Rethinking the design paradigm for university technology projects in international development

by

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B.S. Biomedical Engineering
Georgia Institute of Technology, 2011

Submitted to the
Department of Mechanical Engineering
in Partial Fulfillment of the Requirements for the Degree of

Master of Science in Mechanical Engineering

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ABSTRACT

Since the appropriate technology movement of the 1970s, technology and engineering from developed countries have played a role in international development. In recent years, universities have created graduate-level programs that look to engage students to solve challenges faced by resource-constrained communities globally by leveraging technology and innovation. These projects must balance the need for graduate students to produce scholarly research and the objective of creating impactful interventions for the world’s poor and marginalized population. Furthermore, these projects must be conducted responsibly, remotely, and in fulfillment of project sponsors. This thesis explores two projects to better understand such engineering for development initiatives. The first project is a technology evaluation project that aimed to design and employ methodologies to determine which products in the “developing world” worked best. Specifically, the project’s first evaluation on solar lanterns used in Uganda is described. The second project is a technology development project that sought to develop a scalable electricity grid technology platform to provide universal electricity access in India. The two projects are documented as case studies and conceptualized as design processes, specifically product development processes. Through the lens of the structured product development process, selected aspects of the cases are further explained and secondary literature serves as a basis for suggesting alternative design decisions and actions. Although the successes and failures of the two cases are not assessed in this work, the analysis suggests that technology-focused graduate-level projects in international development may explore alternative approaches that more carefully consider (1) early-stage planning, (2) contextualization of the technology focus, (3) project timescales, and (4) the intent of community engagement. Further work is needed to document and analyze the processes of other projects in this space and to understand how they vary. The product development process may be a useful tool in understanding how these projects might systematically achieve both scholarly and international development impact through the use of design and engineering.

Thesis Supervisor: David R. Wallace
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Acknowledgements

I would like to thank Professor David Wallace for providing a home at MIT when I was looking for a fresh start. Thank you for the teachable moments in research and otherwise (but mainly otherwise), and a massive thank you for accommodating the blah-gistics involved in completing this work. Your commitment to doing things the right way will always resonate with me.

I would like to thank Professor Dan Frey for giving me my first crack at research at MIT. I still remind myself of your sound advice to be curiosity-driven and to tackle problems that are interesting—good work and learning will follow.

I would like to thank Professor Rajeev Ram for the opportunity to explore the space between technology and people. It took some time to find my fit on the project, but I hope I provided some value in influencing the direction of the project. I most valued our extended conversations both at MIT and abroad when you opened a window into your perspective on the great challenges and opportunities that come with trying to solve hard problems.

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Dla Mamy i Taty, wreszcie skończyłem szkołę, ale nie moją edukację. Mam jeszcze wiele do nauczenia od Was i od życia. Ścisłam mocno i kocham Was nad życie. Polska Potęga.


And to the countless friends, colleagues, and acquaintances made over the last two years and beyond—the conversations and experiences that we have shared are woven into my fabric. I hope we continue to cross paths, to share stories, and to discover this big world and humanity of ours.
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1. Introduction

_I should not talk so much about myself if there were anybody else whom I knew as well. Unfortunately, I am confined to this theme by the narrowness of my experience._

- Henry David Thoreau, *Walden*

Universities have been engaged in technology-centered projects intended to contribute to the development and quality of life of resource-constrained communities globally, and this is a very compelling form of contribution for many students. In addition to international service-learning models of pedagogy, universities have begun to develop graduate research programs for “developing world” projects with the aim of delivering innovation and subsequent impact to the international development space. This work documents two such graduate research projects, aims to understand them as design processes, and proposes alternative actions and methods that could have been employed to potentially improve outcomes.

This first chapter outlines the motivation for this work, describes related work, and clarifies the research gap to which this work looks to contribute. The second chapter examines the methodology used to create this work, delineating frameworks for case study analysis and design research. The third chapter describes the two projects to develop a holistic understanding of the cases. The fourth chapter conceptualizes the projects as design processes to serve as a vehicle for analysis and synthesis. The fifth chapter provides analysis of selected facets of the cases and explores alternatives with the support of secondary literature. The sixth and final chapter concludes this work by integrating the findings and recognizing future work.

1.1 Motivation

This work has been motivated by the author's experiences at the Massachusetts Institute of Technology (MIT) while completing the Master’s degree program in Mechanical Engineering.

When he began at MIT in June of 2013, the author's intent was to develop depth in design knowledge and skills and to apply these through a research project with a global context over the following two years. At the time the author anticipated this masters
thesis would be written to address a design question within a specific international development project and built upon two years of research.

However, the projects themselves fell short of expectations for academic research and also some of their stated objectives. This is not to say the projects were failures, only that there seemed to be an opportunity to improve the outcomes of the projects by improving the processes and methods used. In the end, time was divided working on one research project during the first year and on another during the second year, with a variety of proposed thesis topics between the two projects.

With these experiences, the recurring question arose: how might we better approach and execute engineering and design projects for the “developing world” within a university setting? Although international service-learning models in higher education have been well-documented, particularly within undergraduate curricula [1]–[3], the recent growth in graduate-level programs addressing poverty alleviation through technology and innovation present unique challenges and opportunities. These programs must balance traditional design and engineering for development objectives of creating impactful interventions for resource-constrained and, at times, marginalized communities with the need for researchers to produce and publish novel, scholarly work and the incentive to satisfy project sponsors. These programs must meet these objectives both responsibly and geographically remotely. As these programs grow, a lingering question is whether it is possible to solve real problems for real, vulnerable populations within an academic research context in which success is tied to completing a thesis and not to the development outcomes for those populations.

This work seeks to examine how university graduate programs and researchers currently conduct engineering and design for development projects through the lens of the design process in order to improve existing methods and to suggest new areas of consideration and inquiry for the development of these programs.

To examine current methods, two interdisciplinary graduate research projects at MIT are documented in this work. The first is a technology evaluation project that aims to develop rigorous methods to determine which development technologies were best, considering the scalability, the technical suitability, and the sustainable adoption of the technologies. The second is a technology development project that aims to create a novel hardware
and software system to provide an off-grid electrification solution to rural communities in India.

These two cases are selected not because they are representative of the entire spectrum of graduate-level design and engineering for development projects; they are selected because the author knows them best and is “confined to the narrowness of my experience” [4]. Although the selection of the cases presented is not rigorous, the two cases ultimately exist within the aforementioned spectrum and contain elements that may serve as direct representations of or as analogues to elements of other cases.

The selected cases are described and analyzed as design processes because the projects described ultimately are design projects, i.e. they are series of activities that develop a physical and/or virtual product from a need, idea or technology to the product’s realization, which meets the perceived needs of the user and of other stakeholders [5]. The process of design describes how to proceed with these activities in an efficient and effective way [5]. Whether designing a method of evaluation, an electrification technology, or a graduate research program, there is a body of design research literature that describes models and theories to understand design and support to improve design practice and outcomes. By mapping the selected cases onto structured design process, this works strives to provide a lens and a body of resources through which to better understand and support university technology projects in international development.

Finally, while this work is a specific reflection of the author's own experiences, it echoes a question of the broader space of design for development. In writing about the future of design for development, Krista Donaldson states “So is remote design appropriate? No, but as long as the demand [from engineers to practice remote design] continues to exist it is more productive to ask this: What improves the effectiveness of remote design for development projects?” [6]. This work does not attempt to determine the appropriateness of graduate research programs tackling poverty alleviation through technology-centered projects. This thesis is a humble attempt to shed light on how we might make these projects better.
1.2 Related work

This work draws on work in engineering for development and in design research.

Mattson and Wood [7] undertake an extensive review of engineering literature to develop nine principles for effective design for the “developing world”. The principles are related to traditional design principles, and the authors suggest that principles can help designers and engineers overcome the challenges presented by design for development, particularly the designer’s unfamiliarity with the context for which they design and the design constraint of affordability [7].

Margolin [8] describes the historical underpinnings of international development, tracing its start to the end of World War II and the Cold War ideology that elevated capitalism as the preferred economic system. He argues that the First World, Second World, and Third World structure resulting from this time influenced not only development practice but also design for development, and he calls for the better integration of factors such as trade, technology transfer, and cultural expansion to redefine the possibilities of design for development in a more global economy [8].

Mirroring Margolin’s history of design for development is Jesiek and Beddoes’ historical account of the internationalization of engineering education. Jesiek and Beddoes [1] identify diplomacy and development to be the key motivations for incorporating global elements into engineering education between the 1940s and 1970s. In the 1980s, international engineering education was justified as a means of increasing the economic competitiveness of the United States, and globalization served as the rationale for global engineering education initiatives from the mid-1990s onwards. Notably, diplomatic, development, and humanitarian drivers for internationalized education reappeared in the 1990s and 2000s. Jesiek and Beddoes conclude by noting that the number of engineer students studying or working abroad is rising at a lower rate than envisioned [1].

Nieusma and Riley [9] use a case study method to present two “engineering for development” initiatives and highlight the problematic assumptions made by these initiatives about the technology’s role in the development of communities. They call for incorporating social justice goals into engineering for development projects, taking careful consideration of power relations between individuals and institutions and of the
assumed economic models for the technology's implementation. Nieusma and Riley also highlight the potential for technology projects to maintain or extend social injustice [9].

Donaldson [6] suggests the field of design for development is growing in “well-intentioned but seemingly haphazard ways.” In questioning the goals and sustainability of design for development, Donaldson argues that design for development must focus on more than just the product and have a sustained impact on both product and environment in order to affect human development. Furthermore, she calls the dissemination and publication of lessons and failures of design for development projects, especially due to the vulnerability of target users [6].

Austin-Breneman [10] explores the challenge of managing trade-offs between varying stakeholder interests at a systems-level for the design of end-user products in emerging markets. He employs structured design process models as a starting point for understanding how different factors affect design process, and he explores the differences between how practitioners currently manage these trade-offs and how formal models suggest they should. Austin-Breneman then develops a methodology, Design for Micro-Enterprise, that focuses on the needs of the micro-entrepreneur as way of balancing end-user and supply chain needs [10].

In addition to the Design for Micro-Enterprise approach, the literature includes a number of proposed alternative approaches for design and engineering for development. Oosterklaken poses that the first principle for designing for the world’s poor should be human capabilities, which could be accepted more readily by designers than design for human rights or human dignity [11]. Nieusma draws on themes from of feminist design, universal design, participatory design, ecological design, and socially responsible design to synthesize a model for appropriate design that addresses how social power operates within design [12]. Pease et al. propose applying market-centered design and lean startup methodologies in an iterative process to develop products for the “developing world” that are economically viable, impact customer positively and have the potential to grow in the market [13]. Moseson et al. propose a theory of Technology Seeding whereby the dissemination of adaptable technology ideas is the deliverable, not the finished product [14].
1.3 Research clarification

The literature outlines a history of technology for development and of the internationalization of engineering education and indicates a growing design and engineering for development space, albeit an unsystematic growth. Furthermore, a number of approaches for design for development have been proposed. This thesis, however, does not look to prescribe another approach. Instead, this thesis describes technology for development projects, specifically those within graduate research programs, and employs a structured design process model to better understand how these projects are being completed.

