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Development of a Surgical Lamp for Ethiopia by Undergraduate Innovators for Global Health

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Abstract

For populations in low-resource countries, access to proper healthcare is often hindered by a lack of functional medical equipment. In these settings, equity requires adjustment of traditional engineering design priorities to maximize usability and benefit to the healthcare facility. Minimalism, efficiency, and on-the-ground practical value must be prioritized over embellishment, complexity, and state-of-the-art features.

Northeastern University Innovators for Global Health (NU-IGH) is a student organization in Boston, Massachusetts focused on improving global access to medical technology. Students in NU-IGH recently began a partnership with St. Paul's Hospital Millennium Medical College (SPHMMC) in Addis Ababa, Ethiopia. The group identified a critical need for a surgical lamp optimized for the demands of SPHMMC. Design constraints would include low-cost and accessible parts, ease of use and repair, and ability to operate continuously despite frequent, short-term electrical power outages.

The students spent one and a half semesters designing and building just such a surgical lamp. They researched surgical lamp standards and the needs of low-resource hospitals in Addis Ababa. The project resulted in a functional surgical lamp that is approved for use at SPHMMC and which can be produced for a fraction of the cost of surgical lamps in the United States. The lamp's ease of assembly allows for production with tools and parts available in Addis Ababa. This lamp enables hospital staff to perform life-saving surgeries.

Students traveled again to Addis Ababa in 2020 to assemble the prototype alongside SPHMMC's biomedical students and to present a report on the lamp so that additional copies can be made by hospital staff. This paper will present this project's conception and results in the context of the lessons learned by the students that are of use to students and faculty at other schools who might seek to undertake similar projects.

Introduction

The World Health Organization (WHO) estimates that as much as 80% of healthcare equipment in low-resource countries is donated or funded through international organizations and foreign governments, but only 10-30% of that equipment is able to be used — and most of that 10-30% is restricted to those who can pay and are located within large cities [1]. This is due to the simple fact that while most of the world's healthcare is consumed in low-resource settings, medical technology is still designed primarily for high-resource settings. These designs assume a level of infrastructure that is not a reality in many places and follow expensive, complicated design criteria that only exacerbate the problem. Most donated medical equipment lacks the ability to be repaired due to inaccessible spare parts, unreadable or missing instruction manuals, and limited local technical support to perform maintenance and repairs. Even when the equipment is in functional condition, intermittent electricity, water, and other necessities render the equipment unusable. This leaves millions without access to life-saving healthcare equipment developed decades ago and is one of the most prevalent causes of death. In order to move forward from this situation and resolve global inequities in access to healthcare, our engineering design must reflect the unique needs and constraints of low-resource settings [2].

The current ABET criteria requires that students learn to design solutions "to meet desired needs within realistic constraints" (student outcome C) and to "understand the impact of engineering solutions in a global, economic, environmental, and societal context" (student outcome H) [3]. These learning objectives can be difficult to incorporate in an impactful way for students who are accustomed to a high resource living environment in the United States. For example, a common mechanical engineering class project requires students to build a physical structure to support a load, but only allows certain building materials such as pasta noodles or PVC pipes to be used. Even though other materials are readily available at a hardware store near the university, the purpose is to enforce student innovation within a restricted design space. In a sense, the constraints are imposed by the instructor for the sole purpose of being a constraint. Projects like this can be effective learning tools, but the constraints can feel artificial and thus have less impact on the student experience relative to design problems that are inherently constrained. Similarly, without travel to directly interact with people in global societies, especially those whose culture and / or resource availability is significantly different from the students' home, the ability of our students to place their solutions in a global, economic, environmental, and societal context may be somewhat limited.

A few years ago, a group of students at Northeastern University, a medium-sized, urban, research university, formed a team with interests in creating healthcare solutions for people in low-resource countries. The concept is similar in nature to the international group Engineers Without Borders, but focused specifically on healthcare devices. The students thus formed the NU Innovators for Global Health (NU-IGH) with the goal to design and build devices for these settings with open designs that are not only functional for the hospital, but can be both sustainably maintained and have additional copies built by the host institution. The constraints are thus not merely a low cost product, but a product built within the financial, material, and cultural resources of that setting.

