and being fully aware, for the environment, physical surroundings, and people. This is very important for learning about "context" in many humanitarian engineering projects, especially if you are in an unfamiliar setting. In his talks, he gives basic reasons why people should have gratitude, ways to think about gratitude (e.g., the statement "First day... last day..."), and what you can do with gratitude (e.g., how your own gratitude can impact people around you). Some of his essential ideas can be thought of as a sequence:

$$\text{Awareness} \rightarrow \text{gratitude} \rightarrow \text{happiness/joy} \rightarrow \text{opportunity} \rightarrow \text{action}$$

(of course, there are feedbacks that lead to a positive cycle, such as finding opportunities that can also can lead to gratitude).

Consider the following questions:

1. How are suffering, privilege, and gratitude related?

2. How did you feel about his statements about gratitude via the contrast between the availability of technology in the developed and developing world?

3. Does gratitude motivate you to be a humanitarian engineer to take action?

## Culture

The New Oxford American Dictionary defines culture as follows:

> "civilization, society, way of life, lifestyle; customs, traditions, heritage, habits, ways, mores, values"

Sequentially ask cultural/country groups to answer the following two questions about their *own* country or culture (e.g., start with persons having a similar country or cultural origins):

1. What do you *most* like about your country or culture?

2. What do you *least* like about your country or culture?

Also, for persons born and raised *outside* the US, consider the following questions:

1. What do you find unusual in the culture in the US?

2. What do you (not) like in the US?

Next, consider some social situations you will encounter when you visit another culture. How do you go about the following in your culture/country, or one you have visited:

1. *Greetings, oral:* Formal vs. informal in your culture? First meeting vs. friends? Women vs. men? Adult vs. child? Senior citizen vs. youth?

2. *Greetings, non-oral:* Bow, kiss, handshake, hug? What is appropriate? When? With whom?

3. *Body language:* Please describe culture-specific body language in your culture (e.g., gesticulations).

4. *Eating together:* What *are not* considered to be allowed as topics in polite conversation at dinner?

## Dignity

The New Oxford American Dictionary defines "dignity" as:

> "the state or quality of being worthy of honor or respect"

and in their Thesaurus, it lists the following words:

> "self-respect, pride, self-esteem, self-worth"

Consider the following questions:

1. Does every person have the same dignity?

2. What are the requirements to ensure the dignity of a person?

3. Washington Irving said "There is a healthful hardiness about real dignity that never dreads contact and communion with others however humble." How do you talk to a person in a way that preserves their dignity?

The issue of dignity arises in the context of work. Consider the following questions:

1. Booker T. Washington said "No race can prosper till it learns that there is as much dignity in tilling a field as in writing a poem." Does what you do in your work or career define your dignity?

2. Martin Luther King, Jr. said "All labor that uplifts humanity has dignity and importance and should be undertaken with painstaking excellence." Related to humanitarian engineering?

3. David Packard said "A company has a greater responsibility than making money for its stockholders. We have a responsibility to our employees to recognize their dignity as human beings." Relevance to international engineering?

## Rights

First, answer the following question:

What are "human rights"?

Next, consider the following quotes from four individuals:

1. Malala Yousafzai: "I speak not for myself but for those without voice... those who have fought for their rights... their right to live in peace, their right to be treated with dignity, their right to equality of opportunity, their right to be educated." Your reaction?

2. Nicholas Kristof: "Since the end of the 1970s, something has gone profoundly wrong in America. Inequality has soared. Educational progress slowed. Incarceration rates quintupled. Family breakdown accelerated. Median household income stagnated." Your reaction?

3. Jeffrey Sachs: "The essence of sustainable development in practice is *scientifically and morally based problem solving*" (emphasis added). Are there *always* moral issues in engineering for sustainable development?

4. Paul Farmer: "But if you're asking my opinion, I would argue that a social justice approach should be central to medicine and utilized to be central to public health. This could be very simple: the well should take care of the sick." What is the equivalent concept, but for engineering and technology?

Moving to the world and country levels, consider the rights listed in

UN Universal Declaration of Human Rights (UDHR)

and in particular some selected "articles" from the UDHR:

1. *Article 1:* All human beings are born free and equal in dignity and rights....

2. *Article 3:* Everyone has the right to life, liberty and security of person.

3. *Article 5:* No one shall be subjected to torture or to cruel, inhuman or degrading treatment or punishment.

4. *Article 23:* (1) Everyone has the right to work, to free choice of employment, to just and favourable conditions of work and to protection against unemployment. (2) Everyone, without any discrimination, has the right to equal pay for equal work.

5. Article 29: Everyone has duties to the community...

Consider the following questions for only Articles 1, 3, 5, 23, and 29 of the UDHR:

1. *Your Country:* In your country of origin, are these articles of the UDHR met in all cases? Are you concerned or not?

2. *Priority of rights:* Which are the most important of these human rights?

3. *Rights and duties:* Whose duty it is to make sure a person's rights are met for these rights?

4. *Inequality:* Human rights are often thought of as being met to a certain "level," with higher levels corresponding to more fully meeting that right. Then, sometimes "inequality" refers to the case where two person's corresponding rights are not met to the same level (and this idea applies not just to income and wealth). Considering only Articles 1, 3, 5, 23, and 29 of the UDHR,

   - To have justice, must all of these human rights be met to the *same level* for all persons (i.e., perfect equality)?

   - If one right that *you* consider to be unimportant is not met for someone else, is there justice?

   - Who judges what is an *adequate level of achievement* of another's rights?

   - Who judges whether there is an *acceptable level of inequality*?

Rights relative to engineering:

1. *Modify the UDHR:* Do you agree that the following statement should be added to the UN Universal Declaration on Human Rights?

   Technological capacity is a basic human right.

2. *Engineers and Activism:* Would you join a protest in Washington D.C. (that is organized by major engineering, scientific, mathematical, and technological organizations) *to demand global human rights to technological capacity*?

If technology is a basic human right, embedding it in a system of social justice can result in the same or different interpretations of such a right.

## Fairness

The New American Oxford Dictionary defines "justice" as

> just behavior or treatment: "a concern for justice, peace, and genuine respect for people" with "the quality of being fair and reasonable"

Suppose that we simply define "just" as "fair" and "justice" as "fairness." Next, recall that technology is anything that extends human capability.

For the Catholic perspective on social justice:

1. Does it imply that there is a basic right of technological capacity?

2. What does "preferential option for persons poor in technological capacity" mean?

Per the perspectives on social justice that seem to *require* certain types of "charity" (time, talent, or monetary donations):

1. Should "engineering volunteerism" (freely giving away technological capacity—unpaid humanitarian engineering with no course credit) as part of our engineering curriculum?