This thesis seeks to answer the following questions:

- How are graduate research teams currently undertaking technology-focused projects intended to improve the quality of lives of resource-constrained communities?
- How does the existing sequence of steps and actions taken by project teams compare with a structured design process?
- Which factors specific to technology for development projects at a graduate level influence the project’s process and outcomes?

In reference to the Design Research Methodology (DRM) proposed by Blessing and Chakrabarti [5], this thesis partially fulfills the Descriptive Study I stage of design research, which seeks to increase the understanding of design through reviewing literature for empirical research, conducting empirical research, and reasoning. Although the information used throughout this thesis falls short of the empirical standard held by the DRM, this work aims to contribute to the same objectives of describing the current situation for university-based technology projects in international development, identifying problems in the existing scenario, delineating an argument for how factors affect design success, and exploring how the findings might influence the development of a design support to improve design outcomes [5]. This thesis does not attempt to develop or assess tools for improving the design outcomes of technology for development projects in an academic setting.
2. Approach

The approach for this work draws from frameworks utilized in design and in case study analysis. A case study method provides the architecture for understanding, synthesizing and explaining the two graduate-research projects that are the focus of this work. A structured design process is referenced to serve as a model to which the case studies are mapped to allow for further analysis.

It should be noted that documentation of the two projects did not occur over the course of the projects with the intent of developing a case study analysis. The data used for this work comes from compiling personal observations as an embedded researcher with archived documents and communications.

2.1 Case study methods

In developing the two cases for this work, the frameworks provided by Scholz and Tietje are used [15]. Scholz and Tietje propose case studies should be structured in a three-level architecture: (1) understanding, (2) conceptualizing, and (3) explaining. The first level, understanding, is the case itself, and researchers must develop an empathetic and holistic comprehension of the case. By focusing on the case and not on general questions related to it, the study can reduce the complexity of analysis from general problems to a singular set of circumstances. Conceptualizing, the second level, involves a conceptual model of the real world. On this level, knowledge integration and synthesis build a more valid case understanding. The third level, explaining, consists of data and results from different segments of the case. In most studies, only particular fragments of a case are investigated, and the data, whether from the case or from the existing body of knowledge, must be organized into subprojects in a way that satisfies the second, synthesis level [15].

In this work, the first level of understanding takes the form of the two selected research projects as cases. The second, synthesis level conceptualizes the cases as product design processes, providing a model of the real world and a vehicle for integrating knowledge from a variety of sources. The third level of explaining draws on data both from the existing literature of design research and from the selected cases in the form of direct observation, participant observation, and archival records. The subprojects
investigated are intuitively selected from the research experiences as opportunities for exploring alternative and improved methods within the scope of this work—graduate research projects in design and engineering for development. The subprojects are organized to fit the system model of the design process used for synthesis in this work.

In describing and analyzing these cases, this work considers a variety of knowledge types and of aspects of design. As Scholz and Tietje note, casework integrates different knowledge systems by linking knowledge from different disciplines, synthesizing subsystems within a case, mediating different interests groups, and accommodating both analytical and intuitive modes of thought [15]. Furthermore, this work recognizes design to have multiple facets (people, processes, knowledge, methods, tools) within an organizational and economic context [5].

2.2 Design process

There are a number of design processes described in the literature, with the generic product development process described in Ulrich and Eppinger’s seminal work [16] being used as the basis for conceptualizing the cases. Although only one of the two cases matches Ulrich and Eppinger’s focus on engineered, discrete, and physical products, the product development process described in their work suffices as a basic framework for considered the described cases. More detailed and differentiated discussion of generic product development process occurs in chapters 4 and 5 of this work.
3. Case studies

The descriptions of the two cases are intended to provide a holistic understanding of the two research projects before further analysis is conducted. The case studies are process-oriented and include discussions and decisions that transpired through the course of the projects. Additional detail is given to the organizational context within which the projects existed. The first case, the Comprehensive Initiative for Technology Evaluation, is the evaluation project in which the author participated during his first year at MIT. The second case, uLink, is the rural electrification technology project in which the author participated during his second year at MIT.

3.1 Comprehensive Initiative for Technology Evaluation (CITE)

In November of 2012, the United States Agency for International Development (USAID) announced the Higher Education Solutions Network (HESN), a network of eight Development Labs housed in seven universities with the intent “to solve some of the world’s most pressing [international] development challenges” [17]. To do so, the HESN created a collaborative and multidisciplinary network between academia and international development professionals, drawing on the talent at leading universities to lead research and development efforts to directly redefine problems, identify solutions, and strengthen real-world innovations in international development. The HESN represented a five-year program with $137 million of funding from USAID and nearly matching investments from the host institutions. After the five-year funding period, the Development Labs were encouraged to explore sustainable avenues for continuing their innovative work.

3.1.1 Group Organization

The Comprehensive Initiative for Technology Evaluation (CITE) is one of the eight Development Labs of the HESN. CITE was created to develop methods to evaluate “what works” within a group of competing technologies intended to benefit the developing world. The underlying premise is that there are plenty of products designed to improve the quality of lives of impoverished communities but there are few resources that state which products work best and why. In its funding proposal, CITE’s stated goal is to perform pre-and-post deployment product evaluation and to make the evaluation
findings available to development donors and practitioners and technology innovators so that they may make more informed decisions. The opportunity for developing technology evaluations to be used by international organizations was validated at the time of CITE’s proposal in early discussions with a growing network of partner organizations such as Oxfam America¹ and Mercy Corps².

From the start, CITE program took a multidisciplinary approach in both its organization and its proposed evaluation framework. The founding organization included MIT’s D-Lab (Development through Dialogue, Design and Dissemination), Department of Urban Studies and Planning, Strategic Engineering Research Group, and Center for Transportation and Logistics, spanning expertise from supply chains and systems engineering to ethnography and technology design. With this core group, CITE proposed evaluating technology solutions along three axes: suitability, sustainability, and scalability. The suitability dimension explored the technical performance of the products in meeting the needs and use cases of end users. The scalability dimension captured the ability of the product to both reach end users and to scale in its distribution footprint. The sustainability dimension addressed the sustainable adoption of the products, given particular socioeconomic and cultural contexts. Together, these three dimensions represented the basis for the “3S” evaluation framework and for the “Technology Evaluation Reports” that were the primary deliverable of the CITE program. Additionally, the 3S framework characterized CITE’s organizational structure as a team was formed for each “S” dimension. Although there were three evaluation components and corresponding teams, it was stated that the suitability analysis would serve as the basis for the subsequent scalability and sustainability evaluation.

The Technology Evaluation Reports were proposed as documents that contained a 3S score, analysis and recommendations that would allow development professionals to easily make informed decisions about technology solutions for specific contexts. The information could be used to focus research and development efforts on better understood design problems and to improve the ratio of value generated per dollar invested in technology for development interventions. The proposal stated that CITE

¹ Oxfam America: http://www.oxfamamerica.org/
² Mercy Corps: http://www.mercycorps.org/
would be to the development community what *Consumer Reports*\(^3\) is to consumers—a trusted and centralized source of information on the analysis and evaluation of products.

Within the first year of the program, CITE proposed to deliver five product evaluations and subsequent Technology Evaluation Reports. In addition to delivering the evaluations and reports, CITE stated additional goals of developing an online Product Evaluation Pipeline that would pool potential targets of CITE's future evaluations, of producing a movement of future development professionals engaged in evaluation, and of creating regional hubs in the developing world to conduct product evaluations for those markets. To complete these goals, the CITE program received funding for $2 million per year for five years.

### 3.1.2 Project Scope

In the June of 2013, CITE embarked on its maiden technology evaluation. This first evaluation was meant to serve as a "prototype" evaluation—CITE recognized that multiple iterations of evaluations would be needed before an outstanding methodology was developed. Believing that much could be learned by doing and wanting to take advantage of the summer months for field work abroad, the CITE team elected to move quickly and attempt a full 3S evaluation of solar lanterns in Uganda.

A solar lantern is a consumer lighting device that consists of one or multiple light-emitting diodes (LEDs), a solar panel, and a battery. The solar panel charges the battery during sunlight hours, and then the battery is discharged via the LEDs to provide lighting. Solar lanterns are designed to provide lighting for users that have no or unreliable access to electricity and are often marketed as replacements to kerosene lamps. Some models of solar lanterns also allow users to charge their cellphones.

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\(^3\) *Consumer Reports* is a monthly magazine published by the *Consumers Union* that reviews and compares consumer products and services. Through in-house laboratory testing, surveys, and strict independence from advertising and manufacturers, *Consumer Reports* works for a fair and safe marketplace for consumers. It has over 7.3 million subscribers and tests approximately 100 products every year [32].
The selection of solar lanterns was strategic. When considered as a product family, solar lanterns are relatively simple and a well-defined technology group (compared to water filtration products, for example, where there are a number of technologies or combinations of technologies used depending on a number of factors including the quality of source water). The simplicity of the product family was important to the team given the short summer timeline to complete the evaluation. Furthermore, previous members of the team had experience testing solar lanterns, and solar lanterns were a product family that conceivably would have been evaluated regardless over the course of the five-year program. Finally, the CITE team believed they would be able to benchmark its prototype evaluation against an existing international quality assurance standards developed by Lighting Global, the World Bank Group’s platform for catalyzing the international off-grid lighting market.

Figure 1: Solar lantern models that are sold by the Solar Sister organization in Uganda and that were evaluated in the CITE study. Photo taken by Victor Lesniewski.

The decision to focus on the Ugandan context was due in large part to the network of partners available through the larger USAID network. One of the winners of the USAID
Development Innovation Ventures competition was Solar Sister⁴, an organization with a mission of eradicating energy poverty by empowering and mobilizing a direct-sales network of women entrepreneurs in Uganda, Tanzania, and Nigeria. The founder of the organization was conveniently based out of Providence, Rhode Island. USAID was interested to see if the 3S evaluation findings could help accelerate and scale Solar Sister’s model and operations.

