Development Engineering

Development Engineering:

Empowering the Poor through Sustainable Technology-based Solutions

By

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Dedicated to my biological and academic families, including the many smallholder farmers that have made our (my students and I) experiences unforgettable.

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PREFACE

Development engineering prepares students and early career professionals in related fields to develop, pilot, and evaluate technological interventions designed to improve human and economic development within complex, low-resource settings. This book shines a fresh light on what you should (or should not) do to come up with life-changing innovations in these settings. The insights I share are from failed and successful projects conducted with cohorts of graduate and undergraduate students over twenty years. I show the key points and engage through stories or cases that take you there by the vivid descriptions of the places and the people involved. The book is not written just for engineers; the material is easily accessible by all.

The book comes in three main sections. The first section is devoted to resilience factors that endow the poor with the capacity to survive, adapt and continue to live, despite their circumstances. The topics include indigenous knowledge, land, family labor, and diversification. The second section is devoted to what to watch out for, especially for an outsider looking in. Topics include transaction transparency or the lack thereof, funding options or the lack thereof, and ownership protections. The last and longest section of seven chapters is choke-full of tools and practical advice; I narrate in a straightforward language. Overall, I believe you will be inspired to think big, think outside the box, think and do, think about others, and most importantly, not be afraid of failure.

I am excited to share my experiences. I hope that after reading this book, you will be thinking night and day about developing solutions to the problems of the poor and taking these solutions all the way to widespread uptake. Most storytellers prefer to tell about other people's failures and not their own. On the contrary, I am comfortable with telling about my failures, because the notion that failure is an integral part of success liberates me.

I could not have produced this book without the students, with whom I have both failed and succeeded. The students have been quick to embrace the tell-all mindset. The other enabling individuals and/or agencies include colleagues at American and International institutions; partnering academic, public and private institutions; funding agencies that have provided the financial support; and last but not least the smallholder farmers, with whom

the students and I have worked as equal partners. The lists provided below are as inclusive as memory can serve me. My deepest apologies if I have left anyone out.

The entire list of smallholders is too long to present. I have selected five individuals, whose "innovative" attitude made visualizing the trajectory toward products easier. They fully embraced, as equal partners, the goals of increasing incomes or reducing labor. They are Winnie Busingye, Lydia Jjemba, Agnes Luwesi, Rachel Nsangi, and Willy Yiga.

Students in alphabetical order are: Angela Aralu, Ambrose Ashabahebwa, Bariho Davis Bagamuhunda, Daniel Bennett, Phillip Berryman, Brian Bibens, Brad Boyer, Khushboo Brahmbhatt, Jessica Buday, Ryan Brush, Melissa Bystedt, George Cavendar, Rachel Childers, Cody Crockett, Joshua Brandon Dunn, Jonathan Dunn, Steven Etheridge, William Eubank, William Faircloth, Tony Kasinja, Kevin Flack, Katharine Fletcher, Justin Franklin, David Girmy, Dana Goodman, John Huber, Steven Jay, Daniel Johnson, Jonathan Jones, Phillip Jones, Abia Katimbo, Vans Randell Kinsey, Britt Lacey, Edward Lane, Jeremy Leiter, Josh Lewis, Cissy Lindrio, Kristine Maize, Dana Mugisa, Simon Muwanguzi, Kenneth Ndyabawe, Mia Catharine Morgan, Max Neu, Chinelo Ononye, Joshua Pendergrass, Justin Robinson, Denis Semyalo, Molly Smith, Matt Williams, Edison Sempiira, Meghan Shealy, Innocent Sukuku, Richard Ssonko, Dave Sylvester, Allyson Tippie, Charity Tushemereirwe, Godfrey Wangi, Alex White, Aaron Watwood, Joseph Wasswa, and Patrick Young.

Colleagues in alphabetical order are Dr. Noble Banadda, Dr. Keshav (KC) Das, Dr. David Gattie, Dr. John Boscho Kawongolo, Dr. Ed Kanemasu, Dr. Nickolas Kigundu, Dr. Charles Kwesiga, Dr. Kim Love-Myers, Ms. Victoria Collins McMaken, Dr. Charles Muyanja, Dr. Salimata Pousga, Dr. Salibo Some, and Dr. Brahm Verma. Institutions in alphabetical order are: African Sustainable Development Council ASUDEC (Burkina Faso), Makerere University (Uganda), Moi University (Kenya), National School of Agriculture (Morocco), Selian Agricultural Research Institute (Tanzania), Smallholder Fortunes and Thermogenn (Uganda), Stellenbosch University (South Africa), Uganda Industrial Research Institute (Uganda), and University of Bob Dioulasso (Burkina Faso).

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Last and most importantly, I am deeply indebted to my family, for their unwavering support during the writing of this book. I am grateful for their advice and suggestions.

