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Using Human-Centered Design to Connect Engineering Concepts to Sustainable Development Goals

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ABSTRACT

Background. Engineering design is widely recognized as a field that can generate key innovations for complex problems, such as those elucidated in the Sustainable Development Goals (SDGs). However, engineering design training is not widely accessible to the global community, particularly to people experiencing the challenges that the SDGs are striving to address.

Purpose. This manuscript describes the Ignite program created by the Center for Global Women's Health Technologies (GWHT) at Duke University, which uses the human-centered design framework to apply engineering design concepts to address specific challenges associated with the SDGs.

Design/Method. Undergraduate students participate in a design course (BME 290) to learn how to create and deliver a technological solution to increase access to light at night, which is a significant challenge in many communities around the globe. A subset of the undergraduate students partnered with an energy-poor community in which they implemented a curriculum based on the skills learned in BME 290.

Results. Since 2014, 110 Duke students have taken BME 290, and 22 of those students traveled internationally, collectively teaching 275 students in Kenya, India, and Guatemala. Students in Kenya formed an engineering club and taught the curriculum to an additional 52 peers. Duke students also trained 15 other university students, both in the United States and Guatemala, who have taught the curriculum to an additional 150 students in Guatemala, which illustrates the scalability and sustainability of the curriculum across countries, communities, and cultures.

Conclusions. By integrating human-centered design and the SDGs into engineering curricula and targeting communities that work with women and girls, we believe the Ignite program can impact three of the SDGs – renewable energy, quality education, and gender equality.

Key words: Multidisciplinary design; international programs; technology applications

INTRODUCTION

In a display of global unity, all 193 countries represented in the United Nation's General Assembly agreed to the Sustainable Development Goals (SDGs) in 2015 (Gostin and Friedman 2015). The 17 goals, some of which include eradication of poverty, good health, quality education, gender equality, and renewable energy, provide a vision for transformative change across 169 targets by 2030 (Gostin and Friedman 2015). This optimistic vision serves as a call to action for all who seek to create a better future for themselves and coming generations. While there is no one formula to achieve these goals, it is critical to create interdisciplinary problem solvers who have the confidence and skills to work within and outside their communities to develop solutions that will help meet the SDGs (El-Jardali, Ataya, and Fadlallah 2018).

Engineering design is widely recognized as a field that can generate transformative innovations for complex problems, such as those described in the SDGs. The intersection of biomedical engineering and global health has become a particularly attractive sub-discipline because it requires students to combine traditional engineering knowledge with insights from disciplines like public or global health, public policy, sociology, economics, and cultural anthropology to understand nuanced problems (Clifford and Zaman 2016). In this context, students learn about opportunities in global health, work in interdisciplinary teams to tackle challenges, and incorporate cultural dimensions into the design solution to enhance adoption of a technology. Several institutions in the United States are leveraging biomedical engineering to impact global health through using human-centered design (Richards-Kortum, Gray, and Oden 2012; Oden et al. 2010; Malkin 2007).

While interdisciplinary programs in global health have the potential to yield innovative solutions for the SDGs, the learners of engineering design comprise a relatively small pool of students. Engineering design curricula have traditionally been taught in a capstone course in the final year of college to engineering students (Todd et al. 1995; Zhan et al. 2018), the majority of whom are male (men received approximately 80% of all undergraduate engineering degrees awarded in the US in

2017 (National Science Foundation 2017)). Consequently, engineering design training is not widely accessible to the global community, particularly to people experiencing the challenges that the SDGs strive to address. Successful realization of the SDGs necessitates a future in which the people who imagine and build technology mirror the people and societies for whom they build it. Thus, it is critical to place essential skills and tools needed to solve community challenges in the hands of those at the level of the problems. Referred to as liberatory design, this involves instructors designing "with" instead of "for" the community in need (Bennett and Rosner 2019).

We have created a social innovation program called Ignite that uses the principles of human-centered and liberatory design to educate a global community of students on engineering concepts through design thinking rooted specifically in the SDGs. The Ignite curriculum contains three key components: (1) creation of a physical prototype, (2) a community-based design challenge centered on the use and implementation of the prototype, and (3) peer-to-peer learning, which results in a virtuous cycle of learners who become leaders who generate more learners. The engineering concepts focus on the creation of a practical solution related to an SDG. The design solution is targeted at a challenge that learners within the community consider important.

In our initial implementation of the Ignite program, we sought to address challenges associated with energy poverty in low-income communities. One of the major barriers to productivity in energy-poor communities is access to light. Approximately 2.8 billion people worldwide live without electricity (Amegah and Jaakkola 2016). Energy poverty also has a gender bias, with girls being more impacted than boys, owing to their larger share of domestic responsibilities (Munien and Ahmed 2012). For these reasons, Ignite started with teaching students how to build a flashlight, which could be used to perform a variety of tasks at night. The circuitry required to build a working flashlight is relatively simple and can be completed quickly, which enables students to experience the design process from idea through functional solution in a short time and build confidence from the completion of their work.

Our program began in 2014 with Duke University undergraduate students who learned the concepts of the Ignite program through a design course cross-listed between the Pratt School of Engineering and the Trinity School of Arts and Sciences. A subset of the Duke undergraduate students partnered with an energy-poor community in Kenya, India, or Guatemala, where they implemented a curriculum based on the skills learned at Duke. The curriculum covered topics in circuitry, optics, and energy, and the lessons were translated into design activities that relate to SDG #7 (affordable and clean energy), while simultaneously addressing SDG #4 (quality education).