3.1.3 Project Design and Development

The remainder of this thesis focuses on the efforts of the Suitability team of the CITE project. The Suitability team was comprised of one project manager, one faculty member, three graduate students, and one technical advisor. The project manager had experience leading a technology evaluation program within D-Lab and had a background in engineering and social enterprise. The Suitability project manager also served as associate director of the CITE program and made day-to-day decisions when the principal investigator was on academic sabbatical. The faculty member had expertise in design of experiments and had former students who undertook design for development projects. The three graduate students were master’s students in mechanical engineering. One student, who had worked on solar lantern evaluation in Ghana, was completing his master’s degree that summer. One student was mid-way through the masters program, and the author had just begun the master’s program. Additionally, the Suitability team retained a technical advisor who had led the technical testing of consumer products at Consumer Reports.

The Suitability team had the challenge of measuring the technical performance of the solar lanterns in a way that was relevant to both authentic use cases and the needs of the end users. The assumption was that local factors, whether environment- or user-driven, could affect product performance. As a result, plans were made to conduct fieldwork in Uganda for the month of July to begin to understand solar lantern users and to observe how lanterns were being used. In parallel, laboratory testing would be conducted at MIT to measuring various performance parameters. The determination of

which parameters to test would depend on the team’s growing understanding of use cases, and the set of tested parameters would change with findings in the field.

How the testing methodology would be designed—and what form the methods would take—was a subject of discussion. Factors considered in the ongoing discussion included:

- **audience**—who is target user of the evaluation findings: NGOs and funding agencies so that they can make smarter procurement decisions, innovators and designers so that they can create better products, or consumers of the evaluated products so that they can make informed purchases?

- **value-add**—how can we add value to the technology evaluation space given the state of the art and the needs of development organizations and resource-constrained communities?

- **information creation or curation**—should CITE generate new methods to generate new data about products or should CITE curate existing methods and data to uncover new insights about the technologies?

- **expertise**—what expertise do we have or have access to that we can leverage for product evaluations?

- **organizational scale**—how do we develop a methodology that can be scaled with an increasing number of product evaluations, but not with an increase in resources?

- **external validity**—how could a methodology produce findings that were valid for the specified local context and could be applied to other regions of interest?

- **research**—what are interesting research questions in the fields of product evaluation and design of experiments that could incorporated into the methodology design and could serve as the basis of master’s theses over one to two year periods?

- **future evaluations**—what elements of the “prototype” methodology could serve as a foundation for future evaluations of different product families?

- **deliverable**—what is the final product that we are delivering to our audience and our sponsors and what type of information is needed for them to make their decisions?

Even though some of these questions were addressed by the initial funding proposal, there were at times flexibility and uncertainty about how these factors would be addressed in the design of the methodology. Possible directions for consideration in the methodology design included developing methodologies that:
• reduced the cost of testing based on the value that low-cost products should reasonably be evaluated with low-cost methods;

• followed Consumer Reports procedures in a laboratory setting, relying on specialists to test products according to existing standards and subjective benchmarks and to give weights to tested parameters to compile an overall score for the product;

• simplified procedures such that the evaluation methodology could be readily replicated by development professionals in their local context and replicated when new models entered the market; or

• improved or supplemented the international testing standards in cooperation with Lighting Global in order to build on the existing state of the art.

The Consumer Reports model of evaluation grew as the predominant model for evaluation as the summer progressed, in large part due to the team’s technical advisor’s experience with Consumer Reports. Laboratory equipment was purchased, and the idea of low-cost testing for low-cost products faded under the premise that product evaluation is expensive, particularly when one considers that the Consumer Reports has yearly operating expenses of around $250 million for its activities and employs approximately 600 staff [18].

Some elements of reduced-cost methods were incorporated into protocols with adaptive testing. For example, in the water resistance testing, if a solar lantern passed the most extreme case of water submersion, it could be assumed the lantern would pass tests for lower levels of water resistance, saving on testing time and wasted product samples.

Working within the Lighting Global framework was deemed unsatisfactory; the CITE program was attempting to differentiate itself from the established standard. Lighting Global had manufacturers pay a small fee to cover the costs of the testing, which could be considered less than the full independence that typically would be needed to be a trusted evaluation source. Furthermore, Lighting Global did not publish full testing results at the time the CITE evaluation started.

Selected Lighting Global standards were used to benchmark performance for some of the technical testing developed by CITE. Certain Lighting Global protocols, especially those that provided binary pass-fail results, were reworked to provide richer information. Other standards and literature, such as the Illuminating Engineering Society’s The Lighting Handbook were used for benchmarks and guidelines.
Experts were engaged to contribute insights that could help shape the design of the suitability assessment methodology. An ophthalmology professor was consulted to elucidate the role of lighting in vision, to clarify the lighting levels that were clinically acceptable and to measure the profiles of the light emitted from the different solar lanterns. Another expert was brought in through the Consumer Reports network to advise the team on sensory panels, a method of testing in which trained individuals (sometimes consumers) serve as the instruments to gather information about product preferences, characteristics, and differences [19]. In considering this technique, the team explored the possibility of training individuals at MIT to replicate user tasks observed in Uganda in order to perform in-depth sensory and usability testing. The concept of sensory panels were eventually dropped from the testing regime given the complexity of developing and validating such a method for the solar lantern use case.

In addition to conducting performance tests on solar lantern attributes, the Suitability team considered additional features that some lantern models had and others didn’t. One team member used a few of the lantern models at home (similar to Consumer Reports specialists who experience the products as consumers experience them), and consequently suggested including the ability to charge an iPhone as a feature of solar lantern evaluation. This feature did not make the final evaluation, but other features, such as the lantern’s ability to charge from an alternating current wall outlet in the event of a cloudy day, were included in the final evaluation.

As these performance testing decisions were being made over the course of the month of June 2013, the Suitability team was also planning its trip to Uganda to better understand who was using solar lanterns and how. Relying on one student’s past work in evaluating solar lantern use in Ghana, a framework was developed for collecting qualitative data about solar lantern use through user interviews. In addition to understanding how solar lanterns fit into the daily lives of users, the Suitability team wanted to begin to answer questions that would apply more generally to CITE product evaluations. For example,

- Could quantitative instrumentation in the field supplement qualitative methods to better understand product usage and could it be more resource-effective than traveling and conducting qualitative studies for each evaluation?
Did use cases and preferences change with geographical region?

Could valuable information be captured by performing technical tests in the field on the actual products owned and used by consumers in context?

Through which communication channels did user receive information about the product and could those channels be used to deliver information about evaluation results?

The team decided to use both established interview methods and exploratory instrumentation methods to capture solar lantern usage. Over the three weeks leading up to the trip, the three graduate students on the Suitability team developed an instrumentation board that could fit inside two solar lantern models sold by Solar Sister. The boards would be able to record the length of time lanterns were being used or charged, which light setting was being used, and how the lantern was being positioned (vertical, horizontal, or at an angle). This recorded information could be compared with the usage that study participants reported. The team decided that the instrumentation should be disclosed to the study participants in asking for consent, because the value of the information collected did not justify the ethical concerns of covertly recording usage information.

Two of the graduate students from the team, including this author, spent four weeks in Uganda in July 2013 working with Solar Sister to connect with the organization's end customers. Much of the groundwork to build a relationship with Solar Sister and plan trip logistics had been undertaken by the Sustainability team, who was also in country at the same time, but with the objective of understanding Solar Sister's business model. The Suitability students worked with regional coordinator staff to reach entrepreneurs within Solar Sister's network. These entrepreneurs then introduced the two students to solar lantern customers primarily in rural areas of Uganda. The two students asked for consent to participate in the study and performed two sets of interviews with each of the solar lantern users with the aid of an independent translator. None of the 40 Solar Sister customers that were approached declined to consent to participate in a study that recorded their solar lantern usage through instrumentation.

The first interview sought information about a typical day in the life of the user, the user's purchase decision, basic lighting usage, and the user's relative preference for different lantern characteristics. The user's solar lantern was then exchanged for an instrumented
solar lantern of the same model. The two graduate students then returned one and a half
to two weeks later to complete the second interview, which sought information from the
user about how they used the instrumented solar lantern in the past week. The
instrumented lantern was then collected and study participants were given an option of
receiving their original purchased lantern or a brand new lantern of the same model as
compensation for their time for participating. All but one study participant chose to
receive a new lantern. The participants’ original lanterns were brought back to MIT, but
further testing on them was not conducted as this information was a lower priority than
the results of the comparative Consumer Reports testing. The interviews and
instrumentation were completed with 40 study participants in two regions of Uganda.5

Figure 2: Photographs of solar lanterns in use during community visits by the CITE suitability
team in rural Uganda (July 2013). Left: The red solar lantern is placed in a cardboard box while
charging and will be covered by the box flap such that only the solar cell is exposed to prevent
theft. Right: The blue solar lantern is attached to the corrugated tin roof of a home to increase
illumination of the home. Photos taken by Victor Lesniewski.

As fieldwork proceeded in Uganda, the two graduate students communicated early
observations with the team at MIT to help focus which solar lantern models and which
parameters to test. Common use cases, such as cellphone charging, and lantern models
found in the local markets were reported, and the laboratory testing at MIT adjusted
accordingly.

5 For information about the instrumentation, field work, and results please see Gandhi (2014) [33].
During the trip to Uganda, it was suggested that the two graduate students take photographs of children with the solar lanterns for the purposes of public relations. Additionally, there was some team discussion about highlighting special solar lantern use cases, such as midwifery and fishing, and evaluating models for these use cases because it would make for a good sidebar story in the evaluation report. These actions were not undertaken, but were discussed when considering the final product to deliver.

The first evaluation was communicated initially as an internal "prototype" evaluation during which the team could build capacity through trying and learning from a variety of methods. As testing proceeded, however, the first evaluation was communicated as a production run with the expectation that the findings would be definitive and would be published for the sponsor and a wider audience. This led to decisions that reworked portions of the testing to increase rigor of the results.

The final Suitability methodology leveraged the fieldwork conducted in Uganda to inform which attributes to test, how to test some of these attributes, and which test results were deemed more important in evaluating the suitability of the solar lanterns. The evaluation findings were documented in a Technology Evaluation Report and the deliverable took the form of a Consumer Reports comparative rating chart. Solar lantern models were given an overall score indicating overall technical performance. The score was determined by selecting a weighting (based on observations in Uganda) for each performance parameter tested, and the weightings were kept confidential because Consumer Reports keeps their weightings confidential to deter manufacturers from gaming the system.6

Over the course of the evaluation, graduate students were asked to postpone concerns about their academic research until after the first evaluation. While the Consumer Reports methodology satisfied the need to produce an evaluation report, conducting the evaluation did not align with student research expectations for exploring methodology design. The priority was to finish an iteration of evaluation and deliver a product before establishing a research direction for students that fit within the CITE program. Initially,

6 More information regarding the final evaluation methodology and the results can be found by reading “Experimentation in Product Evaluation: The Case of Solar Lanterns in Uganda, Africa” [20]
the report was to be completed in September 2013. That deadline was pushed back to the end of 2013 as work continued.