2. Would communities be better-assisted with this approach?

3. Would students be more or less likely to later do volunteer work?

4. For what reasons, good or bad, do people get involved in volunteer work?

Per John Rawls's "justice as fairness," are there "Principles of Justice for Engineers?"

1. Is there a scheme of basic liberties: Right to learn, to think, to income/wealth, to self-expression, etc.?

2. Are there technology capacity inequalities:

   (a) Fair opportunities (e.g., jobs)?

   (b) Per the difference principle, are inequalities designed to be to the greatest benefit to members of society that are of lowest technological capacity?

Per Amartya Sen's perspective,

1. Assume that technology is a "tool to extend human capability." How does this definition relate to Sen's "capabilities approach"?

2. If you think of augmenting human capability with technology, that is,

   > Human Capability + Technology = Total Effective Human Capability

   can we expect additional opportunities to follow, and a general approach for human development, one that is a core approach to humanitarian engineering?

3. Does it make sense to focus on *essential* capabilities, and "essential technologies"?

4. Does it make sense to focus on extending the most deprived capability, via the "most needed technologies"?

5. Does a similar concept hold for "rights"?

A key statement in many codes of ethics for engineering is that engineers must

   > "hold paramount the safety, health, and welfare of the public."

1. What are the socio-economic, cultural, and environmental (importance of sustainability) differences between the "public" for the developed and developing worlds?

2. Is there are difference between "welfare" (well-being) of the publics in the developing and developed worlds?

3. Consider replacing the above statement that is typically found in engineering codes of ethics with:

   > "hold paramount the safety, health, and welfare of the public, and encourage engineers to pay special attention to least advantaged."

   Do you agree with such a change? Or, would you prefer to modify it before adding it? Or, to not add it at all?

## Development

Per Chapter 3, up to and including the section on international education:

1. In what ways are engineers, and engineering, misunderstood, by non-engineers?

2. Does technology generally increase or decrease inequality in the world?

3. What is "accountability" in development projects? Feedback?

4. Can you name a technology that is of *basic* importance to public health?

5. Can you name a technology that is of *basic* importance to education?

Next, on social business:

1. Can you name an advantage of the social business (social entrepreneurship) approach? A disadvantage?

2. Who should be operating such a business? Outsiders? Community? Individuals in the community?

3. Suppose you consider the "double bottom line" (profits and social impact) or the "triple bottom line" (profits, social impact, positive environmental impact). Consider the following questions:

   (a) Can you *quantify* the double/triple bottom line, for example, what is the social and environmental impacts of a social business? As accurately as for profits?

   (b) What is an acceptable return in terms of profits (i.e., what percentage of investment by a social investor)? What is acceptable in terms of social/environmental impact?

   (c) Can social businesses be *regulated* (e.g., like in some cases for "organically grown" produce)?

4. Is the social business approach the only way to try to guarantee long-term success of a humanitarian technology?

## Helping

Your general view of other people can affect whether or not you will help them, and how you help them if you do. In "Rising Strong" (Brown, 2015), p. 110, Brené Brown asks the question:

Do you think, in general, that people are doing the best they can?

What is your answer to this question? Some additional questions to consider are:

1. Can you accurately determine if someone is doing the best they can? How? Does this relate to suffering and privileges? What if the person is from a different country and culture? A person with different family history? Different opportunities?

2. If you think people are doing the best they can, and they are not doing so well, and ask for help, should you help them?

3. If you think people are *not* doing the best they can, and they are not doing so well, and ask for help, should you help them? Would you feel exploited? Will you have *really* helped them?

A consistent theme in "Daring Greatly" (Brown, 2012) by Brené Brown (and her TED talks) is vulnerability, which has relationships to helping. In particular, helping affects both the helper and the person being helped:

1. *Requesting and getting help:* People, no matter how much they are suffering, or how little ability/knowledge they have to do something, often hesitate to ask others for help. Why? In the context of Brown's ideas in (Brown, 2012), the answer to this question generally differs for women and men:

   - *Women:* The challenge of multitasking, being all things to all people, and trying to get to the point of saying "I am enough." If you ask for help, are you "enough"?
   - *Men:* The desire to show no weakness whatsoever. If you ask for help, are you showing weakness?

2. *Offering and giving help:* For both women and men, in (Brown, 2015), p. 180, Brené Brown says "Offering help is courageous and compassionate, but so is asking for help." People, no matter how privileged they are, or how much ability/knowledge they have about how to help others, often hesitate to do so. Why? In the context of Brown's ideas (Brown, 2012), the answer to this question generally differs for women and men:

   - *Women:* If I help, do I have enough time and energy for everything and everyone else? How do I draw limits? Gain balance?
   - *Men:* If I help, will it make me appear stronger? Will it hide my own weaknesses?

In the helping process, who benefits and who pays (e.g., money, time, effort)? Ralph Waldo Emerson said

> "It is one of the beautiful compensations in this life that no one can sincerely try to help another without helping himself."

Consider the following questions:

- *Helper benefits:* How has helping others helped you? Give an example. Does helping others help relieve guilt over your privilege?

- *Benefits for person being helped:* Can you think of an example when you have helped someone, but it has in no way helped you (i.e., do you agree with Emerson?)?

- *Paying:* In the helping process, who pays? Only the helper? Can you give an example when the person being helped pays? In what way? Embarrassment? Hurt pride?

## Technology

Maimonides said

> "Give a man a fish and you feed him for a day; teach a man to fish and you feed him for a lifetime."

One way to catch a fish is to use a technology such as a fishing pole or a net. Then, you could modify Maimonides's statement to

> "Give a man a fish and you feed him for a day; give him a fishing pole, and teach him to use it, and you feed him for a lifetime."

Can you make up statements to illustrate key aspects of humanitarian engineering by modifying Maimonides's centuries-old statement? Examples include:

1. "What about the woman?,"

2. "Give a man a fish and you feed him for a day; give a man a fishing pole, and teach him to use it, and explain how to repair it, and feed him many days,"

3. "But, to ensure that the fish population is sustained, how many people can have fishing poles?," and

4. "But, what materials should we use to construct the fishing poles to respect the design-for-sustainability philosophy?"

What statements would you propose? For example, can you think of one related to STEM education?