William S. Kisaalita
Athens, Georgia

INTRODUCTION

If you think you are too small to be effective, you have never been in bed with a mosquito.
– Betty Reese

INTRODUCTION

1

Development engineering at UC Berkeley is implemented as a "designated emphasis"–a campus-wide system that provides doctoral students with certification in specialties outside their home discipline, to be added to their doctorates.

> Through coursework, research mentoring, and professional development, the designated emphasis in development engineering prepares students to develop, pilot, and evaluate technological interventions designed to improve human and economic development within complex, low-resource settings.[1]

In my development engineering work at the University of Georgia, I strive for the same outcome, but through undergraduate experiences offered by capstone design-/inquiry-based and graduate research projects. I engage undergraduate and graduate students, in interdisciplinary solution developing teams, to come up with technological interventions to problems in low-resource settings. The students that seek these experiences are highly curious, but often need help to enhance their creativity to turn solutions into innovations. I differentiate a solution from an innovation; a solution becomes an innovation when it reaches widespread use. Widespread use may depend on solution type and/or target market size. This book shortens the time-gap between the development and uptake of the intervention, especially for student solution-developers or innovators to whom the cultural and geopolitical environment settings of the problem-source country or region are new.

So, what is this book about? "The newly hatched chicks cannot stand. They cannot walk to food and water. They die within their first 24 hours," said Salibo Somé, explaining the PowerPoint slide showing a bright-eyed chick, with a morning-sun-yellow-colored fluffy coat. The chick is lying on its stomach on a black cloth, its legs spread out flat on the cloth at 90 degrees. The legs look like they were just glued onto the side of its body. The next slide shows a crude wooden incubator. Hot gases from a kerosene lantern warm the incubator, in which the chick in the previous slide was hatched. Somé, the Founder and Executive Director of a Burkina Faso-based not-for-profit organization, ASUDEC (Africa's Sustainable Development

Council), was giving an invited talk at my institution. He talked about the development problems in his country and his efforts in the poverty-alleviation field. Located in Western Africa, landlocked Burkina Faso ranks the 6th poorest according to the 2014 UNDP Human Development Index, ahead of Burundi, Chad, Eritrea, Central African Republic, and Niger. It has a high population density, sometimes exceeding 48 persons per square kilometer, few natural resources, and fragile soils. Its GDP can be broken down to 31.9%–Agriculture, 22%–Industry, and 46.1%–Services. Over 85% of its 19.19 million people eke out a living from subsistence agriculture and livestock farming (smallholder farmers).[2] Most of these people earn less than one purchasing-power-parity (PPP)[3] dollar, per day. PPP$ are adjusted dollars taking into account the greater purchasing power in other countries.

The locally developed wooden incubator was an attempt to intervene in the problem of local chickens brooding too few eggs at a time. The result of this is a poultry meat production bottleneck among smallholder farmers. Lack of temperature control in the incubators resulted in hatchability rates ranging between 0% and 25%. Additionally, poor temperature control induced leg malformations, resulting in death rates of the hatched chicks as high as 99% in the first 24 hours. A team of four students and I visited Burkina Faso. We interviewed farmers. They complained of difficulties in maintaining a constant temperature and were frustrated by having to wake up at night to tend to the incubator. Additionally, the smoke produced by the lamp irritated the farmers. The cost of kerosene was too high in relation to the low hatching success rate of the incubators. In other words, the activity was not profitable. Because these farmers do not have access to electricity, we built on the crude wooden incubator. We took into account the local knowledge and skills and developed an incubator in collaboration with the farmers. We kept the 100-egg capacity, powered it by a solar panel, and equipped it with a precise temperature control. In this new incubator, chicks hatched and survived well above 85%. The adoption for the incubator was respectable, but it did not reach innovation status.

Working with ASUDEC, we were on our way to improving productivity and speeding up local chicken breeding improvement. ASUDEC provided microloans and training to a few select farmers. These farmers specialized in crossbred egg production using disease resistant local breeds and highly productive European breeds. These farmers provided good quality eggs to a second group of farmers who used the solar incubators to hatch the eggs. The second group of farmers sold their hatched crossbred chicks to a larger group of farmers who raised them for meat sale to consumers mainly in the capital city. The incubator was at the center of this poultry production, or value chain. The term, "value chain" can be used to describe a series of activities that create and build value at every step, in this case from the farmer who provides the eggs for hatching to a retailer who sells the mature birds to consumers in the market. Professor Michael E. Porter introduced this concept in his "Competitive Advantage" book.[4] Each farmer at all three steps of the value chain earned an average profit of 174,000 FCFA ($348) per year, which was more than double the poverty level of $167 in Burkina Faso. With increased incomes, more farmers' children were going to school and had better access to medicines and nutritious food–indicators of improved household well-being. This story captures the meaning of development engineering at the undergraduate level consistent with the UC Berkeley definition in the first paragraph. We wanted to apply the technology to hatching the more popular guinea fowl eggs, but success was not as easy to achieve. I will continue with this story later in Chapter 10.