The Sustainability and Scalability teams conducted concurrent evaluations on solar lanterns, but with the Solar Sister organization and the original equipment manufacturers as the respective unit of analysis, not the product itself. The solar lantern evaluation report was published in January 2015.
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<thead>
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<th>overall score</th>
<th>cost (USD)</th>
<th>type (handheld/desktop)</th>
<th>runtime on high setting</th>
<th>charge time</th>
<th>brightness</th>
<th>task lighting</th>
<th>ambient lighting</th>
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<th>water resistance</th>
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</table>

**features**

- **battery charge indicator**: Device notifies user that the battery is receiving a charge.
- **end of charge indicator**: Device notifies user that the battery has completed charging.
- **device charges from ac**: Device not only charges from the sun but also from AC power.
- **mobile phone charger**: Device includes the ability to charge mobile phones.

**legend**

- OUTSTANDING
- VERY GOOD
- AVERAGE
- MARGINAL
- POOR

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Figure 3: Representative section of the comparative rating chart from the CITE solar lantern evaluation report published in January 2015 [20]. Report layout follows that of *Consumer Reports* featuring an overall score and product cost for each make/model, Harvey Ball representation of product attributes, and visual representations of features.
3.2 uLink

3.2.1 Group Organization

In 2012, the MIT Tata Center for Technology + Design\(^7\) was founded with an investment from the Sir Dorabji Tata Trust\(^8\). The mission of the Tata Center is to apply expertise in technology and management to develop solutions for resource-constrained communities in India and the developing world. The Center has both a research and education focus, engaging graduate students as Tata Fellows in hands-on projects that require both technical knowledge and an understanding of the social, political and economic context. The goal is to produce "shovel-ready" solutions that are ready to be implemented in India and to develop a cohort of engineers and entrepreneurs that will go on to solve global challenges with a focus on performance, practicality, and affordability. In 2014, a sister center at the Indian Institute of Technology in Bombay, India was created to engage Indian graduate students in similar activities.

Tata Fellows are primarily master's students who taken on a two-year fellowship in one of six thematic areas: agriculture, environment, energy, health, urbanization, and water. Fellows are expected to have their research and theses align with their fellowship work, which includes a requirement to spend at least six weeks over the summer and two weeks in January in India each year to work on problem-framing, stakeholder engagement, and design activities. Fellows are expected to work closely with partner organizations in India throughout the two years to ensure that the solution being developed is socially relevant, appropriate and effective.

3.2.2 Project Scope

In the spring of 2013, the Tata Center funded a project proposal that called for developing an electricity grid architecture that would provide universal access, targeting the 400 million Indians without an electricity grid connection. The project would bring together professors from engineering systems, computer science, and electrical engineering to develop a technology platform that would mirror the rapid scalability of

\(^7\) MIT Tata Center for Technology + Design: http://tatacenter.mit.edu/
\(^8\) Sir Dorabji Tata Trust: http://www.dorabjitatatrust.org/
mobile phone networks witnessed in the developing world. In order to enable and support incremental yet rapid scale, the proposal called for the platform to have a flexible and modular infrastructure, to support profit-driven business, and a pay-as-you-go model. The proposed electricity grid architecture imagined an ad-hoc network of electricity generation that could grow with growing demand and would support consumers as “prosumers”, allowing users to engage in peer-to-peer sales of excess electricity with their neighbors.

The proposal set forth four tasks to be completed: (1) developing a distributed and market-based approach to risk allocation within the electricity network to optimize the scheduling of electricity for different loads; (2) creating a power management unit at the point of electricity connection that would allow for flexible electricity demand from the user and for a modular architecture for the system; (3) assessing use cases and system specifications by exploring policy, financing, and market strategies for universal access at a national level in India; and (4) modeling all layers of the proposed system, from the power electronic components to the grid’s architecture to services provided.

The tasks built on the competencies and previous work of the research laboratories involved. The proposal outlined specific technology strategies and methods for achieving required performance and benchmarked the cost of the system based on the current cost of mass-manufactured power electronics available in India. The project’s proposed scale was 5 Tata Fellows.

Although the proposal was submitted as one large electrification team, in practice the proposed project split into two teams: an electrification planning team that assessed the market, policy, and financial environment for off-grid electrification in the Indian context and an electrification technology team that developed the power management hardware and software controls for the proposed technology platform. Over the first year, the two teams travelled together to India, meeting with a variety of stakeholders in the electricity access space from government officials to off-grid entrepreneurs providing solar home systems and community-level “micro-grids” and visiting a number of communities to understand contexts where there is either no electricity access or, in some cases, unreliable grid access. Despite the shared travel, the two teams did not regularly share their work and findings during the term at MIT.
The team developing the technology platform, later to be named uLink, was headed by a professor of electrical engineering and included a postdoctoral fellow who had received her doctoral degree with the professor, an electrical engineering doctoral student and a doctoral student in computer science. The electrical engineering student was tasked with developing the power management unit and the computer science student would develop the control and scheduling algorithms for the platform. In January of 2014, an additional Master’s student in computer science joined the team to work on network communication and security for the smart electricity platform. None of the three graduate students on the project worked directly for the principal investigator (PI) on the project—their advisors were co-principal investigators on the project and not as involved in the project’s development.

3.2.3 Project Design and Development

During the first year of the project, the principal investigator on the uLink team worked with the graduate students to better define their roles on the project in terms of technology development goals. The PI recognized that project goals and individual research goals would not spontaneously lead to the desired overall outcome, and attempted to align groups so that development decisions could be made in the students’ and the project’s best interests.

The two original doctoral graduate students on the project not only pushed the development of the technology but also explored the market for project, in part due to their entrepreneurial interests. They entered a business plan competition as an exercise to form a business case, value proposition, and service model for the technology. Based on the insights from their initial trips to India and on a demographic data set of customers of one solar home system provider, the two students pitched a vision for uLink in which anyone could access the uLink electricity network for the $15 cost of a power management unit. Because of the flexible and modular power electronics, the unit would be plug-and-play for the user, decreasing the planning barrier that is required for most existing community-level micro-grids. The electricity generation for the system would come from relatively wealthier, but still poor, members of the unelectrified village who could invest in a solar home system or another generation source. These generating “prosumers” would sell their excess electricity to poorer neighbors who could
afford the power management unit but not financing the larger solar home system asset. The prosumers would be able to pay back their investment faster as their neighbors purchased electricity on a pay-as-you-go basis using transactions through a mobile phone platform. The assumption that village members would be willing to pay up to $2 a month for electricity serviced was benchmarked from existing micro-grid consumers who paid $2 a month for reliable lighting and cellphone charging for 4-6 hours a day. The uLink system would be able to provide better and more flexible service through its software algorithms, and the uLink grid would scale easily with demand as consumers could pay for more reliable service and add to their power management unit modularly. Furthermore, there was an incentive for prosumers to invest in adding generation to the uLink network.

![Diagram showing the four proposed uses of the uLink system: enables energy access, enables energy sharing, enables an energy marketplace, and enables grid investment.]

Figure 4: Proposed use case for the uLink as an architecture for universal electricity access. Due to the modularity and flexibility of the platform, the uLink system has great scalability via peer-to-peer electricity distribution. *Graphic created by Wardah Inam and Daniel Strawser.*

The PI felt that the primary risk for the project was technological—whether the algorithms developed could provide the needed stability for the system. The two secondary risks he identified, however, were business model risk (whether the technology could be sustainably implemented and reach the intended users) and user adoption risk (whether users would understand the technology, learn how to interact with it, and eventually accept it).
In the June of 2014, the author joined the uLink project, one year into its inception, with the goal of developing the interface between the technology and the users. The objective of the author’s role was to understand the two-way communication between the user and the uLink system and to develop an interface to support these interactions. The more information about a user’s electricity consumption behavior the uLink system had, the better it could provide electricity service to users through the system’s smart distribution algorithms. Furthermore, the system would need to convey information that allowed users to understand and be satisfied with the service received.

In an ideal scenario for system, the user would provide the system perfect information in advance, inputting the time, duration, and type of each electricity-consuming activity so that the system could accurately predict consumption and dispatch electricity accordingly. It was assumed an ideal scenario for the user would require little or no input. The actual scenario would most probably lie somewhere in the spectrum between these two extremes, the system’s ideal and the user’s ideal. The uLink system would also provide opportunities for tiered electricity service and for demand response. For tiered service, users would be able to request and pay more for more reliable levels of service. For demand response, financial incentives would be provided by the system for users to shift or reduce their electricity consumption activities during the periods when there is greatest demand for electricity in the network. All of these technological opportunities and functions would require a determination of the content, frequency, timing, and type of interaction for each event.

Over the summer of 2014, the uLink team aimed to prototype the first power management units and connect them in a demonstration network by the end of the summer. The hardware, software, and system architecture had been outlined previously based on perceived user and technology system needs and research goals for the students, but the hardware and software development had occurred independently to this point. The PI established an aggressive summer timeline to stimulate progress, but he did not expect that the team would fully achieve the stated goal. Some version of prototype was expected by the end of the summer so that the team could better communicate the uLink concept and the technology’s development progress to project sponsors and partner organizations. Furthermore, the prototype could be taken to off-grid communities to test the uLink concept with potential end users.
The electrical engineering student was not available during the summer due to an internship, so the author and the postdoc were asked to prototype the hardware using off-the-shelf components and then work with the computer science students to establish some basic communication between prototype power management units. For the author, it was suggested the hardware prototyping would be an opportunity to understand the technology system inside-out, which would lead to a better interface design.

Also scheduled for the summer was a return trip to India. The goal of this trip would be to meet with the project sponsors and potential partner organizations and to secure a commitment to pilot the technology from one of the potential partner organizations. The author additionally planned to use the trip to conduct an ethnographic study and storyboarding with potential stakeholders in the proposed uLink micro-grid system.
Because the uLink team’s understanding of local stakeholders had relied primarily on discussions during meetings with organizations working in the off-grid electrification space, the author proposed spending time observing and informal interviewing potential stakeholders to explore their perspectives, needs, and existing behaviors. Based on initial observations, storyboards could be used to communicate early interface concepts to and get feedback from stakeholders. The findings would allow for the development of user personas that could drive design decisions after the trip when the team returned to MIT. There was some discussion within the team regarding whether interface questions could be answered by community members through low-fidelity representations such as storyboards or whether a functioning prototype unit was needed to relay the types of interactions a user would experience.