In this paper, a description of one of the NU-IGH projects is given. We will give the context of the project's founding and lessons learned while designing and delivering the solution. Our purpose is to exemplify the process of creating this meaningful extracurricular experience in the hopes that others can take up similar projects on their campus.

Needs Assessment

Five NU-IGH members traveled to Addis Ababa in December 2018 to collaborate with St. Paul's Hospital Millenium Medical College (SPHMMC). During this inaugural trip, these students conducted a needs assessment of the hospital by talking to numerous doctors, nurses, and other clinicians from various departments. Based on these interviews, the students identified a number of projects that could potentially benefit and address the needs of the hospital, one of which was a low-cost, low-resource, battery-powered surgical lamp. The interviews shed light on the issues they faced, such as halogen bulbs that frequently burned out and unreliable power within the hospital's operating room.

The students learned that the surgical lamps that were being used at the hospital relied on halogen bulbs, which are particularly expensive to import and have short life-spans [4]. In fact, the hospital's technicians stated that they spent at least one day every week repairing the lamps and replacing bulbs. The students observed that at any one time, most of the lamps in the operating room were actually operating with half the necessary number of bulbs due to procurement difficulties. With these constraints in mind, the NU-IGH design team decided to tackle the design and creation of a functional LED surgical lamp prototype that the hospital's technicians would be able to re-create utilizing only resources and materials available in Addis Ababa. Learning how to adequately communicate with the hospital staff was critical for this needs assessment to ensure that the prototype would be functional and meet all the needs and design requirements based on the resources of the hospital.

Methods

In this section, the design decisions made by the students are described and defended. As will be shown, the constraints imposed by the needs of an operating room in Addis Ababa created an authentic design problem for the students. Further, the knowledge that their creation would be used by the doctors, nurses, and technicians that the students met during their first trip to the hospital to aid in the delivery of health to the Addis Ababa community meant that the students felt a genuine understanding of the impacts of their work. During the initial brainstorming and literature search, the students researched other low-resource lamps. Inspiration for the initial design came from the University of New South Wales' *Uninterruptible Surgical Lamp*, but the students had to make design decisions tailored to the needs and resources of SPHMMC [5].

Lighting System

The design for the surgical lamp's lighting system had to improve on the existing halogen bulb lighting at SPHMMC. LED lighting was the clear choice for the team's design - LED bulbs are cheaper, more energy efficient, and longer-lasting than halogen lighting. Additionally, they generate less waste heat than halogen bulbs, making this option safer for the operating room and reducing the lamp's design complexity. The requirements the team determined based on cost, light output, and a number of common metrics for surgical lighting systems led to the selection of twenty 5W bulbs that were purchased online from an international online shopping website. Each bulb provides the equivalent lighting output of a 50W halogen bulb, which is a result of the improved energy efficiency of the LED bulbs.

Another important design consideration for the lighting system was the arrangement of the selected LED bulbs. Shadows must be prevented when working under a surgical lamp, as they could inhibit the surgeon's vision and jeopardize the patient's safety. The team's strategy to limit the effects of shadows was to orient the bulbs evenly around the center of the lamp's head. The bulbs were placed in four groupings of five bulbs each, and each grouping was angled so that they would focus on a single point where the full lighting capacity of the bulbs would be maximized. The angles of these groups can be adjusted so that the lamp's head could be placed at different heights while maintaining the light's focus on the surgical table.

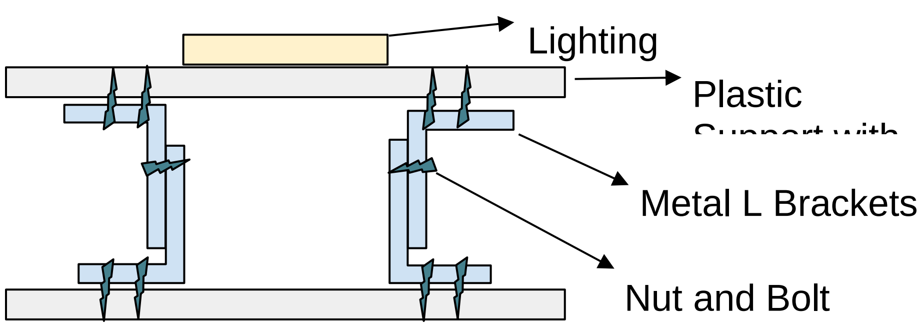

Figure 1. Lighting system structure.