The above is just one of the solution development projects that are the inspiration behind this book. A list of the fourteen projects we (my students and I) have worked on is provided in Appendix A. These projects are not a one-summer exercise. They are "long-term." It takes years and strong relationships with local partners to take a project from an idea to an implementation that yields increased incomes among the poor. As shown in Appendix A, projects have been conducted in Burkina Faso, Morocco, South Africa, Tanzania, and Uganda–covering almost all of the ecological sub-regions of Africa.[5] I have worked with a mix of graduate and undergraduate students in these projects whose majors are not restricted to engineering. We have worked with the poor or the users of the solutions as well as their backers. While working, we have stayed overseas for short (two weeks) and long (eight weeks) periods. Given the nature of rural sub-Saharan Africans–typically poor smallholder farmers–we decided that the solution devices or processes we came up with were either to be manually operated or powered by abundantly available renewable energy. This was the first leg in the eventual branding of our development engineering program as "3*p*-Innovations." The ***p***s stand for ***p***overty-alleviating, ***p***rosperity-/wellness-building, and ***p***lanet-sustaining. I have used the 3***p***-innovation "filters" to choose the projects we pursue. First, the project has to have high promise to provide poverty-alleviation (lifting up those earning $5 per day or less). Second, the project has to have potential for prosperity-/wellness building (market potential in millions of households to support job creation and healthier lives). Third, the project has to have potential to be planet-sustaining (non-polluting, powered manually or by renewable energy, etc.).

Different student teams made and refined devices or processes to improve the productivity of smallholder farmers in rural settings. To provide quality management and reasonable time to project completion, the number of active projects was limited to three. A new project was only adopted after one of the active three was either abandoned or taken on by an independent entity for continued deployment or diffusion. Summer students were employed to make and test the first prototype and the test results provided the basis for refinement by the second team the following year. It was not so easy to find others (e.g., not-for-profit entities or entrepreneurs) in the host country to carry on the work. This was partly because, field research and/or testing (usability studies) was found to be necessary before success in the field was a sure thing. Few wanted to commit the resources needed to get to that point. In response, we expanded the program to include an eight-week summer field research and education component, through which the students worked or researched to move the product further along to make it more attractive for others to adopt for deployment. The main difference between the making or design and the research or education experiences is two-fold: 1) the longer overseas stay (at least eight weeks as opposed to one to two weeks) that allowed deeper involvement as opposed to solution ideas generation, and 2) the product development-oriented inquiry/research focus.

Different student teams came and went, working on the same project to completion. Completion means transitioning from a project to a business. These projects have covered solutions to a wide range of problems. For example, students have worked on solutions at the intersection of agriculture and renewable energy (e.g., the solar incubator for fertilized poultry egg hatching). At the other end, students have worked on low-cost disease diagnoses. Needless to say, we have made missteps from which we have learned lessons of what works well and what does not. The first sub-thesis of the book is that the most holistically low-cost and high-impact solution to complex global problems like energy insecurity, food insecurity, poor health, or poverty in general, is empowering the poor in these situations to increase their incomes[6] and/or reduce labor. By "increased incomes", I mean any form of noteworthy increase, which may be monetary or in terms of a larger livestock herd or more land. The Burkina Faso solar-powered incubator project demonstrates this through earnings that are more than twice the poverty level.

Most people agree that converting good ideas into practical solutions is one of the weakest links in creating and implementing sustainable solutions in resource-poor settings.[7] The second sub-thesis of the book is that "there is a simple way" to achieve increased incomes. The simple way entails engaging with small projects over an extended period. Using some or all of the lessons shared in this book will lower this difficulty and enhance success. The corpus of this book is therefore about the lessons learned and how we have learned these lessons in the past 20 years. The projects listed in Appendix A have served as an "experimental setting" or "laboratory" from which our understanding has been expanded and it is this understanding that I share in this book. Some of these lessons were instrumental in the implementation of the Burkina Faso incubator project. For example, the interview with the Chief revealed a different project interest, but Somé and the farmers' interests were consistent. To get the Chief's blessing for the project, as desired for the benefit of the farmers, required some persuasion. This persuasion would have been difficult without the strong partnership with ASUDEC. In addition, our "long-term" presence on the ground was very helpful.