The beneficiaries of the Ignite program have been predominantly female students between the ages of 14 to 24. In the Kenyan school, the sustainability of the model was realized by creating a leader-learner model in which the learners became leaders, enabling the curriculum to be replicable and scalable through peer-to-peer instruction. Simultaneously this allowed students to internalize the concepts through teaching them to peers in the community in which they live. In India, mothers of middle school and elementary school students participated in Ignite and demonstrated that this program can also be used as part of adult education in innovation and entrepreneurship. The Guatemalan program, which was geared toward middle school and high school students, included a component related to student career goals.

METHODS

Human-Centered Design as a Framework for the Ignite Curriculum

Human-centered design, used to develop and implement the Ignite program, has three formal phases: *hear*, *create*, and *deliver* (IDEO.org 2017). During the hear phase, designers engage directly with the community and hear the needs of key stakeholders. In the create phase, designers collaborate with community members to brainstorm solutions, develop prototypes, and solicit input and feedback. During the deliver phase, designers work with a diverse set of stakeholders to develop a sustainable way to bring their design into the broader community. Through this iterative process, designers often modify their product after the deliver phase with continual input from the community. An illustration of how human-centered design was used to develop the Ignite program is included in Figure 1.

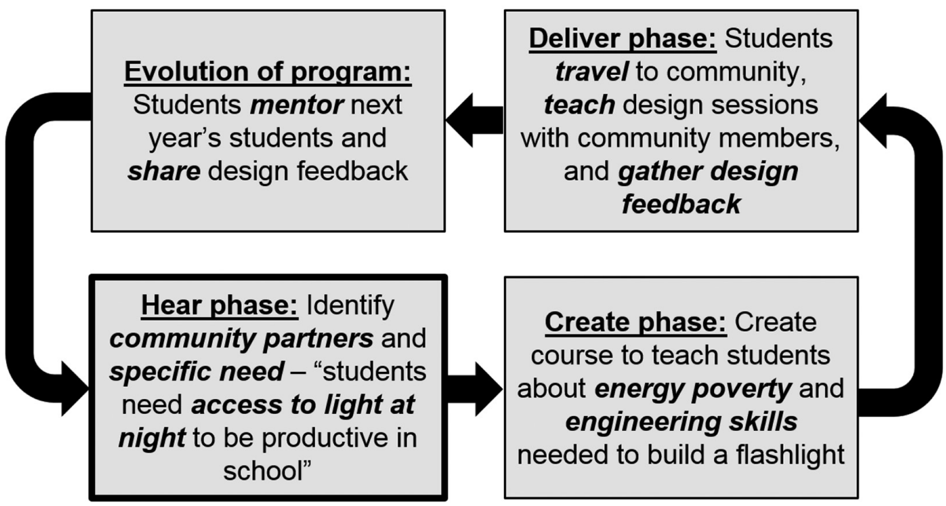


Figure 1. Overview of the Ignite program. Duke students take a course to learn engineering skills related to energy poverty and light. Duke students then work with a school in an energy-poor community and implement the flashlight curriculum using the skills that they learned. As the students become the teachers in these communities, they gather design feedback, which they share with the following year's students.

Hear Phase - Selection of Community Partners and Identification of a Specific Community Need

To identify potential community partners, we initially collaborated with faculty and staff leaders from DukeEngage (https://dukeengage.duke.edu/), a program that gives undergraduate students at Duke University an opportunity to engage in service learning with communities in the U.S. and abroad through an immersive, 8-week experience. We sought to identify DukeEngage experiences that: 1) focused on education, literacy, community development, or outreach, 2) worked with schools and communities that experienced challenges related to the SDGs, and 3) were interested in incorporating hands-on STEM curricula into school programs. Through DukeEngage, we identified community partners in both Kenya and India. The subsequent expansion of the program into Guatemala was driven by a student-led group called Desarrolla, a club that aims to connect the Duke community with Latin America. In total, we partnered with four different schools between 2014 and 2018: the Women's Institute for Secondary Education and Research (WISER) in Muhuru Bay, Kenya; Tulipdale Public School in Kolkata, India; the Future Hope school in Kolkata, India; and Instituto Indígena Nuestra Señora del Socorro (INSS) in San Andrés Semetabaj, Guatemala.

In our initial implementation of the Ignite program, the specific needs statement we addressed was "students need access to light at night to be productive in school". This needs statement, developed in collaboration with faculty and students at our first partner site, WISER, was based on the premise that the students at WISER often did not have reliable access to electricity to complete homework assignments and study for tests after dusk. This need was turned into an opportunity to teach engineering concepts and design thinking in the context of a problem that directly impacted students in the community.

Create Phase - Curriculum for Duke Students Offered as a Duke Course

The design course "Women's Health and Technologies" (listed as BME 290) was open to all students from the Pratt School of Engineering and the Trinity School of Arts and Sciences at Duke University. No pre-requisite courses were required prior to enrollment in BME 290. The backbone of the course was a series of lectures and debates designed to provide context for the hands-on component in which undergraduate students from all years (freshmen through seniors) and a variety of disciplines (both engineering and non-engineering) worked together in teams to learn and apply the human-centered design process to create a solution to energy poverty. Each team aimed to design a renewable energy-based light source for an underserved community in an international setting. Mixed design teams provided both horizontal (engineering and non-engineering) and vertical (first year through fourth year students) integration, which enabled bi-directional learning and peer-to-peer mentorship.