# Appropriate Technology Assignment

This assignment requires teams to construct and provide an in-class demonstration of an appropriate technology (see Section 4.6.3) that is intended for a specific community or country. It is intended for a semester-long course on humanitarian engineering, and requires independence, creativity, and good team cooperation to generate solutions that fit the local context. In this assignment, there is an emphasis on cooperative task completion to promote learning the following skills:

1. How to promote community participation, and how to cooperate with community members; and

2. How to cooperate with team members from engineering and other disciplines.

In particular, a "cooperative learning" approach (Johnson and Johnson, 2014) to having a team design and implement an appropriate technology is used. The social aspects of a humanitarian engineering project are typically the most challenging ones, and this assignment is designed to make you confront these difficulties.

## Team Formation: Inclusion of Local Experts

Start by reading Section 4.3.1 and Section 4.3.2. Team formation and functioning issues here include:

- *Number of teams:* M teams will be formed from the class by the instructor. Everyone enrolled in the class is part of one and only one team, the one assigned by the instructor. Changing teams is not allowed.

- *Team member(s) with local knowledge:* It is **required** that you include on your team a person from the population you aim at working with (e.g., a homeless person, someone from the "diaspora" of the country you aim at working with, or a person from the developing world you know or contact over the internet). Electronic communications can facilitate getting their inputs and evaluations of your project. You will receive no point deductions for getting help from such people, but of course you must cite your sources.

- *Communication Strategy:* Smooth, fast, and accurate inter-team communication is *crucial* to team success. Of course, you should have face-to-face meetings (including team-building social events), at least weekly; Doodle (or a similar tool) can help with scheduling such meetings. It is strongly recommended that your team devises an electronic communication strategy that people are likely to be highly responsive to (e.g., group texts, a favorite social media approach, or an email distribution list). Some students like "GroupMe." Whatever you pick, aim at simplicity and minimizing response delays. The choice of the communication strategy should be made by, and agreed upon, by the whole group.

- *Team Leader:* The leader is the point person for corresponding with the instructor (however, of course, anyone can see the instructor at any time about the project), and may take on other responsibilities the team agrees upon, such as convening meetings. The leader's main task is to promote and facilitate participation and cooperation on the team; no dictators allowed!

**The team must select a single leader and communication strategy** and report the choices to the instructor by providing him the leader's name and email address and a single-sentence description of the communication strategy the team agreed on.

## Project Choice: Community or STEM Education Focus

While your team may pick your project, each team must get the instructor's approval for it. Discussions with the instructor before the choice is made are welcome (e.g., in person or via email). Sometimes such discussions are useful to narrow down the choices. You may pick one of two types of projects:

1. *Appropriate technology, personal or community:* Using Section 4.6.3 of Chapter 4, and references starting on page 718, choose an "appropriate technology," develop it, and implement it. For instance, this could be one for personal energy supply, housing, lighting, water filtration, cooking, etc. Another project could be to develop the personal spending advisor app in Section 1.6.6; this would require, however, development of an app on a smart phone.

2. *Appropriate technology for STEM education:* Read Section 3.4 and Section 4.8 on international education and humanitarian STEM education and develop an experiment/project that can he used for STEM education. For instance, see the experiments at iSTEM and here. For instance, you could consider the design of a communication system that helps to teach how a cell phone works. This could start with a string-cups approach, and then the construction of a radio-receiver system. Cell phones seem to be one of the most complex and ubiquitous technologies on earth; this shows that people value them, and hence they likely will want to learn about them.

The teams incur all project costs (e.g., for materials and supplies); this is meant to encourage teams to *minimize the cost* of the proposed technological solution. **Be careful to schedule sufficient time to buy parts and have them delivered.**

The team must achieve a whole array of objectives given below, but two key aspects that will drive your choice of a project are a *requirement* to:

- Implement the technology in hardware (in some cases it is acceptable to have a focus on software development for a given piece of hardware such as in the app case mentioned above). *This implementation is required.*

- Use Matlab/Simulink to simulate the technology for development, evaluation, impact on social context, or impact of social context on the technology. *This is strongly encouraged, but not required.*

**Each team must pick their project and report the choice to the instructor** for evaluation/approval; use a description of no more than a few paragraphs. It is **highly recommended** that before this is due, at least the team leader discusses project options with the instructor.

## Design Review 1: Task Assignments, Individual Work

The project has four associated steps, each of which is graded. Each step has individual and/or team components. Any imaginable information source can be used, and at any time, for project work, but cite your sources in a bibliography.

Pick a target developing country, city, or community location for your project. **It is required that you have someone on your team from that location or who has visited the location (see above per team composition).** The team must decide which team members are doing which of the following tasks, and each task must be completed by *only one individual* on the team (that is, the report for each must be written by *only* one team member), though intra-team oral consultations are allowed:

1. *Evaluate needs and priorities:* To the greatest extent possible, easier as you have a member of the target population on our team, evaluate needs and priorities of the people. Make this for a specific community or region.

2. *Evaluate needs and priorities, broadly:* To the greatest extent possible evaluate needs and priorities of a much broader region for the need you identified above. This evaluation should be at the country level, and is done to consider if it is possible to scale up your technology.

3. *Evaluate relevance of culture and social context:* To the greatest extent possible, via a member of the target population on our team, evaluate the impact of culture on constraints for your technology design problem. Evaluate the social context, that is the community structure, if possible.

4. *Evaluate physical context:* Here, "physical context" includes many things, such as weather (temperature, humidity, rainy vs. dry seasons), local housing situations, availability of local materials/resources, etc. It is everything but the people, the "social environment."

5. *Evaluate design options #1:* Evaluate options for the technology your project will focus on. Consult the literature and brainstorm. This **must** have significant technical content (e.g., science, math, and engineering).

6. *Evaluate design options #2+:* Same as last item, if there is an extra person(s) in your group, repeating as necessary. All other tasks besides evaluating design options must be covered first before assignment of more people to consider other design options.

7. *Develop specifications:* Specifications quantify the characteristics of the physical make up and operation of the technology. They specify desirable characteristics of the technology that your design aims to achieve. You should, as appropriate, include the social context. You should make these *technical/scientific* specifications, quantifications of desired features in an accurate and scientifically-accepted manner (e.g., ppm contaminants in output of a water filtration system).

8. *Evaluate impact on environment:* This can include resources used (e.g., materials), pollution during operation, and how environmentally-friendly it is to recycle the technology at end-of-life.

9. *Evaluate cost:* This should evaluate the costs of all aspects of the technology, from materials, construction, and operation. You *must* include an analysis of whether local people could afford to buy the technology. You must include a spreadsheet with the budget on it.