The solutions to problems in the projects listed in Appendix A are engineering types. This is by no means a suggestion that the lessons we have learned are not applicable to generating solutions from different majors. Our approach is applicable to problems in fields like public health, nutrition, and you name it. Actually, members of teams working on the problems in Appendix A included students from non-engineering majors like economics, food science and nutrition, and poultry science. Unlike classroom textbook problems, real-life problems do not come labeled with the required majors of the solvers. The effort and mindset that go into field-testing a ghee-making device with a labor-saving goal among women are no different to the effort and mindset that go into a randomized controlled trial of an oral rehydration solution with a diarrhea-based death reduction goal among children. Such a trial passes through our 3***p*** filter. Sick children take mothers away from income-generating activities, exasperating the household well-being. Thus, healthy children positively influence household incomes. The local manufacturer of the oral rehydration solution creates jobs–prosperity-building, and supposedly does so in an environmentally friendly way, by for example, using renewable energy–which is planet-sustaining.

2

Why sub-Saharan Africa? There are two answers to this question. The first is that I was born and raised on a smallholder farm in Uganda, approximately twelve miles from Kampala, the capital. As such, I have a deep cultural and geopolitical connection to Uganda. This connection extends to the rest of the sub-Saharan African countries. Before I provide the second answer, I need to explain how I ended up as a professor in an American university. Soon after graduating from Makerere University with a mechanical engineering degree, I tried to transition my final year design project solution of a hand-operated cane mill into a business. I collaborated with a fellow graduating student, Isaac Musabe, to make and sell the units to smallholder sugar cane growers. These growers were extracting the juice by mortar-and-pestle methods. They were boiling off the water with firewood and selling the remaining crude bright yellow to dark brown sugar-molasses mix for use in tea, coffee or other cooking. This was in 1978; all the sugar factories were in disrepair due to mismanagement, a result of the expulsion of Ugandan-Asians by Dictator Idi Amin.[8] The main sugar producing factories were under the ownership and operation of prominent Ugandan-Asians before the expulsion. The mortar-and-pestle approach was slow, labor-intensive, and left a lot of sugar-containing juice in the cane fibers. Musabe and I were in business for approximately nine months and our sales were disappointing. We had sold only two units and had run out of money. An opportunity, to go to graduate school at the University of British Columbia, Vancouver, Canada, too good to turn down, came my way; I took it and left the business to Musabe–it did not survive much longer.

After graduating with a PhD in chemical engineering and a stint as a postdoctoral research associate, the political-economic situation in Uganda was such that it was not prudent to return. To wait for a better time to return, I accepted a second postdoctoral position. The project ran out of funds after one year, so I accepted a third postdoctoral position. The situation in Uganda had not improved toward the end of the third postdoctoral position. I decided to throw in the towel and take a more permanent position. After several interviews, I accepted an assistant professor position at the University of Georgia, Athens, to teach and conduct research. The year was 1991. I felt very lucky because soon after accepting the offer, the US economy went into recession and many academic institutions including the University of Georgia put in place hiring freezes to meet their budget deficits.

Soon after arriving in Athens, Georgia, I wanted to direct a development engineering inquiry or research and teaching program, to develop and widely deploy solutions like the hand-operated cane mill to improve the lives of smallholders. I was advised that doing so would be tantamount to committing “academic suicide.” Such a program was likely to be frowned upon when it came to promotion and tenure decisions. I needed to develop a research program similar to my postdoctoral research in areas like biotechnology. I argued with myself that it was possible to do scholarly work in development engineering that would make a difference in the lives of smallholders at respectable scholarship levels. The "no" voice won. I continued with work I had started in my last postdoctoral position in tissue engineering, a branch of bioengineering, leaving my dream research on the back burner. The times have changed. Readers starting their academic careers do not have to grapple with the same question that I did. I know of many role models who developed their development engineering-like programs on day one and they are very successful. Three examples off the top of my head are Amos Winter of MIT, Rebecca Richards-Kortum of Rice University, and Manu Prakash of Stanford University. Winter is most known for developing low-cost all-terrain wheelchairs for the developing world. Richards-Kortum is most known for providing low-cost neonatal technologies for preventing newborn deaths in Africa. Prakash is most known for developing the "Foldscope," an optical microscope costing less than US$1 for use in the developing world.

I was promoted from Assistant to Associate Professor and granted tenure effective on July 1, 1997. I was ready to develop a teaching/research program toward improving the lives of smallholders. The problem was that, at the time, there was little funding for these kinds of teaching/academic activities, especially targeting the sub-Saharan Africa regions. Approximately one year after promotion, being one of three "internationals" in an engineering department with over 50 faculty, I was asked to co-author a white paper on "globalizing our students." The white paper was to support the engineering departmental review. There was a national debate on the inadequacy or absence of global content in engineering curricula.[9] Writing the white paper created the "ah-ha" moment. I realized that I could find funding to pursue my long-neglected love through "globalizing" students in inquiry- and/or design-based poverty-intervention projects. Funding from sources like the National Science Foundation was limited to undergraduates. The smaller challenge was finding a way to integrate undergraduate and graduate education in this same space, seamlessly. My active, respectable, and fundable program to mentor undergraduates in inquiry-based/design-based/service-based learning was born. I will describe later how I was able to integrate graduate education.