The first offering of the course had three primary components: lecture, debates, and lab. The lectures covered global disparities in income, education, and health, with a focus on how these inequalities disproportionately affect women. Students learned about strategies to address each of these disparities through case studies that demonstrated how the human-centered design process could be used to create innovative solutions to global challenges. Debates included topics such as “Should there be a different standard-of-care between high- and low- resource settings?” and challenged students to conduct, research, and write substantive analyses of big questions in the global health space. During the first half of the semester, labs focused on teaching students the engineering skills needed to build a renewable energy-based flashlight as well as measurement and testing techniques. During the second half of the semester, labs were dedicated to prototyping and testing solutions designed to address a specific community need that is reflected in the SDGs. They identified this need by engaging with key community stakeholders.

Deliver Phase - Implementation of a Curriculum that Integrates Design Thinking, Engineering Concepts, and a Community Relevant SDG at a Partner Site

Undergraduate students in BME 290 designed light-based solutions that fulfilled specific community needs. A subset of the students, referred to as the Duke student leaders, developed a curriculum to teach students at the community partner site a variety of engineering concepts and skills that would enable them to solve relevant local problems, such as a lack of light walking to and from school, or a lack of sufficient lighting to cook meals or complete homework. The curriculum was implemented at each site over a period of 6 to 8 weeks (the length of a typical DukeEngage program). Through the creation of durable, rechargeable lighting solutions, student learners were taught concepts such as electricity and magnetism, renewable energy, and materials science. In addition, students learned measurement techniques that allowed them to establish design specifications and then determine if those specifications had been met in their solutions. Duke student leaders also taught troubleshooting skills so student learners could identify, isolate, and address issues that could cause their design solution to malfunction or fail. An outline of a representative flashlight curriculum is included in Supplementary Table 1.

Evolution of the Program

During the immersive summer experience, the Duke student leaders obtained feedback from students and members of the community regarding the curriculum and flashlight design, which was shared with the BME 290 class the following year. While the physics teacher at the WISER secondary school represented his community in the inaugural class, Duke student leaders served as representatives on behalf of the actual communities in subsequent years. They also mentored the next Duke student leaders who were planning to travel internationally so that the community’s feedback would be implemented the following year. This model provided opportunities for student leadership and fostered communication and mentorship between older and younger undergraduate students, which in turn has led to program sustainability within Duke.

Data and Statistics

Duke student data were collected under Duke University Institutional Review Board approved protocol number C0930. We recorded the number of students who enrolled in BME 290, the number of students who implemented the educational curriculum in the community partner sites, and some basic demographic information, including the proportion of male/female students and engineering/non-engineering majors. International student data were collected under Duke University Institutional Review Board approved protocol numbers: D0608 for WISER, D0561 for Tulipdale and Future Hope, and E0191 for INSS. We have tracked the number of international students and the number of flashlights successfully built at the international schools that have participated in the flashlight curriculum as well as information on successive generations taught within these communities.

To better understand how the Ignite program impacted the leaders and the learners, we also conducted a series of interviews or focus groups with students from Duke, WISER, and INSS under the same IRB protocols listed above. Specifically, semi-structured interviews were conducted in the Spring of 2019 with 10 students who took BME 290 in the Fall of 2018. These interviews were conducted in English, lasted about 30 minutes, and were recorded. The ten audio recordings were then transcribed, and thematic analysis was used to organize and analyze the data. Key quotations emphasizing the themes are highlighted in Table 1 in the results section. The interviewer worked from a list of questions (included as supplementary content), but could alter and ask follow-up questions to gather more information as the participant spoke.

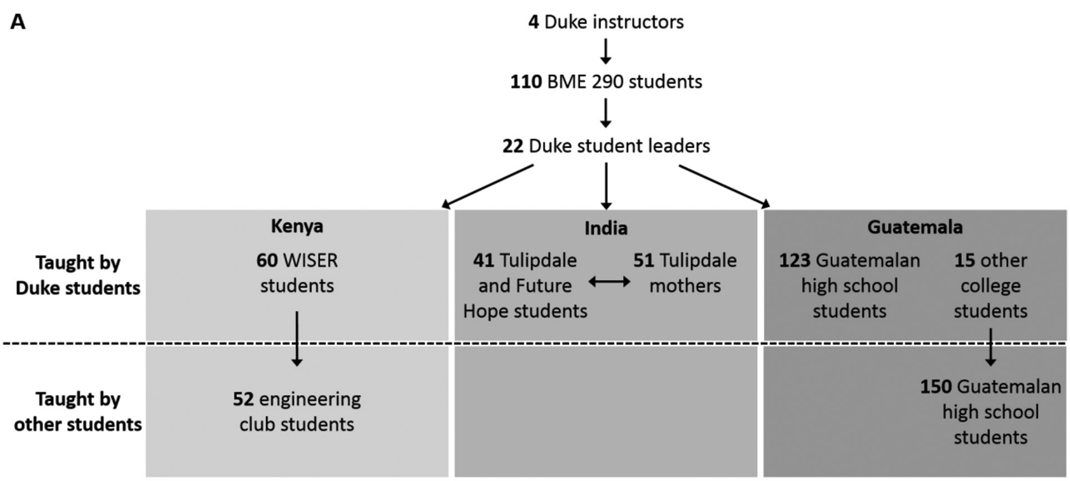
Semi-structured interviews were also conducted with 20 female students plus 4 alumni approximately 1 year after they participated in the WISER engineering club. The interviews were conducted in English, lasted about 30 minutes, and were recorded. Interviews were not conducted by any of the authors, but by a neutral third party. Ten audio recordings were then transcribed and thematic analysis used to organize, code, and analyze the interviews (Guest, MacQueen, and Namey 2012). Two authors reviewed the ten interviews to identify emergent themes and categories for coding. The remainder of the data were analyzed through notes and key quotations transcribed from the recordings. The interviewer worked from a list of questions related to the experiences and perceptions of the students but could change the questions to gather additional information on any topic the participant mentioned. A summary of the interview themes from WISER students and illustrative quotations are included in Table 2 in the results section. Sample interview questions are included as supplementary content.