10. *Develop project schedule:* Use a Gannt chart, get concurrence from your team, and match it to deadlines for various parts of the assignment. Include all team member's subprojects, and tasks, and integrate these into the Midterm, Design Reviews, and Final Project below.

Electronic written reports are required in all cases. Some thought should be given to coordinating which word processor is used so that reports can be combined and modified to form a single report for the Midterm Project below. It is recommended that you use Microsoft Word, though Latex is a good choice. You may not submit a link to a document at, for instance, Google Drive; the e-document must be submitted as a stand-alone readable document the instructor can open in MS Word.

**See course web site for deadline for Design Review 1**.

**Design Review 1 Resubmissions:** Design Review 1 will be graded an returned to the individuals. Then, the reports graded for Design Review 1 may

be improved and resubmitted for grading at any time up until the date given at the web site. There is no penalty for a resubmission. The team members should help each other improve the grades on the individual assignments as much as possible; of course, primary responsibility to improve the assignment rests with individuals (and see below, for how the final grade is computed). This is a key element of cooperative learning: there is a demand that students help each other learn ("positive interdependence" (Johnson and Johnson, 2014)). A key issue here can be the willingness of someone who has a low grade, and hence needs to do more work and resubmit, to seek the help of others.

## Midterm Project: Task Integration and Reporting

The team should synthesize and improve the reports from Design Review 1 and:

1. *Midterm Project written report:* Submit a *single* report on the project that everyone on the team contributes to via their individual contribution in the first design review, and help in combining all the ideas in the group into one cohesive whole. Fill in any holes. This group report should be created with a collaborative authoring tool so that everyone on the team can easily contribute (e.g., MS Word). There are no specific requirements on length/format; just get the job done and be concise.

2. *Midterm Project oral report:* Two team-chosen members should email the instructor to set up a Midterm design review within one week after the due date for the written Midterm Project report given at the course web site. This review is oral, limited to one hour in the instructor's office, and will impact the grade given on the Midterm Project written report. Only two persons may be present. No slides are allowed. You may, however, have the written report available in electronic form (no paper). One key function of this meeting is for the instructor to provide feedback on how to improve the project, if needed.

The oral report will be viewed as your way to highlight what is important and good about your work. The oral and written reports will be graded as a whole, not individually.

**Due date for written Midterm Project report:** See course web site.

**Midterm Project grading:** Let $g_i^{dr1}$ denote the grade you receive on your Design Review 1 assignment, after possible resubmission, and let $g^{mpt}$ denote the team's grade on the Midterm Project (written and oral portion). Then, using ideas from cooperative learning theory (Johnson and Johnson, 2014), your

individual grade $g^{mp}$ for the Midterm Project is computed as

$$g^{mp} = \overbrace{\underbrace{\frac{1}{2}\min_j\{g_j^{dr1}\}}_{Min\ individual\ grade} + \underbrace{\frac{1}{2}g^{mpt}}_{Group\ grade}}^{Midterm\ Project\ grade=g^{mp}}$$

This way, your grade for the Midterm Project depends on your individual performance, the performance of other group members (notice the minimum taken across team members), and the performance of the group that depends on how well the team works together on the team report and oral report. Clearly, then, everyone has an incentive to help low-performers in the group, and low-performers have a motivation to improve their own grade, and this contributes to a better group outcome. This grading strategy encourages *all* individuals to contribute/participate, and all individuals to cooperate. By federal law, the instructor cannot provide all team members each others' grades; however, the team may be able to overcome this problem on their own.

To determine the final Midterm Project grade of the members of a team, however, there is one more modification. The following rule will be applied to encourage *competition* between teams:

**If your team's grade $g^{mp}$ is the highest of all the teams in the class, then $g^{mp}$ will be elevated to $g^{mp} = 100$ no matter what the grade was.**

Competition is added to give each team a tangible reward for cooperating to provide excellent work.

**Important:** You may opt out of this situation where your grade depends on others' grades in two ways: Change your enrollment to an audit, or drop the class. It is quite unacceptable in this class not to try your best, as lack of good effort will adversely affect other students' grades. This is not the normal team-graded approach where some individuals can "coat-tail" their way to a good grade (even though they have poor performance) by the good efforts of others. However, with bad performance and bad attitude by a bad-performer, this approach may require more effort by a good performer, but perhaps less than "carrying" a bad performer without helping them improve. This feature of interdependence of grades is a natural consequence of cooperation and a cooperative learning approach. In fact, such grade interdependencies are not uncommon in engineering, for capstone design classes, for other classes that require team work, and for classes where individuals work on their own but where the final grade is determined "using the curve" (i.e., the mean of the final grades is determined and then grades set relative to that mean assuming a Gaussian distribution).

## Design Review 2: Re-evaluation and Prototyping

Repeat the assignments for Design Review 1 above, but the team must assign persons to a task *different* from those tasks assigned for Design Review 1. This

will involve a reconsideration of *all* the key issues by other team members, making clear additions or reconsideration in other ways, of all issues. Individuals should seek to avoid any repeats of the work done in the past, and try to take a fresh look; it is acceptable to look at all previous assignments from Design Review 1, the Midterm Project report, and even use as a start electronic pieces of these documents from others. There should be a more significant focus on adding technical/scientific analyses of aspects of the project, especially the technical design, and Matlab/Simulink simulations for evaluations. If some parts of your Midterm Project were particularly strong, and do not really need much (or any) change, then no one should work on that part. Other issues aside from the ones listed for Design Review 1 could have arisen and you may want to assign a team member (or members) to new aspects of the project (ones not in the above task list). That is up to the team. Design Review 2 will have one or more persons construct a prototype of the technology; indeed, **the prototype *must* be built by the due date for Design Review 2 and reported on.** Clearly, the goal is simply to make all components of the project as strong as possible, so that after Design Review 2 the team can integrate the pieces into a cohesive whole. Finally, of course, each individual must write up *their own evaluation/work* in their own words, and reference all sources used, including past reports.

**Due date for Design Review 2 assignments:** See course web site.

The reports turned in for Design Review 2 may be improved and resubmitted for grading at any time up till the resubmissions deadline at the course web site. There is no penalty for a resubmission. The team members should help each other improve the grades on the individual assignments as much as possible.

**Due date for *resubmission* of Design Review 2 assignments:** See course web site.

## Final Project: Integration, Completion, and Reporting

The team should synthesize and improve the reports from the design reviews and:

1. *Final Project written report:* Submit a single report on the project that everyone on the team contributes to via their individual contributions in the design reviews, the Midterm Project, and help in combining all the ideas in the group into one cohesive whole. This group report should be created with a collaborative authoring tool so that everyone on the team can easily contribute. Final project reports will be posted at the course web site after grades are assigned.