Just before the trip, separate works-like and looks-like prototypes of the power management unit were completed. The works-like prototype was a single power management unit, so the uLink network concept could be demonstrated—the basic functionality of the product a single end user would purchase could be conveyed. The looks-like prototype was taken for the trip, and used as a communication tool to translate the uLink concept into a physical embodiment. Minimal interface feedback was gleaned from the looks-like prototype in India.

In attempting to secure a partner organization and location for future pilot, arrangements for visiting target communities were made with both the Tata Trust and a foundation associated with a solar home system provider. The hope of the author was that these visits could be extended to conduct the proposed ethnographic study. In practice, despite the accommodations of both organizations, the trip was similar to previous trips—half-day community visits to locations where the organizations had work to conduct. While these visits were informative and provided references in considering how to conduct a future pilot, in-depth personas of potential uLink stakeholders could not be completed given the structure of the visits.

Following the August trip to India, the conversation about a future pilot continued with the foundation of the solar home system provider. The uLink team wanted to pilot the technology during the month of January 2015, the next time there was a break in the university calendar. Some of the motivations for conducting a pilot included:
• collecting data on how rural Indians used the pilot system in order to build an activity-based algorithm for electricity scheduling and dispatch;
• identifying failure modes by having a system in actual operating conditions;
• validating the electricity sharing model, in which a user would sell their excess electricity to a neighbor;
• exploring plausible business models for the uLink system;
• observing how people react to intermittent power and whether they express a willingness to pay for more reliable power; and
• motivating the team by having the technology on the ground.

The uLink team requested that the solar home system foundation identify a suitable community with which to pilot and to assist in collecting preliminary information about the community, such as demographics, expected electricity demand, and willingness to pay for an electricity service. With the information about a specific community, the uLink team would then tailor the pilot system to the perceived needs of the community. On the other hand, the foundation requested specifications of the system and a proposal for the pilot in order to tailor the community selection to the needs of the project. The foundation had some concerns about whether the uLink system could be implemented sustainably for the long term. As discussions continued, it became clear that there was a miscommunication; while the uLink team treated the pilot as a trial for experimentation, the foundation considered pilots to involve leaving a tested technology in a community long-term and evaluating the technology over several months to determine whether it should go to market or be developed further.

When the uLink team sent a pilot proposal to the foundation to install a prototype uLink system in several un-electrified households for two weeks in January and then to remove the technology, the foundation rejected the proposal, stating that a "return to darkness" scenario for the community, in which the electricity access would be taken away after two weeks, was unacceptable and that a longer term commitment with the target community should be expressed. The foundation suggested using the January window to understand the case for sharing power in more detail before proposing and piloting a technology solution. The foundation emphasized building a relationship with the community, understanding the value-add or service that would have to be included with the technology for it to be adopted by users, and building the case for uLink on real data.
In the few weeks the uLink team could travel, the foundation proposed logging data on a number of different systems within and around their customer base in addition to conducting a full needs assessment on the ground.

At the beginning of November 2014, the uLink team decided to move forward with its proposed pilot, but not with the foundation as a partner organization. Because of a connection with an MIT Energy Initiative electrification project that was being conducted there, Rwanda became the target location for a January 2015 pilot. Even though the plan after January was to continue to focus on India, the uLink team believed the data it could collect on usage profiles and electricity sharing in Rwanda would be relevant moving forward. Furthermore, some members of the team felt they had worked too hard over the course of the research project not to see the technology on the ground.

Two weeks later, the location of pilot changed back to India, but with another partner organization originating from the project sponsor’s network. The new partner organization was the corporate-social responsibility (CSR) branch of an Indian steel company. The CSR organization had worked in the communities in districts surrounding its steel plants for almost forty years, but the organization was not familiar with energy projects besides its solar streetlight campaign and had operated in a model where services and infrastructure were provided to communities at no cost. They were excited to have an MIT team pilot in the communities where the CSR team worked, and agreed to host the uLink team for the month of January and identify a target community for the two-week trial.

Ethical concerns for the pilot design were raised within the team as the plans included “return to darkness” scenario that the previous partner organization had rejected. An alternative was proposed to conduct the trial with a community of a similar socioeconomic standing that had a grid connection—the two-week pilot would not dramatically disrupt the participants’ daily lives. Perhaps feedback from participants who already received unreliable electricity service could be richer than a two-week first impression of electricity and could serve as a more critical benchmark for uLink system performance. Some members of the team insisted that the pilot had to occur in un-

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9 CSR at Tata Steel: http://www.tatasteel.com/corporate-citizenship/community.asp
electrified communities because they would be the eventual customers of the uLink system.

When the CSR department identified a target community for the pilot, it was an un-electrified village of over one hundred households. Considering the pilot design called for only five to ten household to participate, another question arose: which households would be recruited to participate and how? The majority of the uLink team trusted the CSR department to work with the community to determine which households would participate or resort to a lottery. Moreover, the majority of team did not have ethical concerns with a “return to darkness” pilot so long as participants knew the uLink system and electricity were to be taken away after two weeks. MIT’s Committee on the Use of Humans as Experimental Subjects (COUHES) approved the protocol.

During the ongoing discussions regarding pilot partners and locations, the development of the technology continued in two parallel tracks, one for software and one for hardware. The computer science students fabricated a custom communication circuit board upon which they developed their base-level code and more advanced algorithms. The electrical engineering team iterated through multiple custom power electronics boards. Because user personas were not successfully developed from the previous trip, the user interface for the pilot technology was designed with inputs from the uLink team to create features they believed were both useful for the end user and would be interesting to ask study participants about. Since the hardware and software development timelines were extended until the January 2015 trip departure, the user interface became a lesser priority when compared with having a functioning and integrated software and hardware system. The interface was simplified for minimum functionality.

When members of the team began leaving for India at the beginning of January 2015, pilot versions of the power management units had not been assembled or tested at MIT. Furthermore, an uLink network of multiple power management units that was supposed to be established for the two-week pilot in an un-electrified community had yet to be demonstrated at MIT.

Although the pilot units were not ready for a trial, the pilot plans continued. Two members of the uLink team arrived at the start of January to meet the partner CSR
organization and plan logistics for the month. There were also a handful of preliminary community visits to both grid-tied and un-electrified areas to begin learning about the context of the electrification problem within the communities and to see how the partner CSR organization worked within their communities. These trips also served to scope out which communities might be suitable for the pilot, even though there was not a clear list of factors that contributed to considering a community “suitable.”

These early community visits tended to take a similar form. Members of the uLink team traveled to the community with a member from the CSR organization, usually a civil engineering team member that oversaw school construction and water projects. When the team would arrive to the community, almost all of the members of the community would come out to listen to and observe the visitors. Translated by the CSR member, conversation would occur in the open between the uLink team members and the village head with several prominent male members, while the rest of the community watched on. The conversation lasted around one and a half hours and tended to be one-way in which the uLink team asked about village demographics, livelihoods, incomes, development priorities, kerosene and cellphone usage, and dynamics between households. On occasion there was an opportunity to take a walk around the community, which culminated in a stop at one or two households.

After the initial community visits and given the unfinished state of the technology at the time, the uLink team members considered adjusting the planned activities for the month from a two-week trial in people’s homes to a series of demonstrations of the technology to the communities that had been visited. Part of the hesitation to pilot resulted from the observations that it would take time and many community visits to build a relationship of trust that would allow for candid conversations with individuals and households. Additionally, the perceived electricity needs with which the technology was designed did not seem to hold in the communities visited. In these communities, there were needs for not one, but multiple lights in multiple rooms of a household, cellphone use and charging was not prevalent, and fans would not be used in the winter month of January.

In the second week of the January, the uLink team members developing software and hardware arrived in India, and promptly converted an empty office space of the CSR partner organization into a laboratory. Equipment was both brought from MIT and
sourced locally, and the development team began testing the hardware components and continuing to code. Integration of the software and hardware had not yet occurred, which would require rounds of debugging. Despite the state of the technology, some members of the team continued to push to have the technology in village households. From the software perspective, having usage data for the system would help develop the algorithms for electricity scheduling and dispatch. From the hardware perspective, having a system in place would allow the team to learn about the efficiencies and stability of the system, which appliances and load profiles would drive the design the power electronics, and which household topology the system would serve. Furthermore, the majority of the team felt having the system in place would allow the uLink team to get user feedback on the interface, validate the electricity concept, and build community relationships through surveys and interviews.

A few more community visits were conducted, including return visits to two of the communities, during which the author sought to develop a fuller profile of the community members. Using hand-drawn flashcards to represent different financial priorities and slips of paper as imaginary money, the author had informal conversations with individuals about financial transactions, spending priorities, and shared resources in hopes of illuminating the daily lives and existing behaviors of the village members, which would help the team both understand the user and frame the uLink technology and service design around existing community dynamics. In these additional community visits, it became clear that gaining electricity access was not one of the top priorities for community members when compared with other challenges such as having food to feed their families weekly and having access to clean drinking water. The technology development members of the uLink team were not able to attend many of these visits due to the need to complete the prototype technology.

As the month progressed and the technology did not reach a pilot-ready state, the focus for the trip became to demonstrate the technology and attempt to capture as much feedback as possible during demonstrations to aid future technology development. The CSR partner organization valued these demonstrations not only as a return on their investment in working with the uLink team but also as a first step in a long process of exploring which communities would want to engage with the uLink team in the future. Technology demonstrations were planned for an agricultural festival for hundreds of
farmers from the surrounding district, for a CSR stakeholder meeting with the region’s mukhiyas (the elected representative of a group of several villages, the most local form of government representation), and for the community the CSR team had originally identified for a pilot which had already been visited twice.

In the last few days of the month-long trip, the uLink prototype system had basic functionality that allowed for demonstrations to occur. Lights, fans, and cellphone charging could be powered, information about the system could be displayed on the LCD screens of the power management units, and selected noncritical appliances would turn off when there was too much electricity demand on the system. The uLink team knew it would be difficult to convey some aspects of the system, such as the electricity trading, powering critical and noncritical loads with different reliability, and a business model that would pay off the system. The system was demonstrated in the three settings, but the capacity and preparedness of the remaining team members to systematically document and capture feedback on the system was lacking. Generally, the questions the demonstration audience asked were how much the system and electricity costs, how long would the electricity stay on, could larger loads be powered by the system, and who would maintain the system.