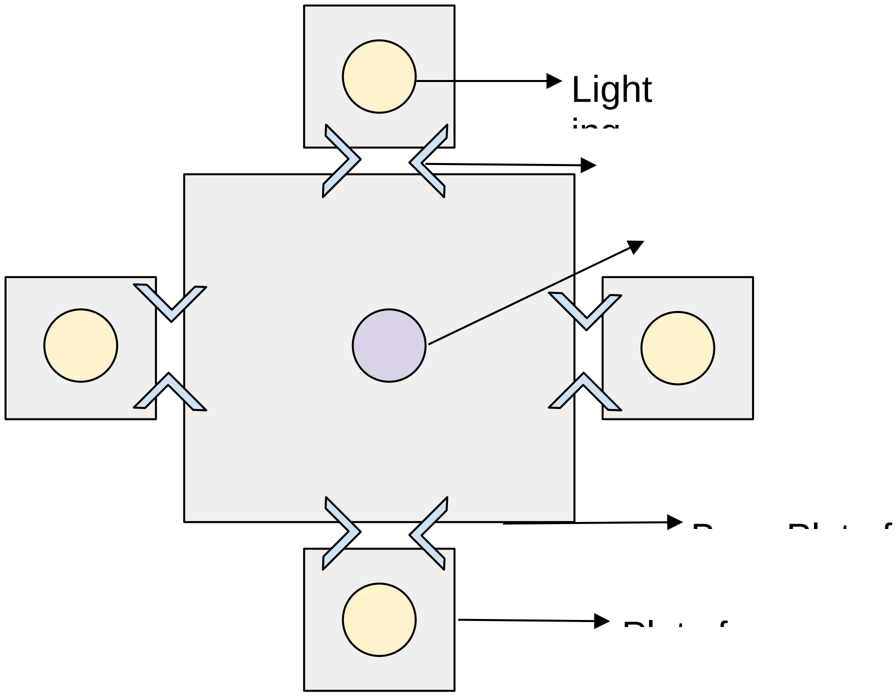

Figure 2. Lighting system design layout.

The lighting system's complete design is shown in Figures 1 and 2, which depict the layout of the groupings of LED bulbs around the center of the lamp's head, and the structure by which the lighting system is secured to the lamp. By using parts that are low-cost and easily accessible through well-known online vendors, the team was able to design a system that was affordable and possible to assemble with only hand tools. Additionally, the lighting design and the electronics that supply its power improve the safety over high-powered halogen bulbs. These factors make the design easily reproducible at other universities, even those that may not have access to the resources necessary to fabricate more complex and expensive lighting systems.

Structure Design

The goal behind the mechanical design was to create a surgical lamp that was stable, mobile, and functional that would be easily assembled without the use of expensive tools or custom parts. To achieve this, the base of the lamp consisted of four wheels and a square base, and the arm was equipped with a telescoping section to allow the height of the light to be changed easily during use. Inspiration was taken from camera tripods for this portion of the project. Most pre-made pieces were too weak to support the final weight of the lamp head, so the telescoping portion was designed with a special steel bolt. This bolt could be removed while the rest of the lamp was held, and a technician could raise and lower the main lamp body. To assure safety, the wheels were strongly attached to the base while constructing to prevent the lamp from falling over while in use.

The hinge components were a crucial part of the lamp that required a lot of work to get right. At first, premade hinge components were used with simple springs attached. The springs were not secured correctly at first and would move around, restricting the mobility of the device. In the final design iteration, channels were created so the springs would not move, and a third spring was added. Another vital part of the lamp was the joint between the LED complex and the rest of the body. A special ball and socket joint was purchased to allow the LED complex to be moved easily. It was determined during the design process that this piece of the device needed to be especially mobile, so operators could adjust the light and avoid shadows during surgery.