Additionally, two semi-structured focus groups were conducted with 18 female students who participated in the flashlight curriculum at INSS approximately two days after the Ignite program concluded. The focus groups were conducted in Spanish by two Duke students, lasted approximately 30 minutes, and were recorded. The data were analyzed through notes and key quotations transcribed from the recordings. Illustrative quotations are included in the results section and sample questions are included as supplementary content.

RESULTS

Summary of the Cascading Model of the Ignite Program

Between 2014 and 2018, a total of 110 Duke students took BME 290, and 22 (20%) of those students traveled internationally, collectively teaching 275 students in Kenya, India, and Guatemala. Students in Kenya formed an engineering club and taught the flashlight curriculum to 52 of their peers, which highlights the sustainability of the model. Duke students trained 15 other university students, in both the United States and Guatemala, who have taught the flashlight curriculum to an additional 150 students in Guatemala (Figure 2A). The international participants, most of whom were girls or women (~93%), worked in teams of 3–4 to build 228 functional flashlights and 49 shared



B

Site	Strengths	Weaknesses	Lessons learned
Women's Institute for Secondary Education and Research (WISER)	Peer-to-peer mentoring, formation of engineering club	Difficult to procure flashlight materials locally	Key for sustainability is having a strong local leader who champions the program year round
Tulipdale Public School/Future Hope	Interest from parents, particularly mothers	Young students had difficulty with fine motor skills required for flashlight assembly	Flashlight curriculum is more appropriate for secondary school students and non-student learners
Instituto Indígena Nuestra Señora del Socorro (INSS)	Duke student-initiated program, community capacity building	Needed to teach local students math skills required to design flashlight circuits	Self-evaluation of needs related to light and career goals led to deeper student engagement

Figure 2. (A) Dissemination of the flashlight curriculum from 2014–2018 with the total number of participants categorized by site. (B) Summary of strengths, weaknesses, and lessons learned at each international site.

recharging stations. The key lessons learned from each implementation site and the strengths and weaknesses of each program, as identified by the Duke student leaders who worked within each community, are included in Figure 2B.

Initial Instruction Through BME 290

To learn the curriculum, Duke students worked in teams of 3-4 to build 32 functional flashlights. Female students comprised 78% of the Duke students who enrolled in BME 290 and 95% of the Duke student leaders. Interestingly, 35% of the students who took the course and 64% of the Duke student leaders were non-engineers. Pictures from the flashlight curriculum implemented in BME 290 are included in Figures 3A and B. Figures 3C and D provide a summary of the Duke student

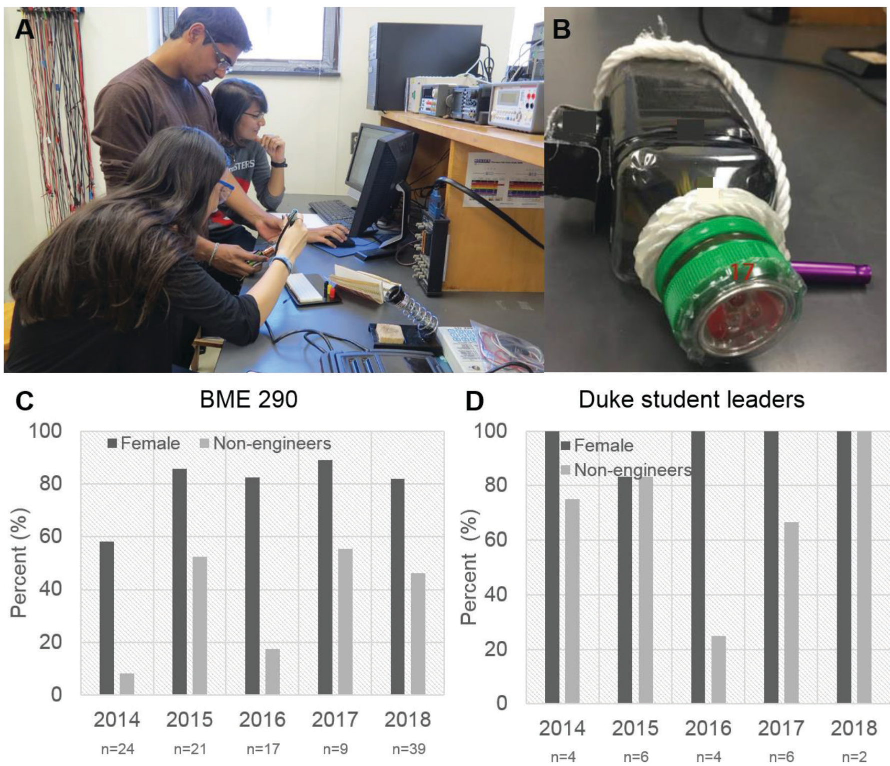


Figure 3. Duke student participants. (A) BME 290 students and (B) flashlight constructed by BME 290 students for use by women walking at night in Kolkata, India. The flashlight was designed to be easy to carry with a built-in alert system, which included a flashing red light and whistle. Distribution of female and non-engineering students in (C) BME 290 and (D) amongst the Duke student leaders who taught the flashlight curriculum internationally. Total numbers of students are indicated below each year.

composition. The core elements of BME 290, including lectures, debates, and labs, as well as their evolution, are described in detail in supplementary content. Briefly, representative community challenges for which students developed solutions included: 1) lack of a consistent light source for cooking, schoolwork, and other family activities that occur after sundown; 2) inadequate lighting for children commuting via bicycle at night; 3) unreliable dental light sources; and 4) immobile and unstable surgical and clinical light.