Figure 6: uLink platform demonstration setup used in India during the team’s January 2015 visit. The uLink power management unit (black box) could provide electricity access for a light bulb, fan and cell phone charger. *Photo taken by Victor Lesniewski.*
As the trip wrapped up, there were opportunities for the author to have conversations with members of the CSR organization that were not involved in hosting the uLink project and generally were not aware of what the uLink team was trying to achieve. In discussing the original intent of piloting the technology for two weeks, the organization members had questions about what the uLink team thought it could learn in only two weeks and how they thought they could build a relationship with a community that quickly when the CSR organization still faced challenges after almost four decades of work in the region. The parting message from the CSR partner was to have the technology ready and to work more closely with them to develop a rapport with and understanding of the communities and their actual needs.

The uLink team is returning to work with the CSR partner organization to pilot the technology in June 2015. The team will target two communities, one that is grid-tied and one that is un-electrified. The CSR organization will be giving solar home systems to the few households in the community that will participate in the uLink pilot before June so that there is no “return to darkness”.

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4. Design process model

This chapter discusses the concept of a product development process and maps such a process onto the two cases studies described in the Chapter 3. The aim of conceptualizing the case studies as design processes is to provide a useful framework within which decisions made and methods used in the cases can be explored and explained as subprojects.

A product development process is a series of decisions and activities that an organization uses to ideate and design a product and then take it to market [16]. Every organization and every product will employ a different product development process, but the process can generally described as starting with a group of alternative ideas for a product and then narrowing the set of alternatives while specifying the product until the new product achieves the desired effect. Within an organization, the three functions typically engaged in the product development process will be marketing, which interfaces between the organization and its customers; design, which defines the form the product will take to meet customer needs; and manufacturing, which broadly ensures the product is produced and delivered to the customer [16].

To be clear, traditional university research programs are not product development organizations, and traditional research plans are not product development processes as they aim to produce knowledge but not marketable products. Furthermore, the research projects will not have resources dedicated to marketing and manufacturing among other functions require to bring a product from an idea to market. When research programs aim to produce deliverables beyond the findings of their studies, to implement a solution, or to create impact as is the case with many international development projects, they may find product development analogies a useful tool in processing more complex inputs to achieve a more complex output.

4.1 Generic product development process

A generic product development process has six phases: planning, concept development, system-level design, detail design, testing and refinement, and production ramp-up [16]. This generic product development process tends to represent “market-pull” product development, in which the development team starts with a market need that “pulls” the
design and development steps, using available technologies and methods to deliver on those needs. The process described applies well to engineered, discrete, and physical products. However, the process can be adapted to other types of products and to the unique contexts of the organizations developing any type of product, as will be discussed in the following case study analyses.

![Figure 7: Schematic of a generic product development process from Ulrich and Eppinger [16]. The process starts with an opportunity and defining a product vision. A breadth of concepts are generated and assessed during the concept development phase. The subsequent refinements narrow the design until a product that meets customer needs can be reliably produced.](image)

Before the project's approval and the start of the development process is the planning phase, in which the organization considers its strategic and market objectives along with an assessment of available technology to create a product mission statement that clearly guides the remainder of the process. Customer needs are determined, alternative concepts are created and assessed, and at least one concept is selected in the concept development phase. In the following system-level design phase, the selected concept is specified through a defined product architecture and set of subsystems and components. The subsequent detail design phase brings the full specification of all parts and components. During the testing and refinement phase, pre-production versions of the product are made and evaluated. The alpha prototype helps answer if the product design will work and satisfy customer needs. The later beta prototype will answer performance and reliability questions to guide any changes in engineering before the production run. The final stage of the product development process, the production ramp-up, sees the product made and allows for a gradual transition to ongoing mass production as the product is launched [16].
When the cases studied in this thesis are modeled as product development processes, they do not necessarily follow the generic model. In the following sections, this work attempts to characterize variations in the case models and provide a general structure to the observed processes, which did not necessarily occur in a structured or sequential manner.

4.2 CITE model

For the Comprehensive Initiative for Technology Evaluation, the process of writing the proposal that was submitted to USAID can be conceptualized as the planning phase. The market opportunity identified was the collective of development organizations which do not know which technology solutions are most effective when looking to procure products for their development interventions. One can consider the project vision coming out of that planning phase to be “to design and develop a support that enables the user to make informed purchase decisions on technology products used in developing countries.” While the methodology for evaluating products was to be designed to determine which technology solutions actually work best, it was the decision-making support that was to be delivered at the end of the process. The solar lantern evaluation report can be viewed as the first in a family of products that would maintain the same architecture, but different subsystems and components (i.e. technology-specific testing protocols).

Although the concept generation phase of the generic product development process calls for thoroughly exploring a breadth of alternative concepts that can address customer needs [16], the CITE suitability team concept generation mirrored a variant of the generic process, the technology-push process. In a technology-push process, an organization will start with a proprietary technology and explore suitable markets to which the technology can be applied [16]. If one considers the proprietary Consumer Reports method as a “technology,” decisions made during the product development process can be better understood.

The planning phase of CITE did not explicitly indicate that design of the methodology and of the decision support would follow a Consumer Reports framework, but in practice, Consumer Reports was central to CITE. In presenting a prototypical Technology Evaluation Report in the funding proposal, CITE represented a hypothetical technology
evaluation in the form of a Consumer Reports comparative ratings chart, complete with iconic Harvey Balls.\textsuperscript{10} In the organization of the Suitability team, the former technical director of Consumer Reports took a predominant decision-making role, despite only being an advisor and consultant in title. After all, then Secretary of State, Hilary Clinton, said to think of MIT's work as "a kind of Consumer Reports for development" in her speech announcing the formation of USAID's Higher Education Solutions Network.\textsuperscript{11}

In the technology-push process, the technology is matched to a market in the planning phase and an assumption is made that the technology will be central to the product concepts conceived and assessed by the team [16]. When considering CITE's process as "technology-push," the point at which the process had the widest set of alternative concepts was not during the concept development phase, but during the system-level design phase. Although the different factors and directions that were considered for methodology design could be considered concepts, those alternatives should actually be considered as different subsystems and components within a defined product architecture, the Consumer Reports methodology. Consequently, proposed methodology directions, such as reducing testing costs or instrumentation in the field, were incorporated into the design of individual attribute testing protocols, such as the water resistance test, but did not change the overall product architecture of using laboratory testing and specialists to produce a comparative ratings chart.

The transition between the system-level design and detail design phases for the CITE process was fluid, as different testing protocols for different solar lantern attributes were tried, assessed, and either reconfigured or dropped from the methodology. When conceptualizing these individual protocols as components specified in the detail design phase, the CITE process in these stages mirrored the development process of quick-build products, such as software. Much in the way quick-build products allow for repeated design-build-test cycles, rapid "building" and testing of prototypical protocols was achieved, in part because the CITE deliverable was not a complex physical product, but rather a set of testing methods and results. The quick-build product process involves

\textsuperscript{10} Harvey Balls are round symbols that communicate qualitative information. Please see Figure 3 for an example.

\textsuperscript{11} U.S. Department of State: https://www.youtube.com/watch?v=hhXGKeGoX_s
prioritizing features in the system-level design followed by design-build-test iterations beginning with the highest-priority features and moving to lower-priority features as time and budget permit [16]. Similarly, the CITE process prioritized and iterated through some testing protocols, such as charge cycles and lighting quality, but deprioritized and dropped others, such as the sensory panel and drop tests.

As was mentioned in the case description, the first evaluation of solar lanterns was initially communicated as a “prototype” evaluation to explore and test different methodologies, but then evolved into a production run evaluation that was intended to be used by the target audience, which crystallized as the development organization and not the end user of the product. This shift in evaluation use and intended audience may have occurred due to pressure from the project sponsor to produce demonstrable results. Instead of producing an internal report and a set of methods upon which to build future evaluations, the expectation became creating what could be considered a final product—an evaluation report to be used by development organizations in making decisions about solar lantern purchases. When viewed through the lens of a product development process, this change could be viewed as a jump from the detail design phase to production ramp-up, with at best an accelerated testing and refinement phase in between the two. An “alpha prototype” evaluation report may have been tested with development organizations to see if customer needs were met before final design decisions were made. Instead, decisions had to be made without validation from the customer and the organization had to shift toward production, which among other actions involved reworking protocols, integrating and communicating findings in a way that addressed the perceived needs of the customer, and investing in graphic and document design for producing the report. This jump to production ramp-up may explain some of the difficulties the CITE program faced in publishing its first Technology Evaluation Report, over a year after the “prototype” evaluation was to be completed.
Figure 8: A generic product development process flow adapted from Ulrich and Eppinger [16] compared to the CITE project’s process flow. As technology-push, the CITE process made the Consumer Reports framework from the proposal the basis for concept generation. As a quick-build product process, the CITE model iterated through individual testing protocol designs. The CITE model jumped from the detail design to production ramp-up, skipping the step to test and refine the Consumer Reports framework as a product for the international development space.

4.3 uLink model

As with the proposal for the CITE project, the funding proposal submitted to the Tata Center for designing an electric grid architecture for universal access can be conceptualized as the planning phase for the uLink case. One may consider the uLink project vision resulting from that planning phase to be “to design and develop a flexible and modular technology platform that enables scalable electricity access and service.” The market opportunity identified in the proposal was the need for electricity access for the 400 million Indians without electricity grid connection. The product to be delivered at the end of the project would be the physical technology platform.

It can be argued that the uLink product development process is another example of a technology-push process, in which development decisions would be driven by the new technology platform. Although the proposal identified a broad market opportunity, the development plan explicitly outlined both the hardware and software approaches needed for the proposed scalable grid architecture, building off the work of the research labs involved. Moreover, finding specific use cases for the technology platform was outlined as a concurrent step to the product development. As predicated by the technology-push process, the concepts generated and assessed during the concept development phase for uLink all included the same technology architecture, but differed in the way particular hardware and software challenges would be solved.
Another variant of the product development process that is useful to consider for the uLink case is the “high-risk” product development process [16]. The uLink product can be considered a high-risk product in that there were large uncertainties both in developing novel hardware and software and in identifying a specific market opportunity in which customers would sustainably adopt the technology platform. When adjusting the product development process for high-risk products, the largest risks are addressed in the earliest stages through design and test activities. Additionally, the organization should assess the risk at every stage and ensure the risks are being mitigated, and not postponed, as the development process continues. When viewing the uLink process from a high-risk perspective, early technology development in the form of hardware prototyping and software modeling intended to reduce some of the technical risk. For the market risk, the split of the electrification planning team from the uLink team may have contributed to a delay in risk reduction. Actions such as the participation of the two original graduate students in the business model competition might be seen as tests for reducing uncertainty about the market for the technology.