Despite the complex challenges faced in designing a reliable structure for an articulating surgical lamp, the only tools needed for assembly were a handsaw, hand held drill with standard drill bits, and simple handheld tools to secure hardware in the lamp. The use of aluminum as the primary material for the structural design helped keep the cost and weight of the lamp low while providing the necessary strength to support the lamp's lighting components. Once again, all the required parts for the lamp's structure were secured from popular vendors which will keep the design widely accessible.

Battery Backup

The needs assessment at SPHMMC showed that the irregular supply of electrical power contributed to the unreliability of its surgical lamps. This can cause significant problems in an operating room, where surgeons rely on the light from surgical lamps to perform their surgeries safely and effectively. Thus, the team decided that the lamp would include a battery backup system that would keep the lamp in use during an unexpected power outage. The ideal power source for this battery backup system was a 12 V, lead-acid battery. This type of battery meets the voltage requirements of the 12 V LED light bulbs in the lamp, and makes it easy to source the batteries locally in Ethiopia or in the United States as they are widely available due to their use in cars. The addition of a switch to the lamp's electrical circuit added the capability to easily switch between battery power, wall power, and off. Because of this, surgeons will be able to easily switch to battery power in the event of a power outage, and switch the lamp off when not in use.

Feedback During Process

During the design process, students kept in regular email contact with local technical and nontechnical contacts in Ethiopia. These included contacts made at SPHMMC on NU-IGH's previous trip to Ethiopia. Students utilized these contacts primarily for feedback on what SPHMMC's needs were, what approaches would be most helpful to meet those needs, and what materials and parts would be accessible in Addis Ababa.

Design for Cost

When designing the lamp, it was important to keep costs low for the prototype and the final product. The group decided on metal pipes as the main structural component of the device. The most expensive component is the special ball and socket joint used to connect the LED lighting complex to the rest of the lamp. While it is important to keep costs low for NU-IGH, it is also important for repairs and the construction of future models of the lamp in Addis Ababa. In Appendix A, a final cost sheet is displayed.

Additional Costs for Project

Beyond the cost of materials and supplies in creating the solution, a project like this incurs significant additional costs related to travel: lodging, food, in-country transportation, and airfare. The airfare for the faculty advisor was sponsored directly by the university. Support for the remaining costs came from a combination of $4000 from an undergraduate research grant awarded by the Provost's office and fundraising using an internal donation platform similar to GoFundMe. In total, the travel related expenses were approximately $6,500, the vast majority of which was airfare. Approximately $5000 were spent on airfare, lodging costs were approximately $500, and the group meals and in-country transportation were about $1000 total.

Results

Final Design

The following images show the final design of the surgical lamp as it was brought to SPHMMC. The lamp's head consists of groupings of LED lights at adjustable angles, attached to a plate in the center where a rod would allow for easy adjustment of the direction of the light's focus.

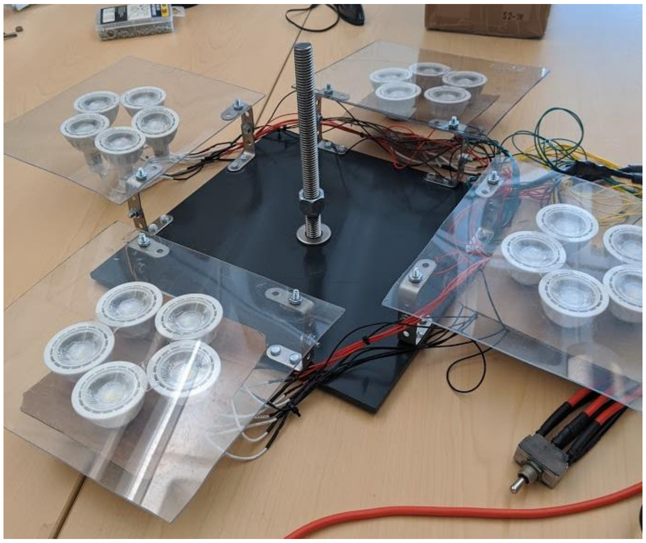

Figure 1. Close-up image of the lamp's head with LED bulbs.