The course was designed to equip students with the skills, knowledge, and mindset necessary to better collaborate with community partners to address challenges through the human-centered design process. To evaluate the impact of BME 290 on both addressing course learning objectives and preparing students to become future social innovators, semi-structured interviews with 10 former BME 290 students were conducted. Students shared very positive sentiments about the unique way in which the course brought together an interdisciplinary team to prototype a tangible solution to a real-world problem. Seventy percent (n = 7) of those students stated that the course allowed them to develop the skills needed to collaborate with a community partner. Many of those students also emphasized that no other course at Duke allowed them to directly work with a community partner. Additionally, 90% (n = 9) of students discussed how they implemented the steps of human-centered design throughout the course and noted the usefulness of this skill. A common sentiment, expressed by 50% (n = 5) of students, was an overall increase in confidence gained throughout course. When asked about potential connections that could be drawn with this course, 60% (n = 6) of students noted that they could make connections to other Duke courses. Notably, 90% (n = 9) of students noted a connection between this course and their future, in terms of their majors or career plans. Table 1 displays these themes with representative quotations from each of these categories.

Five of the Duke students interviewed have become teachers of the curricula in both domestic and international settings upon completing BME 290. During the interview, these students reflected on how the course influenced their understanding of basic circuitry and allowed them to become confident in their ability to share this knowledge with others. Three of these students (60%, n = 3) mentioned how human-centered design helped facilitate a unique learning experience within the communities where they were teaching.

Creating a Model of Peer-to-Peer Education in Kenya to Ensure Sustainability

In the first year of our program, we partnered with an NGO called WISER, which funds a secondary boarding school for girls in Muhuru Bay, Kenya. Several of the authors developed the first Ignite curriculum in collaboration with a Kenyan WISER faculty member. The Duke student leaders spent 6 weeks working with 50 students at WISER (~40% of the student body) to train them on practical skills in renewable energy, circuit design, and flashlight construction. The WISER students worked

Table 1. Summary of themes, number of students out of 10 total students who mentioned each theme, and representative quotations from semi-structured interviews with students upon completion of BME 290.

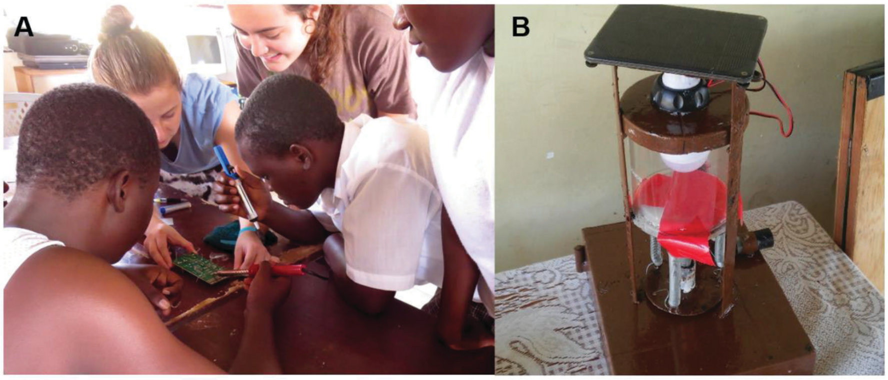
Theme	Students who mentioned theme	Representative Quotation(s)
Develop the skills needed to collaborate with a community partner	70% (n = 7)	"I always talk about how it is a real-life situation. We spoke to a doctor who actually does need this product and how this experience augmented my education and showed me how my education is useful in a real-world setting." "I haven't had a class here that actually results in a product that you envisioned and was based in a true community representative story…I think this class helps people to not lose motivation by providing an example of how all of this knowledge can play out in a real-world setting."
Implement the steps of human-centered design	90% (n = 9)	"I was really excited about the class, especially knowing that at the end of the class I would have a working product that I never would've thought I would be able to build at the beginning of the class…So it's not just giving you a PowerPoint on this is how to do the hear, create, and deliver phases, but allowing you to actually implement the phases." "I actually got to see from start to finish, a product of my vision created, which is an amazing experience. You spend so much time in class listening and to actually do something is really cool."
Apply learned skills to other disciplines	50% (n = 5)	"I learned a lot of lessons about the importance of collaboration with your peers that you're taking classes with and how that can help you succeed. I would say that now I am very confident that I can excel in a science class at Duke."
Connection between this course and other Duke courses	60% (n = 6)	"I wanted to do something again that was hands-on and used the knowledge I gained in other classes. Many of my classes at Duke were more lecture-style and learning about things but never applying them. I am interested in actually seeing how my knowledge can be applied and how I can get results to then change something in the future."
Connection between course and future career	90% (n = 9)	"This made me feel that I could do engineering…and it gave me confidence that I could pursue a Masters in Design, which I have been thinking a lot about since taking this class, and I now feel confident that I have the ability to do that." "Engineering, as much as it is about building new innovative things, it also can be used in making health care more effective. The crossover between health and engineering also branches over into social justice and that's something that I didn't think about before taking the class." "I also feel like it really helped me find an interdisciplinary major and area of study. I was interested in computer science and global health and had always seen them as very separate, but now I want to go into health tech and see how computer science relates and can be combined."