2. *Final Project oral report:* A designated team member (only one person) gives an electronic presentation on the project during the Final Exam-

ination period in front of the entire class (see course web site for that
date). All team members assist in adding points of clarification and in
answering questions. Also, other team members should help make up the
e-presentation slides. The number of slides *must* be less than $N$ including
the title slide (after the $N$th slide, the presentation will be terminated)
and presentation time will be strictly limited to $N$ minutes. The instruc-
tor will give you the value of $N$. The person who is to deliver the talk
must practice it beforehand in front of the team at least once. You should
*minimize* the number of words on the slides as no one can effectively listen
and read at the same time. Use pictures and diagrams as they are worth a
thousand words. Questions will be allowed from the whole class after the
talk for a few minutes (to be defined by the instructor). An outside expert
or experts may be invited to evaluate the projects, and their assessments
may be used in setting grades. Final project oral presentations and slides
will be posted at the course web site after grades are assigned.

The oral report will be viewed as your way to highlight what is important and
good about your work. The oral and written reports will be graded as a whole,
not individually. The Final Project oral reports will be presented in front of the
whole class so you will learn about all class projects.

**Due dates:** See course web site.

**Final Project grading:** Let $g_i^{dr2}$ denote the grade you receive on your Design
Review 2 assignment, after possible resubmission, and let $g^{fpt}$ denote the team's
grade on the Final Project (written and oral portion). Then, using ideas from
cooperative learning theory (Johnson and Johnson, 2014), your individual grade
$g^{fp}$ for the Final Project is computed as

$$g^{fp} = \overbrace{\underbrace{\frac{1}{2} \min_j \{g_j^{dr2}\}}_{\textit{Min individual grade}} + \underbrace{\frac{1}{2} g^{fpt}}_{\textit{Group grade}}}^{\textit{Final Project grade} = g^{fp}}$$

As with the midterm, to encourage *competition* between teams:

**If your team's grade $g^{fp}$ is the highest of all the teams in the class,
then $g^{fp}$ will be elevated to $g^{fp} = 100$ no matter what the grade was.**

This rule should encourage students to provide *constructive criticism* of the
results reported in another team's presentation during the Final Examination
period.

**Agreement:** It must be agreed that the instructor may share the solution ma-
terials for your project (reports, presentation, photos, movies, etc.) by posting
it on the web, and for these please provide MS Word or .pdf files. If you do not
want your name on the project, please remove it. Of course, the project grades
will not be shared with anyone.

# Teaching a Course From This Book

Issues related to curricular constraints and prerequisites, multidisciplinary coverage, and ways to format a course that is based on this book are discussed next. This section is primarily intended for someone considering teaching a course based on this book.

## Curricular Constraints and Prerequisites

The content of this book, and the (on-line) course based on it, are the result of a number of curricular and prerequisite constraints:

- *Disciplinary accessibility and prerequisites:* Content had to be accessible to *all* engineering disciplines. This creates a significant challenge in making the course *technical* as there are very few technical engineering subjects in common to all engineering majors, and that will naturally attract students. This led to the use of computer simulations via Matlab since all our engineering students have experience with it. Also, a very small amount of calculus is used since it can be assumed that all students will have some basic math and with this we can study dynamics. The only idea from calculus that is assumed to be known is the derivative; however, standard explanations of it being the slope are adequate here in all cases (e.g., in the study of dynamics, sensitivity, and optimization). The integral is only needed in discrete-time form, that is, as a simple sum. Only the most basic ideas of statistics are used like the average and standard deviation. Combining these allows us to: (i) develop some types of humanitarian technologies, (ii) study social impact and context, and (iii) study "sociotechnological systems," ones comprised of technologies embedded in dynamic human groups such as communities.

  > Curricular constraints result in wide accessibility to this book.

- *Reliance on curricula in engineering disciplines:* Content can, however, rely on the technical part of the curriculum in each engineering discipline; hence, there is no need to cover technical issues for each and every discipline, which is clearly beyond the scope of any single book. This fits with the lack of emphasis here on specific technologies as discussed above.

- *Educational level and fieldwork preparation:* Content had to be designed to be accessible to all, from sophomores to PhD students, with an occasional second-semester freshman. The desire to offer the subject to lower-level students is driven by the need to provide the fundamentals of humanitarian engineering *before* students conduct projects via engineering fieldwork, locally or internationally, and before more advanced engineering classes that might be on relevant technologies (e.g., water filtration) as it is hoped that this book will provide motivation for later study of humanitarian technologies. For such projects at OSU there are additional preparatory courses, "service-learning," independent study, research, or capstone design, where specific and often "appropriate technologies" are developed before fieldwork on site.

- *Core course for a minor:* At OSU we have a humanitarian engineering minor that can be taken by any undergraduate engineering student. This book is the basis for the three-credit required "core course" for this minor, that also requires six credits of coursework on "human welfare" and six credits of "project/field work." Hence, this book covers basic issues that need to be understood by anyone with a humanitarian engineering minor (e.g., poverty, social justice, development, and participation) since the human welfare category can be fulfilled with a wide range of possible courses (e.g., sustainability and environment, sociology, development studies, economics, or disabilities) and possibly not some key foundational topics.

## Multidisciplinary Approach

Humanitarian engineering is highly multidisciplinary. It requires a broader foundation of knowledge than traditional engineering. Like engineering, it includes all the physical sciences (e.g., physics and chemistry), life sciences (e.g., biology), and mathematics/statistics; however, it also includes parts of all areas of social science. Compared to the traditional engineer, a good humanitarian engineer needs to know more about people, and in particular social human groups of all sizes, and how they interact. Humanitarian engineers need to know how to collaborate in diverse groups, where diversity means inclusion of experts outside engineering, members of a community, both genders, and other cultures and races. Most humanitarian work gets done "on the back of relationships" between people, and large structural problems of social justice require large diverse groups of people working together for their solution.

Driven by both technical and social needs, this book incorporates elements of the following:

- *Engineering disciplines:* Humanitarian engineering can fit into any engineering discipline and this book fits all these. At The Ohio State University (OSU), where I am employed, the engineering disciplines are civil, environmental, electrical and computer engineering, computer science, biomedical, mechanical and aerospace, chemical-biomolecular, agricultural, industrial, materials science and engineering, and architecture.