The surgical lamp's structure consists of square aluminum tubing that provides sufficient strength to support the weight of the lamp's head. A ball and socket joint and hinges in the structure provide a range of motion to adjust the direction of the lamp's focus, and a telescoping mechanism in the vertical supports of the lamp allow for height adjustment as well. The aluminum structure was joined at the base to a dolly that allows for simple transportation by keeping the structure of the lamp on wheels.

Figure 2. Close-up image of the lamp's support structure.

The image below shows the full structure of the lamp upon assembly at SPHMMC. A 12 V lead-acid battery was sourced locally and upon attachment to the lamp's circuit, it successfully powered the lighting system. At a total cost-to-produce of under $500, the team was able to create a sufficient lighting solution for SPHMMC at a fraction of the cost of typical surgical lamps in the United States.

Figure 3. Fully assembled surgical lamp at SPHMMC.

Implementation On-Site

After reconstructing the lamp at the hospital, it was presented first to the hospital engineering staff who had assisted in the reconstruction. At a meeting, the design was described, making sure to explain the rationale behind all of the students' key design decisions. Multiple copies of a written report containing the same was also delivered. Every component was detailed so that replacements can be found and additional copies of the lamp can be fabricated by the hospital's technicians.

The technicians made several suggestions for changes at this meeting, and the team implemented immediately as many of the suggestions as possible. For example, the weight of the bulbs and the lamp head made the lamp's base mechanically unstable. The structure needed to be strengthened. A thick piece of plywood would have worked perfectly, but obtaining a sheet of new plywood in Addis Ababa would have been very difficult. Instead, the technicians suggested repurposing wood from used shipping containers found in the hospital's loading dock. Containers were found, dissembled, hand sawed into proper shape, and added to the lamp's base.

After this work with the technicians, the lamp was presented to the lamp's users, the operating room doctors and nurses. At this meeting, the students were told of an additional requirement that hadn't yet been met. After a surgical procedure takes place in the operating room, all equipment in the room must have the surfaces disinfected by wiping with a chemical agent. Thus, the lamp's base, which at that point had many touch points and surfaces, had to be covered with a single, wipeable surface. A covering of plastic or metal would do, but several flexible pieces would be needed so that they could be fitted over the battery and other components. Several technicians, students, and the faculty member made a trip to Addis Ababa's central market to find a solution. The Mercato, as it is known, is often claimed to be Africa's largest open air market and can be a very difficult place for non-locals to navigate. After considerable effort, a stall selling sheet metal was found, and a small strip was bargained for and purchased. Usable bolts and nuts to hold down the sheet metal were found and bargained for at a separate stall. Taking these back to the hospital, the students and technicians worked together to cut, shape, and add the parts to the lamp.

Additional changes made on-site include incorporating springs to the support shaft and arm of the lamp. Prior to arriving in Ethiopia, the significant weight of the lamp head with the LED bulbs caused the arm to fall and not maintain its locked position. The students and technicians at SPHMMC spent the first two days at the hospital trying different configurations and springs to keep the lamp head up. Four springs were ultimately used. Two of them were in parallel and connected the end of the shorter arm to the longer arm. The other two, also in parallel, connected the longer arm to the main shaft. Unfortunately this spring system did not allow for any movement on-the-go of the lamp head or adjustment of the height. This flexibility had to be sacrificed for this prototype, but the students discussed with the technicians how this should be a key improvement for the next iteration.

The first hour at SPHMMC was a humbling experience and highlighted how drastic the differences in healthcare systems between the United States and Ethiopia are. While driving to the hospital, the students saw people selling coffins on the street leading up to the entrance to SPHMMC. They saw hundreds of people leaving and weeping outside the HIV/AIDS center because someone had just passed away. Bed sheets and scrubs were air drying on clotheslines outside. The emergency room had a line that stretched around the building and people were sitting on each other's laps in the waiting room. Conversations throughout the week with the technicians, nurses, and doctors highlighted their frustration about the lack of resources and inability to help more people, which further fueled their desire to create more solutions tailored to the needs and means of the hospital.