in design teams over a 6-week period. Most of these groups built several flashlights using recycled materials, such as plastic water bottles and peanut butter jars, to address problems associated with lack of lighting for a variety of different tasks including studying at night. The circuits themselves were made from basic components that were easy to repair or replace. Many of the flashlights also had hand cranks or squeezing mechanisms to allow them to be recharged without using electricity from an electrical grid or generator. After the end of the instruction period, a WISER faculty member supported a subset of the initial learners as they (~23 students) formed the WISER engineering club. To conserve supplies, these students disassembled the flashlights they had created and then practiced their skills by reassembling them. The students also developed a system of peer-to-peer mentorship in which experienced WISER students taught new club members or even nonclub members who were interested in the material.

In 2015, the Duke student leaders taught two new curricula to the WISER students who were interested in more advanced topics. The goal was to teach WISER students: 1) how to construct an efficient recharging mechanism, and 2) the human-centered design process to enable the students to develop critical thinking skills that they could apply to more open-ended problems. Students learned how to use mechanical energy to recharge their flashlights, which tied into their physics curriculum. They also learned how to identify needs in their community and engage stakeholders to develop solutions to these needs. Approximately 23 students participated, 19 of whom had participated in the previous curriculum.

Building on this momentum and under the leadership of a WISER teacher, the engineering club has thrived since 2015. As students quickly mastered flashlights, a WISER faculty member helped them apply their design skills to create a diverse set of projects for science competitions. Though they had not participated in competitions previously, the WISER students quickly found success. In 2016, a group of students from the WISER engineering club reached the regional level in a national science competition called the Kenya Science Congress. Their project was a sustainable energy lamp designed for the fishermen in their community to attract fish at night. The inspiration for the lamp came from the fact that the fishermen in their community typically use kerosene glass lamps that would go out, break easily, and pollute the water. Fishermen had also complained about the expense of kerosene so the lamp built by the WISER girls was rechargeable using a solar panel, hand crank, and shake mechanism that transformed the movement of the waves into light. Pictures of the flashlight project and a summary of the evolution of the WISER curricula are included in Figure 4.

To evaluate the impact of the WISER engineering club program, semi-structured interviews with 24 current and former WISER engineering club members were conducted. Students shared overwhelmingly positive impressions of the curricula taught by the Duke student leaders and of the science competition activities pursued independently. Eighty-three percent (n = 20) described how the club had helped or had the potential to help the WISER community or a broader regional, national, or even global community. Students most commonly reported that the flashlights had helped them to study or perform chores during power outages at WISER, and the majority of students also spoke of the club's potential ability to create innovations to improve the surrounding community. Seventy-five percent (n = 18) of students stated that they had used skills or knowledge from the engineering club outside of club time, such as at home to build flashlights and repair broken electronics. Fifty percent (n = 12) of students said that they



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Year	Curriculum	# Duke students	# WISER students	# flashlights built
2014	Flashlight curriculum taught by Duke students	2	42	20
2015	Recharging mechanism and human centered design taught by Duke students	2	18	30
2016	Engineering club led by WISER students	0	24	30
2017	Engineering club led by WISER students	0	28	15

Figure 4. WISER. (A) WISER learners and Duke student leaders and (B) flashlight constructed by WISER students for the Kenya Science Congress. (C) The curriculum, number of students who participated in the Ignite program and WISER engineering club, and number of flashlights built from 2014–2017.

had taught others something from the club, 21% (n = 5) of whom taught friends or family outside of WISER. The original flashlight curriculum was designed in conjunction with the WISER faculty member to follow the physics curriculum and serve as a laboratory exercise to enhance learning. Eighty seven percent (n = 21) of participants reported that they recognized there was a connection between classes and the engineering club, and 29% (n = 7) stated that the club helped them and other students learn physics. Finally, 67% (n = 16) of participants discussed how the club connected to future possible careers or occupations related to engineering. Table 2 contains a summary and representative quotations from each of these categories.

We believe that the sustained success and evolution of this program is largely attributable to the presence of a strong local leader who champions the club year-round and provides new opportunities.

Table 2. Summary of themes, number of students out of 24 total students who mentioned each theme, and representative quotations from semi-structured interviews with current and former WISER engineering club members.

Theme	Students who mentioned theme	Representative Quotation
Club's past or future ability to help the community	83% (n = 20)	"...when we were in Form 4, ...the electricity were never there. But you see that didn't stop us from learning. We used our skills that we acquired from the engineering club. We made lights all around the class and everyone could get access to that light and just continue their studies." "I feel happy and interested to like produce the flashlights and help maybe the people around cause in our community in Muhuru Bay... they use the kerosene, which will be expensive... to some people who cannot afford it...I will be helping them like producing the flashlights and they'll be distributed in some houses."
Use of knowledge outside of club context	75% (n = 18)	"Yeah like when we stay at home, we use the candles or the small lamps... with the knowledge of engineering, I went home and now just bought bulbs and wires and connected the house..."
Teaching others about engineering club ideas and skills	50% (n = 12)	"I've taught my brother, my elder brother actually... I went and shared the idea of making the torch with him at home and we figured out how to make some basic torches from even repairing those that are broken..."
Connection between club and classes at WISER	88% (n = 21)	"I went to engineering since at first I had problems with connections in physics...building of torches, it has helped me so now I don't have a problem with connecting circuits in the lab. Thus, it has enhanced my practical ability in physics."
Connection between club and future career	67% (n = 16)	"Yeah there is a very big connection. Like in engineering club there is a lot of innovation and inventions...So at the time when we do the work practically I feel like okay I'm already there as I've already achieved my career in, in an indirect way."