- *Mathematics and statistics:* The need for mathematics and statistics is as great in humanitarian engineering as for any engineering discipline. Here, mathematical modeling (e.g., via nonlinear discrete time equations or ordinary differential equations) is used to represent a range of dynamical systems and standard analysis concepts are employed (e.g., equilibria, stability, sensitivity analysis, and optimization). Also, in our computational analysis via Monte Carlo simulations we use simple ideas from statistics.

- *Social sciences:* Each of the social sciences has a role in this book:

  - *Economics and Political Science:* Development economics, quantitative development economics, governments' role, democracy, political

philosophy, and technology policy.

- *Social Work:* US and international, community theory and change ("macro" and "micro").

- *Psychology:* Counseling, organizational, and social psychology.

- *Sociology:* Diffusion of innovations, technological change in society, and rural sociology.

- *Anthropology:* Culture.

- *Philosophy, ethics, and religion:* Social justice, religious and secular, and engineering ethics.

- *Education:* International and comparative education, cross-cultural STEM education, and assessment.

- *Health:* Global public health.

- *Environment:* Pollution, climate change, and sustainability.

- *Business:* Social entrepreneurship and social business.

Subjects above that are rarely, if ever, found in engineering books are religion and the social sciences. Typically, engineering education only includes such subjects as elective courses in "general education" requirements; hence, a particular engineering student may not see any of the social science, philosophy, religion, education, health/environment, or business subjects unless they choose to. The incorporation of the above diversity of topics, and particularly the social sciences, presents a significant challenge for engineering education, in particular, as the curriculum for supporting humanitarian engineering education expands along these lines.

I feel that the inclusion of a number of the above topics is bound to represent a *trend* in engineering. People's lives are increasingly coupled with technology and this brings engineering closer and closer to being a "direct contact profession" (see Section 4.1.1). As this happens, and considering the intrinsic role of technology in extending human capability, it is inevitable that at least a portion of engineering will become a "helping profession" like social work, psychology, education, and healthcare. It may be that only one discipline within engineering takes this role (e.g., humanitarian engineering), but it may be that elements of humanitarian engineering will be added to each engineering discipline. Regardless, if engineering is at least in part moving in this direction we must learn from the professional helpers (e.g., social workers); this is why a number of the above topics are integrated into the treatment in this book.

This multidisciplinary educational philosophy fits what I call the "psychology of the typical humanitarian engineer." I have found that people involved in humanitarian engineering seem to be "split brain," with the left side holding their analytical engineering skills and the right (social) side reaching out with a strong desire to help people in a tangible and compassionate way (I know the split brain idea is over/mis-used, including here). This book seeks to develop

Humanitarian engineering demands coverage of materials from a wide array of disciplines.

analytical engineering skills that can appropriately ride on the back of empathy to create effective technologies that help people. The educational goal here is to build bridges between the analytical and compassionate sides of the humanitarian engineer's brain, their natural tendencies/skills, so they can be more effective in helping people.

## Course Format Options

There are, of course, many ways to teach the materials from this book, in a range of formats, from short courses to full semester-length courses. There are also ways to augment the materials in this book that can be used to format a course specifically tailored to your own needs. Three candidate course formats are as follows:

1. *Comprehensive:* For this format, you teach all the material in this book, but (i) only briefly outline the "engineer's role" section in Chapter 1, (ii) skip a few of the cases for social justice (e.g., one or more of the religious cases), and (iii) keep the coverage of the technical sections as the end of the four chapters at a more superficial, rather than deep technical level. This is the approach I use to teach the material at OSU for a three-credit hour one-semester course, where I have 42 class lectures, each 55 minutes long. You may want to replace some of the material used in this approach with items (i)-(iii) used in the next format.

2. *Engineering for Sustainable Community Development:* While the first three chapters are all useful background, Chapter 4 contains the central topics and is designed to stand-alone. Hence, in this approach Chapter 4 is covered in detail, except the section on sociotechnological systems. To define context, rather than covering the first three chapters of this book, it may be useful to discuss the following for your city, region, or country: poverty and development information/data, key environmental problems, culture, and selected social justice issues (e.g., discrimination or inequality). You may also want to talk about local service-providers, charities, foundations, or humanitarian groups. In addition, for an expanded treatment, you could: (i) talk in some detail about the technical matters in the design of one or more appropriate technologies, (ii) have fieldwork projects for a local community and/or STEM education for disadvantaged children be a part of the course, and (iii) invite speakers, local or regional experts on community development, to come address the class. Using these ideas, this format could be made to be as short as nine hours (if you pick and choose some parts), or as long as a semester, or even two.

*Community development is the key topic in this book to cover in a first course.*

3. *Computational Humanitarianism:* This format covers the four technical sections at the ends of the four chapters in great detail. But, motivational material from various parts of the book are used to introduce the technical issues. For instance, poverty data is provided for the world. Coding and use of Simulink are required, and full details on the differential equation

approaches (e.g., stability analysis) and optimization (e.g., for parameter tuning) are covered. Extensions to the ideas and methods in the book are introduced, and such extensions are also expected of the students. This is the format I use for a semester long course at OSU; however, with appropriate shortening, it can be made into a short course that is between seven and 17 hours long.

These formats have each been used in at least one of the on-line courses given at the web site for courses based on this book.

# Information Sources

There are many humanitarian technologies, in virtually all categories of technology, and disciplines of engineering. If your team knows how and where to look, most often you will be confronted with a big challenge. How can we study this huge volume of information carefully? How can we find the best information to help us develop a technology to meet community needs? These challenges are a symptom of the information explosion driven by the internet. Here, some strategies are suggested to address these challenges. After that, a number of good information sources for humanitarian engineering are provided.

## Principles of Information Source Use

To find good information to help your team solve a technical challenge, useful approaches are to gather information from the humanitarian engineering "community" (group of people working in this field), to focus on authoritative sources, to have an approach to cope with information complexity and dynamics, and to respect history. Each of these issues is discussed next.

### Research and Crowdsourcing the Humanitarian Engineering Community

You should never get an idea, and think "no one has ever thought of this, any time, anywhere." That is not a professional approach to engineering. You need an element of the attitude of "scholarship" for responsible practice. Research on humanitarian engineering technology (and more generally, humanitarian engineering) is a basic part of being a competent humanitarian engineer, and thereby being more effective in working with people on the ground to make the most and best impact. This is a broad principle, applicable to all aspects of humanitarian engineering. The modern word for this idea is called "crowdsourcing" and it is often explicitly enabled via various internet platforms, such as blogs, tweets, Facebook, virtual communities, cooperative design web sites, etc. These are all referred to below, in addition to the print literature, which is frequently referred to by the on-line approaches.