The first project was implemented in 2003. Student teams, mainly seniors, worked on a real-life problem from an African "customer." The students traveled to the location during the spring break, for approximately one to two weeks. They presented solution concepts and appreciated the context of the problem first-hand. When they returned to the US, they completed the analysis for the "best" concept and sent the final report and a taped final presentation to the customer by the end of the semester. I established relationships with local universities in each country in which we worked. For example, I was granted a "visiting" professorship, equivalent to adjunct status, at Makerere University in Uganda that I have renewed every three years ever since. Such appointments provide access to local students to team with my American students to create global problem-solving teams.

The second answer to the "Why-sub-Saharan Africa?" question is that the majority of African countries lag behind the rest of the world in a number of well-recognized measures of human development. Data from the United Nations 2010 Human Development Report[10] in support of this view are summarized in Appendix B. The Human Development Index (HDI) is a statistically generated fractional number between 0 and 1.0 that measures average achievements in a country in three basic areas of human development, including: 1) a long and healthy life, 2) access to knowledge, and 3) a decent standard of living. The HDI is a simple average of normalized indices measuring achievement in each of the areas outlined above. As shown in Appendix B, HDI measures from sub-Saharan African countries for poverty, gross national income per capita, renewable energy use, expenditure on health, education, population growth/projection, and corruption are not distinguishable from those for countries in the lowest HDI group. In other words, sub-Saharan countries are major contributors to the lowest HDI group. What moves me to action is that these sub-Saharan countries exhibit the fastest rate of annual population growth, e.g., 2.7%–Zimbabwe versus 0.7%–USA, suggesting falling further behind down the road, if all of us do nothing now that is different from "business as usual."

Although, the "experimental settings" from which we have learned lessons are found in Africa, I have been surprised at how applicable the lessons are in other developing countries as well as countries with developed economies. The first time I encountered this was after one of my talks. An individual from the audience, working in the US Appalachian Mountains related how our sub-Saharan experiences were similar to her experiences. Perhaps this should not be surprising; researchers have conducted experiments using approaches from the psychology tradition, the results from which are in agreement with the above observation from the Appalachian Mountains researcher. Some of this work was recently summarized in a review article by Johannes Haushofer of the MIT Poverty Action Laboratory and Ernst Fehr of the University of Zurich Department of Economics.[11] The hypothesis driving these studies is that poverty has psychological consequences that lead to the same behaviors whether the poor are from the Kibera slum of Nairobi or Washington County of the US State of Georgia. As an example, poverty affects what economists call "time discounting". To illustrate the concept, imagine two groups of people, one is made up of the poor and the other is made up of well-to-do types, defined by a relevant measure. If you offer each of these participants $5 today or $20 next week or in the near future, a significant number in the poor group will take the $5 now whereas a significant number in the well-to-do group will choose the $20 in the future. The money in this experiment can be interchanged with anything of value and this does not affect the results.

3

Approaches to "eradicating poverty" are currently framed by two schools of thought on the opposite ends of the spectrum. The dominant figure on one end of the spectrum is Jeffrey Sachs,[12] former advisor to the United Nations and former director of the Earth Institute at Columbia University in New York. Sachs' idea is that foreign aid is the key and argues that the reason poverty is still with us is because the rich countries are not committing the billions of dollars required to solve the problem. The dominant figure on the other end of the spectrum is William Easterly[13] of New York University. Easterly's idea is that aid does more harm than good. Easterly argues that the poor will lift themselves out of poverty; their governments just need to create free markets and the right incentives. Both Sachs and Easterly are economists and have published books on their ideas, framing this debate. From Sachs' viewpoint, infusions of massive aid can jumpstart nations or individuals to leap out of poverty and self-sustainably thrive thereafter. Sachs' Millennium Villages Project,[14] where the whole village is provided with most needs, ranging from fertilizers to medical services, free of charge, is consistent with this thinking. Sachs' critics raise the question, if this thinking is on the right track, why does data on many countries show that those that receive more aid do not grow faster than their counterparts that receive less aid. Easterly's viewpoint has been interpreted as an assertion that there is no such thing as a poverty trap from which the poor can be freed by aid. Easterly's critics point to the existence of poverty traps demonstrated by instances where individuals with potential to thrive, do so when they are lifted by a "helping hand" in any form, such as school fee donations for children.