WISER's engineering club continues to use the original flashlight modules to train new members, but the experienced students work on more complex projects under the guidance of a WISER faculty member who continues to create close connections between the projects in the engineering club and his advanced physics class. The students in the advanced physics class participate in the engineering club, which can help them experiment with and master difficult concepts related to electricity and magnetism.

Adapting the Program for Non-Student Female Learners in India

In 2015, we started a new partnership with two schools in Kolkata, India, Tulipdale Public School and Future Hope, which serve many children without reliable access to electricity. While the flashlight curriculum was appropriate for the adolescent students at Future Hope, it was too advanced for the elementary level students at Tulipdale. However, there was significant community interest in the flashlight curriculum from the mothers of these students. Thus, in 2016 and 2017, the Duke student leaders adapted and taught the engineering program to the Tulipdale mothers. Many of the mothers spoke little or no English, but the Duke student leaders were able to illustrate concepts through hands-on learning and demonstrations. In 2017, several mothers from the previous year returned to participate in the curriculum for a second time. The returning mothers quickly became natural leaders in the classroom and felt empowered to help their peers during challenging tasks. One of the Duke student leaders said "the [Tulipdale] mothers [in Kolkata] gained a technical skill, but above that, they were empowered. In a strictly female setting, the mothers could complete a STEM project by themselves and exercise creativity in casing and decorating their circuit." Additionally, during the exhibition following the culmination of the summer program in 2017, multiple mothers expressed their eagerness to begin selling their flashlights in the community. At the local community fair, where their flashlights were on display, more than 30 families offered to purchase their flashlights, indicating that this program has the potential to turn into a micro-financing initiative. Pictures from and a summary of the flashlight curriculum data implemented at Tulipdale and Future Hope is included in Figure 5.

C

Year	Curriculum	# Duke students	# local students	# flashlights built
2015	Flashlight curriculum taught to Tulipdale and Future Hope students	4	25	8
2016	Flashlight curriculum taught to Tulipdale mothers and Future Hope students	4	32	26
2017	Flashlight curriculum taught to Tulipdale mothers	2	35	35

Figure 5. Tulipdale and Future Hope. (A) Parent program participants and (B) a flashlight constructed by a Future Hope student. (C) The curriculum, number of students who participated in the Ignite program, and number of flashlights built from 2015–2017.

Duke Student-Initiated Program to Scale the Ignite Program in Guatemala

In contrast to the DukeEngage model to identify community partners, the expansion of the program into Guatemala was driven by a student-led group called Desarrolla, a club that aims to connect the Duke community with Latin America. In 2017, a Duke student from Guatemala and a team of peers initiated a partnership with us to implement the flashlight curriculum at INSS, which is a Catholic boarding school for girls ages 14-20 in San Andrés Semetabaj, Sololá, Guatemala. This school students from a wide range of socio-economic backgrounds. Some students are from the city and have regular access to electricity, but a majority of students are from rural communities with limited or no access to electricity in their homes and communities. The goal of the curriculum implemented at INSS was to educate students about STEM-related fields and careers to empower them to pursue higher education and careers in STEM. To achieve this goal, the Duke student leaders taught the students at INSS how to identify needs within their own communities through self-evaluation and then design a flashlight prototype to address those needs (see Table S1). While students at INSS were not initially enthusiastic about circuit construction or solving for variables using Ohm's law, once self-evaluation and activities centered on career development were introduced, students became enthusiastic about constructing flashlights. One student said, "I believe us girls are just as interested in science, math, and engineering as the boys… I just wish schools offered us more [STEM] classes. I think we just need to take courses like [this], then we can demonstrate that women are just as capable as men in STEM fields in Guatemala." This curriculum is now being scaled across Guatemala by a foundation in Guatemala City called FUNDEGUA. Specifically, FUNDEGUA arranged for Duke student leaders to teach the flashlight curriculum to students from Universidad del Valle de Guatemala (in person) and University of Michigan (through a series of online webinars), who have disseminated the curriculum to 150 local Guatemalan high school students to date, reflecting its scalability. Pictures from and summary of the flashlight curriculum implemented at INSS is included in Figure 6.