The system-level design phase for the uLink case occurred within the first year of the project, due in part to the early technology testing and constraint of concept development to the architecture proposed at the start of the project. By June 2014, the uLink team had defined the subsystems and components for the hardware network and had selected control and distribution strategies for the software. In the detail design phase, the uLink case followed a development process that is commonly seen in complex systems whereby subsystems and components are developed in a highly parallel process with teams usually working separately [16]. The hardware and software were developed and tested separately by different sets of students, requiring critical and extensive integration steps later in the process.

The uLink pilot attempts in the summer of 2014 and in the beginning of 2015 manifested as points of integration and as opportunities to enter the testing and refinement phase. The uLink process model may continue to loop through the system-level design, detail design, and testing and refinement phases, with testing results and customer input feeding back into system-level adjustments and a subsequent round of detail design. As the technology matures and the uLink team eventually looks toward manufacturability
and producing the power management units at a $15 price point, the system-level design will be heavily refined while retaining the essential product architecture.

**Generic Product Development Process**

- Planning
- Concept Development
- System-Level Design
- Detail Design
- Testing and Refinement
- Production Ramp-Up

**uLink Product Development Process**

- Funding Proposal
- Modular, Flexible Grid Architecture
- Algorithm and Power Management Units System Design
- Hardware Design
- Software Design
- Hardware Test
- Software Test
- Integrate and Test
- Production Approval
- Pilot and Validation

Figure 9: A generic product development process flow adapted from Ulrich and Eppinger [16] compared to the uLink project's process flow. As a technology-push process, the uLink project had an architecture concept from the proposal that was central to concept generation. Due to the high risks associated with uLink, early design and testing of the technology occurred as a way to mitigate risk. As a complex product process, the hardware and software were developed and tested independently. Producing a number of units for a pilot study in India is analogous to a production ramp-up.
5. Analysis

This chapter seeks to explain selected segments of the product development processes exhibited in the two cases. Focusing on factors that may influence the design decisions and outcomes of the projects, this analysis looks to secondary literature to develop a more critical understanding and to present alternative approaches. This knowledge and analysis should provide insights on conducting graduate-level design and engineering for development projects within a university setting. For clarity, the analysis is organized according to phases of the product development process as discussed in the previous chapter.

5.1 Planning

The planning phase for design and engineering for development projects is critical in a university, graduate-level setting. Given the nature of the project funding, of the available talent, and of the technology focus, how the planning phase was executed significantly shaped the two cases.

5.1.1 Mission statement

In the structured product development method of Ulrich and Eppinger, the planning phase concludes by converting the opportunity statement for the project into a product vision and combining this vision with a detailed definition of the target market and with operational assumptions for the development team to create a mission statement. This mission statement is intended to provide clarity and guide the organization through the development process [16]. In product management literature, the concept of a mission statement of a product development project is also described as a “product innovation charter.” Although direct empirical evidence of the charters creating performance benefits is limited, there is a general consensus that almost all components that appear in product innovation charters are positively and significantly correlated with some measure of firm performance [21].

Whether or not a project mission statement or product innovation charter contributes significantly to a project’s success, the idea of embodying a project’s vision, market, and operational assumptions in a document can be a particularly useful tool for product
development processes within graduate-level research programs at universities. Due to the variety of disciplines, values, and incentives that team members brought to the described cases, how decisions were made and what factors drove those decisions were at times unclear. For example, in the fall of 2013, the students across all teams of the CITE project self-organized and called a meeting with project leadership to clarify what the CITE model was and what assumptions were being made—essentially a mission statement in the form of a slide deck was presented.

Furthermore, the operational realities for these types of projects include satisfying project sponsors. For example, locations for fieldwork trips facilitated by project sponsors may not have been ideal locations for the development of the project, but the interaction between the research team and a local partner organization provided other benefits to the project sponsor’s operations. In this way, decisions may not be market-or-need driven.

Another operational reality that would be listed in the mission statements for the described projects is completing the project with graduate students. For many students, a primary incentive in graduate school is to conduct novel research on a single or related set of topics over an extended period of time. In many cases, the benchmark for this research is publication at conferences and journals, which may not have an interest in international development.

There is a tension that can exist between descriptive research methods and normative design methods [22]. In attempting both research and design, graduate students on the projects were at times engaged with competing interests. For example, completing technology evaluation reports in a Consumer Reports style in six-month cycles achieved some project goals and delivered a product, but was misaligned with student research.

5.1.2 Technology first

In the planning phase of both cases, the project teams established technology-focused approaches. By specifying a Consumer Reports style Technology Evaluation Report and the product as the unit of analysis for the 3-S framework, the CITE proposal not only pushed a “technology” in the Consumer Reports approach but also elevated the suitability dimension of a product as more important than sustainability and scalability. In
defining the project as a technology platform and prioritizing software and hardware development, the uLink case also took a technology-first approach.

As the technology-push model is explained by Ulrich and Eppinger, the technology must be matched with a market opportunity in the planning phase, and the product will likely not succeed unless it provides a significant competitive advantage or suitable alternatives are hard to come by. The technology-push model is risky, although the risk might be mitigated by considering alternative concepts that do not rely on the new technology [16].

In both of the cases documented in this work, it seems as though both the technology and the market opportunity were assumed by the projects, but not matched. The audience for the CITE deliverable was not clear at the start of project, and although development organizations crystalized as the audience as the evaluation progress, the Suitability team did not validate the Consumer Reports model with development organizations. For the uLink project, the market was assumed to exist within the 400 million un-electrified Indians, but the team continued to search for a specific market and business model that matched the technology. As a result, the system-level design for the uLink platform may have to evolve as a suitable market is found.

In the field of design and engineering for development, concentration on a technology may fulfill organizational goals but not developmental ones. As Donaldson suggests, it does not matter how user-driven the design of a product is, if the focus is only on the product, human development will not be achieved. Furthermore, Donaldson identifies a lack of focus on the later stages of product development (production, distribution, maintenance) as a hindrance to design for development [6], although universities arguably have more competence in the early stages of design. Nieusma and Riley cite an over-attention to technology, which ignores the structural forces that lead to sustainable development [9]. Given that assessing technological success is relatively easy and that everyone on a technology-centered development project agrees that the technology must work at the end of the day, technical expertise tends to dominate other perspectives in determining how the project is developed [9].

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12 This may explain in part why CITE has since explored other models for its evaluation. Please see Pombrol (2014) for one such alternative [34].
5.1.3 Early stage flexibility

One characteristic of both cases is the lack of flexibility in changing the problem framing during the early stages of design. Some literature suggests that providing project teams working on design for poverty alleviation with the flexibility to adjust the scope of the project is critical to innovation [23]. In the observed cases, however, the direction set in the planning phase has a dominant influence in subsequent phases. This may be in part due to the technology-push approach taken by projects as well as the organizational and funding constraints of the projects once a project is approved.

In some ways, this situation mirrors the paradox firms face in managing new product development. Firms may have capabilities that distinguish them strategically from other companies. These core capabilities exist in the skills and knowledge of their employees, in their technical and managerial systems, and in the values and norms of the firm. This deeply embedded knowledge set can enhance product development, but also has a flip side in which the embedded practices inhibit innovation and resist change [24]. In the two cases examined, the knowledge and skills of the researcher team certainly drove project innovation, enhanced by the technical systems embedded in the participating laboratory groups. However, successfully launching a new product that solves a development challenge may require balancing these core capabilities with the core rigidities that arise from the managerial system or embedded research interests.

If the projects are resistant to change, more time and resources may need to be put into the planning phase of such university-based technology-centered development projects to ensure the problem framing is correct, the market opportunity is real, and the customer needs are identified. Not doing so enhances the risk that as a development team learns more about the problem space and market but is structurally unable to adjust to user needs, the project may just take inspiration from a development challenge instead of solving it. Much in the same way that over 70% of the total life cycle cost of a physical product is locked in at the early design stage [25], graduate-level technology-centered development projects might commit most of their cost in terms of design freedom within the planning phase of the project.

If the projects are flexible to changing scope as Vechakul suggests [23], it may be a reflection of the challenge of timelines inherent to graduate-level technology for
international development projects. The planning of these projects must satisfy a research timeframe, within which research is conducted and a thesis is completed. Adjusting the problem framing of a project could be viewed as a way of adjusting the project timeline to match the research timeframe. In reality, time must be spent exploring what needs to be done for the development problem to be solved, and it might take years not only to understand the complex challenges of resource-constrained communities but also how to resolve those challenges with technology. Moreover, social mechanisms that deliver basic needs to the community develop over a much longer time scale than the implementation of development interventions, particularly those involving technology [9]. Ultimately, the planning stage question is where does the long-term mission of the project live: with the research or with the development of communities? Alternatively, is it possible to achieve both long-term missions given the timeline challenges inherent to university-based development projects?  

5.2 Concept development

The factors considered for analysis within the concept development section focus on user- and customer-facing interactions, as they were observed to create challenges in the studied cases, particularly with the uLink project.

5.2.1 Customer needs

Failing to understand user needs is the common refrain for why design for development projects fail, even though the way to understand user needs is presumed to be the same anywhere in the world: talk to and observe users [6]. Whether one takes Paul Polak’s rule of thumb to have conversations with at least 25 users while keeping eyes open [26] or follows Griffin and Hauser’s benchmark of conducting 20-30 interviews to get 90-95% of user needs [27], the bottom line remains that time must be spent speaking with potential customers and users. In one study of user research methods for development engineering, the authors found that professional designers spent more time on the earlier, data-gathering stages of the design process and suggested that other design for development projects focus on early-stage, user research efforts [28].

13 Please see Section 5.4.2 on resource commitments for a related analysis of time constraints.
While the uLink team conducted a notable number of trips to India during the early stages of the project, the content of the trips centered not on customers and users, but on potential partner organizations and stakeholders. The community visits that the uLink team did conduct early on did not focus on user interviews. Rather, the team relied heavily on NGOs and rural electrification providers to convey user needs, and a demographic data set from one solar home system provider was used to develop user personas.

But as Nieusma notes in his work on challenging knowledge hierarchies, organizations can be partially effective in speaking on behalf of communities, but will do so “in a manner different from those groups speaking for themselves” [29]. While the first year of trips focused on engaging stakeholders besides potential users, the subsequent trips, as discussed earlier, focused on demonstrating the select product architecture through a pilot.

5.2.2 Prototyping

In conceptualizing the uLink case as a high-risk product development process in the previous chapter, it was suggested that the largest risks should be mitigated early and often through designing, which the uLink team attempted to do through software modeling and through a business case competition. However, prototyping without technology could have been employed to reduce market and user adoption risk. For example, renderings or user interface mock-ups could have been used.