As an engineer and a scientist, I have reflected on Sachs' and Easterly's viewpoints with the goal of finding a space where I am most comfortable.

It is difficult for me to say who is right or wrong or under what circumstances one is more right or more wrong than the other. In my training as a scientist, I solve problems by first establishing a hypothesis that clearly provides the dependent and independent variables, that is defensible, and that is testable. My training as an engineer emphasizes the translation of what is learned from testing the hypothesis into a public good, which may be a product or a process that adds value. When I hear a problem like chicks that could not stand, the question that comes to mind is how can we solve it? The Sachs-Easterly debate seems to be 30,000 feet above where I am. Yet it is relevant because how we as a society determine principles that govern how resources are distributed and utilized at 30,000 feet, affects how poverty-alleviation is implemented at hundreds to thousands of feet above sea level (e.g., 3,000), where the smallholders are.

To help find my space, at a much lower elevation, I developed two constructs or frameworks. In the first framework (Figure I.1), the state of poverty is a consequence of genetic and environmental factors. Examples of environmental factors are unfavorable climate/soils, or government policies. An example of genetic factors is a community with a lower resistance to an environmental problem like a drinking-water contaminant. The state of poverty can be visualized or measured in different ways, the simplest of which is household daily income. For example, all households earning less than PPP US$1.25 per day can be designated as being extremely poor. The causal effect of poverty has been studied. Alleviation studies have reported positive effects on psychological well-being or stress and related measures such as certain mental disorders, unhappiness and anxiety.[15] There are well-established procedures to measure such disorders. For example, stress can be measured by levels of the saliva stress hormone, cortisol, and unhappiness can be measured with the General Well-Being Schedule.[16] Therefore, in Figure I.1, an increase in poverty leads to a negative affect and stress (inside circles) and a decrease in poverty via impactful interventions has the opposite effect, decreasing the overall large outer circle. The feedback loop (perpetuating and prolonging the escape from poverty) has been hypothesized to be due to the effect of negative affect and stress on risk-taking and time discounting. Studies designed from psychology research traditions have shown that fear and stress cause higher levels of risk-aversion[17] and the poor easily forego higher future gain for a low present gain (shortsightedness) or more specifically, an increase in time discounting. These behaviors can be measured with well-established instruments, like the Improved Measure of Risk Aversion.[18]

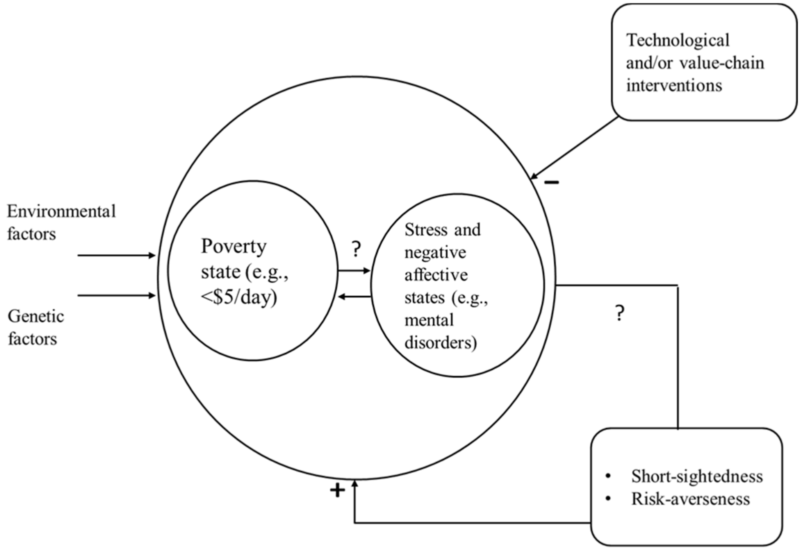

Figure I.1. The framework for a better understanding of poverty with respect to its causes, resulting behavior among the poor, and interventions. As shown, the state of poverty is a consequence of genetic and environmental factors. The state of poverty (the size of the circle) can be visualized or measured in different ways, including daily income and/or negative affective states (small circles inside the big circle). The meaning of the negative sign from the technological/value chain interventions arrow is a reduction in the circle size (poverty reduction). However, this is counterweighted by the positive sign with the opposite effect because of two characteristics resulting from being poor, such as shortsightedness. Question marks in the framework signify that: while many studies have conclusively shown these causal relationships, some of these studies have been conducted in the "laboratory" and a few field studies have not succeeded in establishing the suggested causality, calling for continued field study. Adapted with permission from William S. Kisaalita, "On the diffusion of solutions for alleviating poverty," *Resource–Engineering and Technology for a Sustainable World* 24(4): 20-21, July/August 2017. Reprinted with the permission of ASABE.