Sometimes, you can get ideas from development experts outside engineering who suggest useful technology (e.g., (Sachs, 2006) discussed in Chapter 3). There is an active humanitarian engineering community around the world that is incrementally improving humanitarian technologies, or creating new ones,

that any professional humanitarian engineer must be aware of. Considering the wealth of such sources, there is a need to narrow down the set of places to look and sources to consider. Choose "authoritative" sources. These are ones you see many competent engineers using, in a kind a "group vote" on what is best; you should view the engineering community as an ally in coping with the complexity of figuring out what is best to do.

Finally, if you only ask someone on the team (e.g. one of 2-10 people) you have to be very careful. I have had personal experiences in this where I was working with one other person and was convinced that by helping that person, they had found absolutely everything using a search/assessment approach like discussed here; then a year later, another person joined the team and discovered a huge body of highly relevant literature simply because in searching, the new person chose different keywords! This is the nature of search engines, including all the popular ones. They simply do not succeed always, and often they "fail" by providing way too many links rather than the best links (the best is not always the first-listed link, in spite of how popular search engines list the oder of links). Sometimes if you choose one word combination, you can't sift through everything because there is a large area of study that uses a similar word that has many people clicking on those links, and all that is listed first by typical web search metrics, and then what you are looking for is on the $10,000^{th}$ page that you will never find. Other times, different fields in engineering and science use different terminology for the same topic so your search can miss large bodies of highly relevant work.

### Managing Information Overload

There are good on-line resources, some of which are outlined next; however, the user of any of these materials, on-line or print, should be cautioned about trusting what is being said. Your stance should be that you never fully trust any engineering source (including those developed by you; everyone makes mistakes); you should take a critical view. Yet, you should always seek an "authoritative" source, taking a critical, deep, and rigorous intellectual view in evaluating any alternative or idea. Just because it is included in a book does not mean it is the best approach, or that mistakes are not made there, and I am not just talking about typos. Just because it is at a web site does not mean that it is a good approach; indeed some humanitarian technologies may be presented that are not needs-driven, but "a solution looking for a problem." Your trust level may raise, however, if there is a formal review procedure by "experts" (however standards for that are defined) before publication (e.g., a closed reviewer-based system like Scholarpedia versus Wikipedia where at times anyone can post, including people who not only do not know what they are talking about, but may be malicious where untrue statements are knowingly stated as fact). You should study the review or standards policy, if it is stated, at any of the web sites below. If there is no policy, and often there is not, then you have to be careful.

The conferences below likely only include papers that have been reviewed;

*To avoid information overload, focus on authoritative sources.*

however, behind the scenes, review processes can have significant variations in how well papers were screened for quality. Why? It is difficult to get top experts to review papers because they are busy. Indeed, the review process itself is based on volunteerism. In practice, conferences typically seek three reviews for each paper, however, sometimes only two are used. Under a time constraint, one of the reviews might have to get done by a graduate student or any person who will volunteer to do it quickly. Typically, there is a "program chair" who is a widely-recognized expert in at least one topical area, and most often a committee of experts makes the final choice of papers and establishes the program (the "program committee"). Yet, sometimes, to make the conference a financial success, the "quality bar is lowered." There is a very basic challenge to conference organizers: how high of quality should be demanded vs. how many people do you want at the conference, so you collect their registration fee? Having a low number of top quality talks may drive attendance up (people really want to come listen) or down (some people will only pay the registration fee and go to the conference if they also get to talk, to make it worth their while, or to get their organization to pay for their travel).

Journals generally provide a more rigorous review process and higher standards for acceptance of a paper. For example, most often 3-4 or more reviews are required, there is oversight by not only associate editors who are widely-recognized experts, but also an editor that tries to ensure the overall quality and integrity of the process; however, again, behind the scenes sometimes problems do arise in maintaining quality. The frequency of such problems is proportional to the quality of the review process. A journal gains a reputation based on what appears in the journal over a number of years (sometimes measured with the "impact factor" though it is of questionable value), and there is a tendency by many people to know, and use more frequently, what are considered the top journal(s). Of course, there is in engineering a general non-public "consensus" on what is the best journal (or conference) this is normally learned by word of mouth.

Most engineers use a basic principle to determine whether to trust what they read: If several reputable people or groups or companies have successfully developed and implemented the same type of technology they consider the technology more "mature" and to likely be a solution that should be seriously considered (just like the scientific process where "truth" is discovered over time by scientists re-running experiments of others and extending ideas; simple confirmation of others results is quite valuable). Most engineers would, of course, "check it out themselves" (e.g., via a prototype), but at least they will know that investing time and money on such a prototype makes sense. Then, they will also gain confidence that if a modified technology is needed, at least they are starting from a solid foundational technology. Overall, you should view engineering and technology development as a human process that advances slowly in spite of mistakes and poor choices of what should have been done in the past.

In addition to acknowledging the complexity of scholarship in the face of the information explosion as discussed above, you must also recognize that everything is changing over time (e.g., web sites, that unfortunately sometimes do not

get updated often enough, so you really do not know if you know the "latest and greatest" unless perhaps you contact the source person). The second I click save on this document it is out of date; web sites and other on-line sources update by the microsecond. This may seem like an obsessive-compulsive perspective, but I am emphatic on this issue to make a point about being humble in the face of the real challenge. The only feasible and responsible approach in the face of such dynamic complexity is to connect to the humanitarian engineering community in as many ways as you can, have a broad sense of where things are going, and then also have a very clear idea about the best approaches for your specific interests. In other words, you should seek to nurture both breadth and depth in your approach to humanitarian engineering, just like any good engineer would do for any area they work in for any job they have.

Source information changes dynamically. To cope with this, continually monitor the literature and people working in humanitarian engineering.

### Problems with Lack of Respect for History

Humanitarian engineering was not invented around the year 2000, in spite of the way quite a few people view the field. It is probably as old as engineering itself, especially if you consider the wide number of infrastructure projects that have been completed in the developing world, and the developed world when it was undeveloped. Specific examples of this abound, and hence there needs to be much more careful listening to the past by carefully considering what was done. For instance, sometimes early versions of technologies, that were in a simpler form, may make good sense for a community. Keep in mind that the key idea is to think expansively not only is space (whole-world), but in time (yes, long ago). The internet and library help with respecting the history, but older information tends to not be on the internet since it predates it. If you write a paper, do try to reference original sources and be generous in your referencing as this helps others.