Both hospital employees and students expressed that they felt the partnership was meaningful and productive. Students who were eager to use their engineering skills to help others and promote equity expressed that NU-IGH provided them with an opportunity to do so. Both students who went to Ethiopia and those who did not reported that the surgical lamp project provided them with valuable learning about global health and engineering techniques. Likewise, hospital technical staff and administrators expressed gratitude to the students for their work and a desire to continue and build upon the partnership.

Discussion

With the surgical lamp design and prototype now in the hands of SPHMMC, it is up to them to choose how best to use it to their benefit. They have the option to keep the design as it is, or adjust it with alternative components and materials to best meet their needs and sourcing capabilities. In addition, they can either begin to produce many of these surgical lamps to use in the hospital or, if that proves unfeasible, simply take inspiration from the design to better repair existing surgical lamps and other hospital equipment. The collaborative nature of NU-IGH's partnership with SPHMMC is highly important: students acknowledge that they cannot possibly know the needs and capabilities of a hospital in a country they have never lived or worked in as well as the technicians there, nor will they ever have as much on-the-ground experience solving their problems as locals do. Therefore, the American students do not expect to simply impose a solution on the hospital that will perfectly address their needs. Rather, they treat their projects as a knowledge exchange in which both parties contribute their unique expertise to learn from each other and find better solutions.

For SPHMMC, the most tangible gain was the surgical lamp design and prototype which can be implemented in the hospital as they wish. In addition, NU-IGH hopes that their partnership will allow their technicians to learn from the design and from their collaborative work to improve their engineering and repair capabilities. In particular, they hope that this partnership can help technicians gain the engineering knowledge and mindset to begin designing and building more creative solutions to their medical device needs, rather than being stuck simply repairing donated equipment that is not tailored to them in the first place. In addition to implementing the surgical lamp, the students led workshops showing the technicians the basics of Arduino, an electronic prototyping platform, and donated 13 Arduino kits to the hospital in hopes of encouraging more prototyping. Many workshop technicians are biomedical trade students rather than engineers, so one of the goals of the partnership is to share engineering and design skills they will find useful.

In addition to design project experience, the most valuable gain for the American students in NU-IGH is an approach to engineering that is more equitable and user-focused. Students working on a design project such as the low-cost surgical lamp must accept that the best design is not necessarily the most cutting-edge one. Rather, the best design is one that is well-tailored to serve its function in the environment where it will be used. Further, different user environments require different technologies, and a surgical lamp designed for a hospital in the United States may not work well in a hospital in Ethiopia. Students learn that just because a solution may appear better for a context they are familiar with doesn't mean it actually is better for the context in which the product will be used. By learning about and engaging with the difficulties of designing medical devices for a low-resource hospital, students must also reckon with the role that engineering plays in social and economic inequalities, both globally and domestically. Products like medical devices tend to be designed for communities with the most money to pay for them and the most resources to build them, and therefore often can't meet the needs of those who need them the most.

With these ideas in mind, the surgical lamp's design was also guided by ethical considerations that had to be integral to the design and implementation of a device for medical applications in a low-resource environment. First and foremost, the students recognized that reducing the cost of the device should not come at the expense of its safety. If the resulting product was not safe, it would unfairly put those who use them at risk, and compromise the goal to develop technology for communities that need better medical resources. Additionally, it was crucial to the design process that the team was in constant communication with stakeholders at SPHMMC, who provided insight into the hospital's needs and feedback on the lamp's design. Without the input from those who would actually use and implement the lamp, it would be impossible to create a design that fulfilled what was missing in the existing technology. By engaging with those who worked in and around the hospital, students were better able to gauge how their design would solve certain issues in the low-resource setting.

Prior to both trips, the students participated in semester-long pre-travel courses hosted weekly by the IGH presidents, academic advisors, and organization alumni. This course consisted of signals processing labs and Arduino crash courses to ensure that they were technically prepared to assist with any repairs, troubleshoot the surgical lamp, and teach Arduino to the technicians. Another critical aspect of the workshops were the cultural communication trainings and Ethiopian culture lectures. Since the students were traveling to a foreign country and collaborating with Ethiopians, it is important that they are respectful of the values and culture of the people there. Furthermore, it is crucial for the students to recognize their privilege and cultural differences when communicating with the hospital staff.