I have characterized intervention strategies as either technology-based or value chain-based or a combination. For example, introducing a high yielding rice variety for highlands[19] can be considered a technological intervention, while building a new network of local buyers and export markets for an existing agricultural commodity can be considered as value chain-based.[20] It is possible that poor women smallholder farmers' income can only be increased if the two approaches are implemented simultaneously, which can be viewed as a combination of the two strategies. I include the question marks in the framework to signify that while many studies have conclusively shown these causal relationships, some of these studies have been conducted in the "laboratory." Few field studies have not succeeded in establishing the suggested causality, calling for continued field study.[21]

In the second framework, the success or failure of science/engineering-driven solutions in developing economies can be represented by a four-quadrant figure (Figure I.2). The inspiration for Figure I.2 came from the quadrant model of scientific research by Stokes.[22] The vertical axis represents STEM (Science, Technology, Engineering and Mathematics) complexity behind the solution. Another way of characterizing widespread use is when the solution units in use are above the "tipping point"–which I will discuss in detail in Chapter 10. Briefly, a tipping point is that moment when a critical mass is reached, beyond which the increase in uptake is exponential. The horizontal axis represents the extent to which the solution has succeeded in the market place (achieving the innovation designation) or its widespread use (diffusion). In E. M. Rogers' "Diffusion of Innovations,"[23] diffusion or widespread use is the process in which a solution is communicated through certain channels over time among members of a social system. The presentation in Figure I.2 uses quadrants for simplicity, but the scales are continuous. For example, even within a quadrant there are differences between the STEM complexity at the bottom and top of the quadrant. Technology examples are added to convey the meaning of the quadrants. The top-right quadrant is designated as the mobile phone quadrant. Over half of the people in developing or poor countries use mobile (cell) phones.[24] The World Bank estimates that the region's wireless phone market is the fastest growing in the world. The mobile phone market is growing, mainly due to peoples' desire to increase productivity, even in places where there is unreliable electricity, little portable water, poor schools, inadequate roads, and food and energy insecurity.

In the bottom-right quadrant are innovations–solutions that have succeeded in the market place, but whose origination did not require a high level of STEM. A characteristic example is artificial insemination (AI), with an emphasis on the genetic improvement of dairy cattle. Old Arabian documents of around 1322 AD indicate that an Arab Chieftain, who wanted to mate his prized mare to an outstanding stallion owned by an enemy, introduced a wand of cotton into the mare's reproductive track. The Chieftain used the wand of cotton to excite the stallion sexually, causing it to ejaculate. The semen introduced into the mare resulted in conception.[25] Although the development of the AI industry as we know it today has required more STEM in areas of male management and semen collection, evaluation, preservation, and insemination,[26] the STEM involved was not high enough to place the innovation in the top-right quadrant. Another example that fits into the bottom-right quadrant is fighting iron and iodine deficiency with salt double-labeled with both iron and iodine.[27]

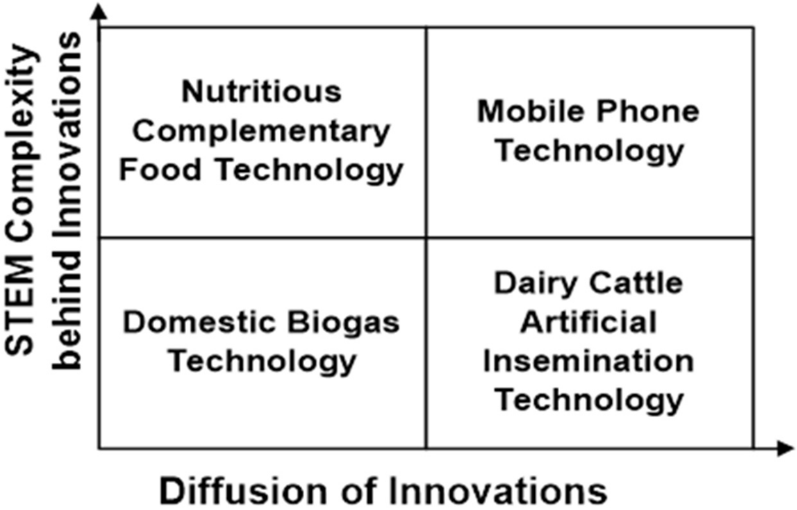

Figure I.2. Quadrants of spread of solution/innovation that are developed with the help or use of STEM (science, technology, engineering and mathematics). A solution/innovation example is provided for each quadrant to illustrate meaning. Adapted with permission from William S. Kisaalita, "Perspectives on context, design teams and diffusion of technological innovations in low-resource settings," *Technology in Society* 46: 58-62, 2016.