The uLink team’s tendency was an all-or-nothing approach to prototyping. Taking a technological perspective, prototypes were conceived as an integrated technology that displayed some minimum functionality or else the uLink concept was too difficult to explain. By taking a system-level approach to prototyping, the uLink team may have missed opportunities for incremental learning instead of depending heavily on the success of integrating subsystems.

In professional design practice, low-cost prototyping has been used in “developing world” contexts to gain user insights on not only user interfaces but also more abstract concepts like financial services [30]. Even with a complex technology platform such as uLink, insights for both the interface and the business model could have been gained by
testing elements of the uLink concept through simple prototypes that contained no technology.

5.3 Detail design

Although the detail design phase can be thought of as addressing production costs and robust performance from the perspective of engineering design, alternative design for development literature suggests the details of design are particular significant when designing for the world’s poor.

5.3.1 Moral significance

In presenting an approach to design that focuses on human capabilities, Oosterlaken draws on the work of philosophers and sociologists to highlight that engineered products and technologies lack neutrality. Instead, products are inherently normative and embody values in their features that can lead to good or harm. In developing a new product or technology, there are many options for designs. Therefore, as Oosterlaken states, “the details of design are morally significant” [11].

This approach suggests projects such as CITE should consider other, value-based dimensions for assessing technology solutions, not just quantifiable performance parameters. For a project such as uLink, there must be careful consideration of the human interactions facilitated by the technology platform. For example, the peer-to-peer electricity trading central to uLink’s product architecture and operation raises a number of questions about the social dynamics created and facilitated by the technology. Will the system provide universal access to electricity and to potential economic development or will it exacerbate the gap between community members who can afford to be “prosumers” and those who cannot? Will community members be willing to sell or buy electricity from anyone in their community or are there social barriers to those interactions? If electricity service is unsatisfactory, will community members blame the technology or their neighbors?

Carefully selecting the details of the design can be the difference between realizing stability or insecurity, justice or injustice, equity or inequality. Incorporating moral values into design decisions becomes all the more difficult in cultures and communities foreign
to the development team, but the details matter for more than manufacturing and robustness.

5.4 Testing and refinement

This section discusses the ethics and resource commitments of the two cases that directly relate to a project team’s interactions with the resource-constrained populations they propose to serve. These factors appear throughout the product development process, but have perhaps the greatest implications during the testing of technology for development projects.

5.4.1 Ethics

There is an immense body of ethics literature that could be discussed, but this work chooses to focus on the scenarios observed in the case studies. It should be noted that ethical questions could arise at any point of the product development process, especially when working on solutions for resource-constrained and, at times, marginalized communities in contexts that are not necessarily understood by the research and development team.

In the CITE case, the request for photos of Ugandan children with the solar lanterns and the consideration to evaluate lanterns for unique use cases such as midwifery (about which the Suitability team had no qualifications or agency to comment) did not improve the evaluation methodology, but could be traced back to the marketing incentives embedded in the proposal and the planning phase. (The irony should be noted—CITE’s work, in part, meant to uncover development technologies that had marketing campaigns that did not reflect product performance—no project is immune.)

The points at which ethical concerns were most prominent and arguably most consequential were when the research teams planned to significantly intervene in communities to collect information regarding the technological solutions. In these situations, MIT’s Committee on the Use of Humans as Experimental Subjects (COUHES) was relied on as the vehicle for ethical verification. Human subjects research, however, is a blanket term used for a variety of research, from biomedical to psychological. The different types of human subjects research vary based on the degree
of asymmetry between the researcher and the person being investigated, on the breadth of the research, and on the potential degree of harm or benefit. As a consequence, various forms of research encounter different ethical dilemmas, and the COUHES procedure, inspired by a need to improve the ethics of biomedical research, may have limited impact on the ethics of fieldwork [31].

Cassell suggests a more appropriate basis for evaluating the ethical adequacy of fieldwork is respect for the autonomy of the people investigated, always considering them “as ends in themselves, never merely as means” [31]. In addition to filing a COUHES application, research teams can engage an independent individual from the university ecosystem with prior fieldwork or development experience to observe and comment on the team’s decision-making process. Furthermore, research teams should take the responsibility of considering all possible methods for testing their hypotheses or answering their questions, balancing the fidelity of information that can be expected from a method with the disruption it presents to a community member.

The CITE Suitability team decided that not disclosing the lantern instrumentation to study participants was not worth the uncertain and probably marginal benefit of a blind trial, particularly given the exploratory state of the project. On the other hand, the uLink team may have sought to answer some of its technical questions at MIT and not through a pilot and could have considered less disruptive methods for understanding electricity consumption profiles considering the early stage of prototyping and testing.

Justifying these interventions by stating that the findings from the trial will benefit multitudes of people in the long run when the product is released or by claiming the sunk costs of the project team are too great not to proceed is not good enough. There is a graveyard of technology for development projects to show for it.

5.4.2 Resource commitments

University projects tend to be resource-constrained, particularly for fieldwork, when considering time as a resource. There are examples in the literature where university teams have proceeded with project plans in context, knowing that their time limitations would not allow for the stated goals of the trip, but assumed a limited project was better than no project [9]. Another university team had not conducted an assessment of their
implemented technology due to time and funding logistics, even though the team agreed on the value of the assessment [14].

Although time pressures are a well-known challenge of product development [16], the imposition of time constraints on university teams due to class and conference schedules creates artificial time pressures. Trips for both the CITE Suitability team and the uLink teams were planned on the basis of the time between semesters during which researchers are available and willing to travel, not on the basis of the activities that needed to be completed to best fulfill project goals.

Per the analysis of Nieusma and Riley, decisions to carry on with “constrained” project trips require further questioning [9]:

- Proceeding under such constraints could achieve what goals?
- Would face what constraints?
- Would most likely benefit whom?
- And who would bear what costs?

Members of both the solar home system foundation and the CSR organization with which the uLink team worked questioned how much could actually be achieved and learned about communities in two-week stretches. Additionally, the partner organizations suggested another type of time commitment to increase the likelihood that the technology project would succeed—a long-term commitment from the uLink team to work with a community over many trips, making community members not a means but an end in themselves.
6. Conclusions

*trust that none will stretch the seams in putting on the coat, for it may do good service to him whom it fits...

- Henry David Thoreau, *Walden*

This thesis explored university-based and technology-focused projects in international development. This thesis specifically focused on graduate-level projects that leverage Master’s and doctoral students to both conduct scholarly research and deliver project milestones. Following the established model of service-learning, such graduate projects are gaining prominence as they provide a compelling for students to make contributions to global challenges over the course of their research program.

The motivation for writing this thesis was the author’s own experiences working on such projects, which at times seemed to fall short of stated objectives and of expectations for academic research. This did not mean the projects were failures, but an opportunity was identified to better understand how these types of projects could be better approached and executed.

In order to better understand graduate-level technology for development initiatives, the author developed case studies of two such projects in which he was involved, a technology evaluation project and a technology development project. The technology evaluation project, CITE, aimed to develop and employ rigorous methods for determining with technological solutions in development work best. The case study highlighted CITE’s first attempt at an evaluation of solar lanterns within the Ugandan context. The second project, uLink, aimed to develop a scalable technology platform that would provide universal electricity access to hundreds of millions of Indians. The case study detailed the project’s attempts to integrate its hardware and software development with perceived market opportunities.

The two case studies were then conceptualized as structured design processes to provide a common framework for characterizing the projects and for conducting further analysis on select aspects of the cases. Specifically, the events of the case studies were mapped onto a generic product development process. Noted were the differences between the case study descriptions and a typical product development process. These process variations and their implications for the projects were described in terms of
established product development processes adapted for particular product types. Both case studies were characterized as cases of “technology-push” projects, but the CITE project had some characteristics of a quick-build product process and the uLink project displayed elements of processes for developing both high-risk products and complex systems.

Leveraging the structure and concepts provided by the product development process model, the author then analyzed select facets of the two case studies that may have implications for similar academic projects in international development. Secondary literature was used to help explain some elements of the processes and to source alternative actions or methods. The findings from the analysis suggest that the following aspects of such projects might be approached differently: (1) early-stage planning, (2) contextualization of the technology focus, (3) project timescales, and (4) the intent of community engagement.

In the case studies, the planning phase of the product development process occurred in creating the funding proposal for the projects and significantly influenced the subsequent stages. As such, more consideration might be given during planning to better identify a market opportunity, to manage the tension between the descriptive research goals and the normative design goals, and to determine the range of flexibility a project might have to adjust to a dynamic problem given its more rigid resources. The case studies highlighted a tendency to prioritize technology over context, reflecting the strengths and interests of the project teams. However, the literature suggests that in designing remotely for the “developing world,” challenges arise when users are not well understood and when the ecosystem within which a product is distributed is not fully considered. With regards to time as a resource constraint, the cases showed time pressures specific to the graduate-level projects. Academic commitments limited opportunities to travel and therefore limited the scope of the project work, and the timescales and lifetime of a graduate degree or project did not match the time required for development to occur within a community. Lastly, in exploring the project teams’ engagements with resource-constrained communities, the analysis suggested an ethical framework in which community members were not solely an information point, but were the reason the projects existed and a guiding factor for how the projects could be run.
Given the engagement with marginalized communities and given the multi-million dollar budgets that come with these university-based development projects, there is a responsibility to report and to learn from their successes and failures. Defining and assessing the project success or failure for the selected cases is a complex process and was not the intent of this work. The cases outlined in this work should not be considered success or failures until the projects complete their course. However, the cases provide a vehicle for understanding some important facets of graduate-level university projects that aim to leverage technology and design for the poverty alleviation.

This work has not been generalized and should not be stretched to explain all projects. Other projects take other approaches, and part of the future work required is to document and explain those approaches. By cataloging projects at MIT and beyond, an understanding may be developed about which elements of graduate-level technology for development projects are specific to certain institutions or to certain projects and which elements more broadly define the space of engaging graduate students to tackle poverty alleviation through design and engineering.

The product development process may be useful as a structured framework for not only modeling and analyzing this catalog of projects but also improving the process. Within that framework, future research can attempt to define and validate meaningful metrics for determining the success of such projects at different stages and can develop and evaluate design supports not only for those who carry out the research projects but also for those who plan and manage these graduate research programs.

In academic international development projects, universities/students are asked to not only produce research but also develop products. However, university graduate programs do not typically produce products—but they do produce learning, research and new technology. These projects have neither the time nor the human capital that traditional product development firms do to deliver a product, but for the foreseeable future, the mandate for university projects to deliver both scholarly and development results.

Technology-based research in-and-of-itself should not be a means for claiming innovation within the international development practice. Likewise, poverty alleviation should not be a means for creating compelling research programs. The ideal state
occurs when both the academic and community impact are never considered merely means, but as the mutual and equal ends in themselves.
References