Conclusion

NU-IGH plans to continue and build upon its model from the surgical lamp project in future design projects. Its design group's next project after the surgical lamp is a low-cost ECG electrodes project based on the group's needs assessment from their last trip to SPHMMC. One design goal the group is planning on integrating is the ability to mass produce a device locally in Ethiopia. Designs that can be manufactured at scale with local resources and capabilities provide a blueprint for a sustainable long-term solution in which devices can be manufactured in Ethiopia, for Ethiopian users, without relying on more expensive and less tailored products from foreign countries. This would have the dual effect of both providing truly sustainable device access and also helping promote local manufacturing and economic development.

NU-IGH's surgical lamp design and implementation process offers a valuable form of engineering education and a more sustainable model for engineering humanitarian work. Rather than simply building and donating equipment for hospitals in other countries, students collaborate mutually with those hospitals. Students see firsthand the environment they are designing for and choose a design based on reported needs from users. At every step of the design process, they must consider whether materials are sourceable in the target country and whether the design will be practically and economically usable by the hospital. Finally, students deliver the prototype to the real-life context in which it will be implemented, collaborating with local technicians to improve it. Throughout this process, students learn to design for broader social context and unfamiliar needs. NU-IGH hopes that its model can be implemented by students in other American universities to achieve more productive engineering humanitarian work and more effective engineering education.

References

1. *Medical device donations: considerations for solicitation and provision*. World Health Organization, 2011. [E-book] Available: https://apps.who.int/iris/handle/10665/44568
2. D. Niemeier, H. Gombachika, R. Richards-Kortum, "How to transform the practice of engineering to meet global health needs," *Science*, vol. 345, pp. 1287–1290, 2014.
3. "Criteria for Accrediting Engineering Programs, 2020-2021," ABET. [Online]. Available: https://www.abet.org/accreditation/accreditation-criteria/criteria-for-accrediting-engineering-programs-2020-2021/. [Accessed: 22-Feb-2021].
4. "The Difference Between Halogen and LED Lights in Surgical Rooms," Bovie Medical, 05-Apr-2019. [Online]. Available: https://www.boviemedical.com/2016/08/01/the-difference-between-halogen-and-led-lights-in-surgical-rooms/. [Accessed: 19-Dec-2020].
5. University of New South Wales Graduate School of Biomedical Engineering, "Uninterruptible Surgical Lamp," Engineering World Health 2016 Design Competition, May 2016.

Appendix A: Cost Sheet

Name	Price	Quantity	Total Cost
Moving Cart	$32.99	1	$32.99
PVC Sheet, 24" x 24" x 1/4"	$33.44	1	$33.44
Corner Bracket, 4" x 4" x 7/8"	$2.03	1	$2.03
Aluminum Square Tube, 1-1/4" x 1-1/4" x 1/16" Wall x 36" Long	$22.31	1	$22.31
Aluminum Rectangular Tube, 1/16" Thickness, 3/4" x 3/4"	$24.00	3	$72.00
Lever locking hinge	$17.21	1	$17.21
Friction Hinge	$10.48	1	$10.48
Ball and socket	$31.99	1	$31.99
40mm L Brackets	$8.99	1	$8.99
PVC Sheet, 12" x 12" x 1/4"	$11.33	1	$11.33
Polycarbonate 12x18" sheets	$8.99	2	$17.98
Double-sided Tape	$10.95	1	$10.95
Epoxy	$4.97	1	$4.97
Various Hardware	--	--	$20.00
Springs	--	--	$80.00
10 ft 10 AWG wire	$15.98	1	$15.98
10 pc LED bulbs	$28.99	2	$57.98
20 pc LED sockets	$8.59	1	$8.59
25 pc wire connectors	$3.18	1	$3.18
AC/DC 12V Power supply	$18.99	1	$18.99
15A Fuse and holder	$6.78	1	$6.78
Switch	$10.80	1	$10.80
		TOTAL	**$498.97**