DISCUSSION

There are a number of unique features that distinguish Ignite from other problem-based, community-need-oriented engineering curricula. Perhaps the most notable is its adaptability across multiple contexts without substantial infrastructure. Another distinguishing feature is that the human-centered design framework encourages interdisciplinary university students, who study concepts at the intersection of technology and global health, to directly engage in social innovation. This methodology allows participants to approach each Ignite program site as uniquely different, allowing for more site-specific curricula to be developed. The student leaders come to recognize that those within a community are best equipped to address the issues they experience because they understand the context of their

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Year	Curriculum	# University students		# local students	# flashlights built
		Duke	Non-Duke		
2017	Flashlight and human centered design curriculum taught by Duke students	3	0	79	25
2018	Flashlight and human centered design curriculum taught by Duke students	2	0	44	9
2018	Flashlight curriculum taught by other University students	3	15	150	32

Figure 6. INSS. (A) Program participants and Duke student leader and (B) flashlight constructed by INSS students. (C) The curriculum, number of students who participated in the Ignite program, and number of flashlights built in 2017–2018.

culture, beliefs, and geopolitical position and how those factors impact the design of an intervention or technological solution. A third distinguishing feature pertains to learners. Ignite is built upon the assumption that while students have access to an unprecedented amount of information online, critical thinking and problem skills are not best learned from videos, but instead require sustained mentorship. Continually generating new student leaders decreases the need for continued support from institutions in the U.S., which has the potential to make the program more sustainable. The premise of the Ignite program is that any STEM content can be internalized through a design-thinking framework. Further, the SDGs create personal relevance to the communities in which these curricula are taught. Critical-thinking, problem-solving, and personal relevance are essential to creating cognitive maturity (Veenman 2011).

An added benefit of the Ignite program is that it empowers women and girls in international communities to engage in STEM-related activities. Gender inequalities remain prevalent across cultures and countries (GlobalGiving 2018). Countries with higher levels of gender equality also have less poverty, more economic growth, and a higher standard of living; thus, SDG #5 is to "achieve gender equality and empower all women and girls" (GlobalGiving 2018). Our international partnerships with WISER, the mothers at Tulipdale, and INSS specifically target girls at the secondary school level and women in adulthood. Additionally, the majority of Duke undergraduate participants in the Ignite program have been females from both engineering and non-engineering majors. Research indicates that the study of science is more meaningful to women if connections are made to other fields (Hill, Corbett, and St. Rose 2010). Additionally, research supports the notion that when young females have female mentors in STEM, it significantly improves their scores and college-level retention in engineering disciplines (Dennehy and Dasgupta 2017).

The ways in which the Ignite curriculum has evolved between partner sites aligns with the principles of liberatory design/inclusive design models in which participants enter a community with the mentality of designing "with" and not "for." This approach promotes trust as community members guide how the Ignite model should be adapted to maximize the impact on their local community. Ignite is unique compared to other STEM programs related to the SDGs because it supports a paradigm shift in engineering and design education: learners are empowered to use their unique voices to contribute meaningfully to the classroom environment (Bennett and Rosnerr 2019; Newell and Gregor 2000).

Furthermore, when students who have participated as Ignite learners have the opportunity to become the next set of Ignite leaders within their communities, they benefit bi-directionally, as teaching these concepts reinforces their leadership skills and cultivates a mentality of shared community and commitment to social good. Peer-to-peer mentoring reinforces students' knowledge and skills, builds leadership and communication skills, and empower students to persevere in STEM coursework (Herrera et al. 2008; Bleske et al. 2016; Snyder et al. 2016).

The Ignite program is readily scalable as few resources are needed to implement the program. For example, to execute the initial phase of this program, the engineering supplies for INSS totaled approximately $540 ($6.83 per student taught). The total cost to support Duke personnel traveling to Guatemala was approximately $2,500 ($38.47 per student taught), which included flights, lodging, and food. However, as the efficacy of the leader-learner model improves, personnel costs will be significantly reduced because older students in the school will have the skills needed to teach their younger peers, thus eliminating travel expenses.

There were several challenges or limitations associated with the initial implementation of the Ignite program. First, it was difficult to procure flashlight materials locally; thus, Duke student leaders addressed this challenge in two ways: 1) for the first year of the program in each country, flashlight materials were purchased during the semester while in the U.S., so Duke student leaders could begin teaching the curriculum immediately upon arrival at each international site, and 2) Duke student leaders worked with the community partners during the summer to identify local stores from which additional materials could be purchased for subsequent years. Another limitation associated with the Ignite program was that young students, particularly elementary level students at Tulipdale who were less than 11 years old, had difficulty with fine motor skills required for flashlight assembly. Thus, the flashlight curriculum at Tulipdale was adapted to teach the mothers of the Tulipdale students, many of whom indicated significant interest in the program. Lastly, while implementing the Ignite program at INSS, Duke student leaders realized that local students needed additional math skills to design flashlight circuits. Therefore, Duke student leaders adapted their curriculum to cover basic algebra and fractions so that INSS students could use Ohm's law to compute the resistor values needed for their flashlights. Lastly, the iterative nature of the Ignite model in its first years of implementation made it challenging to apply consistent and robust evaluation and monitoring metrics, as the program was modified on the ground at each project site. Thus, qualitative and quantitative assessment of the longer-term impact of the program is outside of the scope of this study. Rather, this work provides: 1) a description of the initial implementation and iterative process of development of the Ignite program at several locations, and 2) a qualitative assessment of the short-term impact at Duke, WISER, and INSS. However, the Ignite model has now been standardized into an adaptable model with appropriate metrics including interviews and surveys, which are currently being implemented with Duke and INSS students and also in 16 new project sites in the US, Guatemala, and Peru, which will be the subject of future work.

The Ignite program initially leveraged the human-centered design framework to teach STEM skills and promote critical thinking and problem solving for students in low-resource communities. We believe this curriculum can potentially impact 3 of the SDGs – renewable energy, quality education, and gender equality. Ultimately, human-centered design provides a framework to engage communities in practical problem solving and may be sustained within the communities through a leader-learner model and peer-to-peer mentorship.

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