The criteria that separate the top from the bottom quadrants is STEM training and the skills of solution-developers. In the top quadrants are solution-developers with a STEM college education all the way to the doctoral degree level and in the bottom are others with lesser STEM training and skills. In the left quadrants are those solutions that have either failed in the field or require a subsidy for their continued market presence, whereas in the right quadrants are solutions that have become innovations; they are in widespread use or scaled in multiple countries or regions. A characteristic example in the top-left quadrant is using food technology to enhance the nutritional quality of food.[28] Another example is GM crops,[29] which require complex STEM skills and many years of training to establish. Unfortunately, despite the promise they represent for African smallholder farmers, at the time of writing, there is limited acceptance. South Africa remains the only country in Africa that has engaged in the widespread planting of GM crops.[30]

In the bottom-left quadrant are solutions based on simple STEM with no or low uptake. Some of these solutions may need more STEM knowledge and skill (e.g., moving to the top-left) before widespread use (moving to the right) can be achieved. This is the point where the seamless integration of undergraduate and graduate education occurs. For some solutions in the bottom-left quadrant that have potential for widespread use, transition from a project to a business to achieve widespread use is typically needed. However, the business model (how the business is operated to capture value for the owners) may be wrong. The location may be wrong. The choice of customers to start with may be wrong. All of these lead to a lack of widespread use. Domestic biogas use in sub-Saharan Africa is a well-known technology in this category.[31]

Framing science/engineering- or technology-driven solutions or innovations as presented in Figure I.2 is a way to convey two things. First, visualization of how to integrate undergraduate and graduate education, and second, visualization of how to integrate design- and inquiry-/research-based approaches in solution generation and transition to innovation or widespread use. The framework also makes it easier to ask fundamental questions that are important in generating knowledge in the development-technology nexus. For example, questions like, what are the underlying drivers for technology adoption in low-resource settings, what are the characteristics of the environment and solutions that promote a short path to widespread use?

How does the framework help me in coming to terms with where I stand in the Sachs-Easterly debate? To answer this question, I closely examined the lessons learned that are presented in the thirteen chapters that follow. If Sachs and Easterly are on opposite ends of the spectrum, then where I am depends on the problem. To illustrate the lack of a concrete position, I advocate not giving, but selling, in Chapter 11, which would align me closer to Easterly. However, I do not advocate leaving the smallholders completely to the whims of the market place. They are typically not in a position to pay, as they live on a hand-to-mouth basis. However, when we structure the business model for them to pay back in kind, my position shifts in Sachs' direction. A possible criticism of how I am relying on the framework is that I am thinking at the 3,000-feet level, about a concrete problem, and not bothered with the 30,000-feet level questions of how to spend billions of dollars to fight poverty. I argue that thinking about a concrete problem is my strength and it is what makes it easier to show results with the little funding that I am entrusted with. I am not alone in this thinking. Abhijit Banerjee and Esther Duflo have advocated a similar position.[32] It is possible that some problems easily lend themselves to either the Sachs or Easterly approach and other problems fit somewhere in the middle. Transitioning solutions to invocations in the framework means moving from the left to the right. Therefore, in any given context, if any of the approaches advocated by either Sachs or Easterly is in a better position to move a solution or solutions from the left to the right, then it is the right approach. Therefore, at the 3,000-feet level the desired outcome wags the approach, whereas at the 30,000-feet level the converse is true.

The emergence of the student humanitarian engineer/scientist on college campuses in the US is being forged by science and engineering being recognized as innovative forces. This is especially true in development, and the convergence–where life sciences are meeting physical and computational sciences, and engineering, is giving rise to solution concepts to "grand" development problems. It is also well understood that turning these solutions into sustainable and scalable innovations in low-resource settings, is by itself one of the grand challenges of our time.[33] In response to this grand challenge, today's science/engineering majors are embracing creating solutions either through required classes (e.g., Design, Entrepreneurship, etc.) or through extracurricular activities (e.g., student clubs like Engineers without Borders). Students' goal-orientedness or thinking at the 3,000 feet level, their enthusiasm and fresh, out-of-the-box curiosity in approaching these problems are refreshing. This has been recognized by public and private agencies through funding programs that have been created to bolster student involvement. For example, the EPA runs an Annual Student Design Competition for Sustainability Focusing on People, Prosperity and the Planet, which is in its 18th season[34] at the time of writing. NIH runs the Team-Based Design in Biomedical Engineering Education program.[35] In 2012, USAID unveiled the Higher Educating Solutions Network.[36] At its inauguration, a high-ranking USAID administrator revealed that, as the USAID teams visited schools and met the humanitarian student engineers/scientists who were eager to make a difference in the world, "we saw the future and we were not in it." The National Collegiate Inventor and Innovators Alliance (recently rebranded as VentureWell) funds "Sustainable Vision" grants for "transformational education programs in which technologies are created to benefit people living in poverty and deployed in an