So, I feel compelled to provide at least one example of good work done before many thought nothing was happening. Laura Brigitte Parsons, a student member of ASCE at the time, published a Oct. 1996 paper (Parsons, 1996); I recommend studying it as she was far ahead of her time in the way she thought about humanitarian engineering (see Problem 4.38); subsequently, many people learned the lessons that she discovered. I know of a number of other examples, but for work that was not published. One view of the historical context for humanitarian engineering is in (Mitcham and Munoz, 2010).

While the reader is encouraged to see the annotated bibliographies at the end of the chapters for many references, here a number of other good sources are provided next.

## Web Sites and More

There are general sources on many aspects of humanitarian engineering:

- Engineering for Change (E4C): This site has humanitarian technology ideas, a solutions library, professional development links, webinars on a

range of subjects, and courses via the "Engineering for Global Development (EGD)" program.

- IEEE Special Interest Group on Humanitarian Technology (SIGHT): SIGHT is a program for local development projects all over the world. SIGHT has useful resources, for instance, members from all over the world that may serve as good in-country partners.

- IEEE Smart Village: This program seeks to empower "off-grid communities through education and the creation of sustainable, affordable, locally owned entrepreneurial energy businesses" (from their web site).

- ASME Innovation Showcase (IShow): Is a global competition for hardware, design, and engineering, to take products to market. It has had events in a number of developing countries.

Other organizations relevant to humanitarian engineering include:

- Humanitarian Engineering Center

- UCLA Institute for Innovation in Health

- Practical Action

- Engineers Against Poverty

- Institute of International Humanitarian Affairs, and in particular their program High Tech Humanitarians (HTH)

- Engineers for a Sustainable World

- Engineers Without Borders

- Engineering World Health

- TechChange: The Institute for Technology and Social Change

- Scientists Without Borders

- SciDevNet "Bringing science and development together through original news and analysis."

There are also sites for humanitarian architecture.

Some more good sources for humanitarian technologies are:

- Village Earth: Appropriate Technology Sourcebook: This has a wide range of humanitarian technologies and also has a number of relevant topics in STEM education; see the links for "science teaching" and "nonformal education and training."

- Humanitarian Technology Network: There is overlap with other humanitarian technology web sites, but a lot of options here.

- Appropedia: This has useful information, and a cooperative platform, but there is overlap with other sites. There is also a Wikipedia site on appropriate technology.

There are also wikis dedicated to specific humanitarian technologies (e.g., for the "one laptop per child" program for collaborative authoring of documentation and cooperative software and hardware design).

There are some additional humanitarian technology sources, including:

- The National Center for Appropriate Technology

- Design Other 90 Network

- Development Center for Appropriate Technology

- Centre for Appropriate Technology

- The Appropriate Technology Collaborative

- Appropriate Infrastructure Design Group

The Abdul Latif Jameel

### Poverty Action Lab

has useful resources, including supplementary information in (Glennerster and Takavarasha, 2013).

There is a wide array of relevant information at the United Nations and World Bank web sites. The USAID has a

### Learning Lab

that has resources relevant to development, and the

### US Global Development Lab

There is also the

### Global Innovation Exchange

Science and technology challenges for sustainable development are given in (Buluswar et al., 2014), with additional information given at

### Institute for Globally Transformative Technologies

of the Lawrence Berkeley National Lab.

The Innovation Policy Platform, by the OECD and World Bank,

### Innovation Policy Platform

has relevant information (e.g., (Bank, 2010)), much of it with respect to technology policy as in Problem 3.5 where additional sources on technology policy are provided. Along these lines, there are other reports on technology and education at the OECD.

## Conferences and Reports

There are conferences dedicated to humanitarian technology that can be very useful for disseminating your own work, learning about the latest developments by others, and for networking with other humanitarian engineers:

- IEEE Global Humanitarian Technology Conference

- Humanitarian Technology: Science, Systems, and Global Impact

- Engineering4Society

There is a site that promotes global STEM, global conferences on STEM, and a conference on technology for education:

- Global STEM Alliance

- The Global STEMx Education Conference

- International STEM Education Association

- International Society for Technology in Education

For a series of reports and other information on the US approach to STEM education see:

- The US National Academy of Engineering STEM Education reports

- STEM Education Coalition

Also, useful resources for STEM education are at the

Smithsonian Science Education Center

(e.g., teaching resources).

## Magazines and Journals

There is a "magazine" (in spite of the name, most often thought of as a "journal" due to the integrity of the review process and quality of papers there) that often publishes on topics of humanitarian engineering and technology (e.g., see the Special Issue on Volunteerism and Humanitarian Engineering, Dec. 2009, the source of several papers for Chapter 4):

IEEE Technology and Society Magazine

Also, see the magazine

DEM+ND: ASME Global Development Review

that is also called "DEMAND."

There are relevant journals for archival dissemination of your work and for learning about significant advancements:

- International Journal for Service-Learning in Engineering, Humanitarian Engineering, and Social Entrepreneurship; click here

- International Journal of Humanitarian Technology

- Journal of Humanitarian Engineering

- International Journal of Engineering, Social Justice, and Peace

A journal that may be useful for global STEM is the

International Journal for STEM Education

Sometimes, humanitarian engineering, technology, and education papers are published in the conventional engineering discipline-based journals (e.g., IEEE Transactions, ASME, or ASCE).

# Recommendations for Further Study

While elements of each of the following were used in this book, a more complete study of the following is recommended:

1. *Understanding the Lives of Low-Income People:* A. Banerjee and E. Duflo: "Poor Economics: A Radical Rethinking of the Way to Fight Global Poverty," (Banerjee and Duflo, 2012).

2. *Sustainable Development:* J.D. Sachs: "The Age of Sustainable Development," including his on-line course (Sachs, 2014).

3. *The Engineer as a Helper:* G. Egan, "The Skilled Helper: A Problem-Management and Opportunity-Development Approach to Helping," (Egan, 2014), and/or E.H. Schein, "Helping: How to Offer, Give, and Receive Help," (Schein, 2011).

4. *The Community Development Practitioner:* M.S. Homan: "Promoting Community Change: Making It Happen in the Real World," (Homan, 2011).

5. *Fieldwork (not engineering, but relevant):* T. Kidder: "Mountains Beyond Mountains: The Quest of Dr. Paul Farmer, a Man Who Would Cure the World," (Kidder, 2009).

6. *Knowing When it Works–Assessment of Outcomes:* R. Glennerster and K. Takavarasha: "Running Randomized Evaluations: A Practical Guide," (Glennerster and Takavarasha, 2013).

The annotated bibliographies and homework problems at the end of each chapter may provide additional information sources of interest in the form of books, reports, articles, web sites, and videos.

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