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Engaging Electrical and Computer Engineering Students in Humanitarian Engineering Projects

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Abstract:

Electrical and Computer Engineering (ECE) students are equipped with a toolbox of many relevant tools for working on international development projects. These include low-cost, open-source microcontrollers (such as the Arduino) and computers (e.g. Raspberry Pi), low-cost communications devices (e.g. Ubiquiti equipment), low-cost solar panels and LED lights, etc. There is an opportunity to engage ECE students in humanitarian engineering-oriented capstone projects that are focused on addressing the UN Sustainable Development goals in underserved communities around the world. These types of projects are particularly engaging with today's students who are interested in making a difference in the world and may struggle to see such an impact in traditional electrical engineering curricula. The topic of humanitarian engineering may be particularly important for women and minorities underrepresented in electrical and computer engineering. It also can help instructors address the challenging ABET outcomes related to global and social responsibility.

Over the last fifteen years, the author has engaged over 100 ECE students in capstone projects oriented towards humanitarian engineering. In this paper, the evolution of curricular elements to address the special requirements for conducting such projects will be presented along with examples of projects and student outcomes for such projects

Keywords: UN Sustainable Development Goals; capstone projects; sustainable development; humanitarian engineering

Introduction

Many communities in the world lack basic needs including access to clean water, access to electricity, limited connectivity, and low quality of education. Over 700 million people lack access to electricity [1], over 2.2 billion people lack access to clean water, and over 2.6 billion do not have access to the Internet. To address these concerns, the United Nations established a set of goals, the UN Sustainable Development Goals [2] which were agreed upon by most of the world's nations in 2015 following the limited success in achieving the prior Millenium Development Goals. The field of humanitarian engineering (HE) has emerged as a means of educating students to participate in projects to address these global challenges. However, most students participating in HE projects tend to be civil or mechanical engineering students. In a seminal paper that explored the humanitarian orientation of engineering students, the authors reported that of the 1900 undergraduate students surveyed, 73% of Civil and Environmental Engineering (CEE) majors agreed or strongly agreed that "helping others is a central message in my discipline, while only 45% of electrical engineering students agreed or strongly agreed with the same statement [3]. In the author's experience, extra-curricular opportunities to engage with HE projects, for example through student clubs, are often rooted in the civil and mechanical engineering disciplines. For example, many Engineers without Borders student chapter projects focus on water access and building construction. These projects tend not to be appealing to Electrical and Computer Engineers since they do not use knowledge and skills related to their disciplines.

Yet, there are many opportunities for engagement of electrical and computer engineering students in HE projects. Furthermore, the professional organization of ECE members, the Institute of Electrical and Electronic Engineers (IEEE) has developed a Foundation-level initiative in HE for the past 15 years. Over the past 15 years, Dr. Singh has supervised ECE-based HE student projects and the rest of this paper

shares examples of such projects, educational support needed to conduct such projects, and the ABET outcomes that may be met through these types of projects.

The ECE Toolbox for Conducting HE Projects

Over the past 15-20 years, many ECE hardware and software tools that may be used in HE projects have emerged. These include low-cost microcontrollers/microcomputers, such as the Arduino and Raspberry Pi. Not only are these devices low-cost, but they have a lot of powerful capabilities. For example, the Raspberry Pi microcomputer can be configured as a server, can have a large external memory (64GB) through a micro-SD card, and can interface with various external devices, including motors, sensors, HDMI displays, etc. These devices are open-source hardware and are supported by open-source software, including a web browser.

Another set of ECE hardware tools that may be used for bringing access to electricity to remote communities are low-cost solar panels, LED lights, and lithium iron phosphate ($LiFePO_4$) batteries. These materials may be combined with interfacing electronics to design a low-cost LED light for use in villages where grid access to electricity is not available.

In the field of electrical communications, there are a number of low-cost communications devices such as those made by Ubiquiti. These antennas tend to be relatively powerful and are widely used globally in community mesh networks.

Finally, with a wide array of sensors, transducers, and low power electronics, ECE students are well equipped to perform a range of design projects with a focus on serving underserved populations and providing them an improved quality of life.

Evolution of IEEE's Programs in HE

In 2009, visionary members of IEEE recognized that tapping into the over 400,000 members worldwide with technical expertise, IEEE volunteers could address the UN Sustainable Development goals. A meeting was convened in Washington, DC in June 2009 and included sponsorship from Vodaphone. It brought together several speakers working on the implementation of HE projects such as Chris Fabian from UNICEF and Dr. Laura Stachel from WeCare Solar as well as some of the IEEE visionaries (including Richard Baseil). Following this inspirational meeting, a second meeting was organized in October 2009, also in Washington, DC, to gather interested volunteers to organize around three themes: 1) renewable energy to provide electricity access to remote communities, 2) provide connectivity to communities, and 3) biometric identification for health applications. The first IEEE Global Humanitarian Technology Conference was organized by IEEE Region 6 and was held in Seattle from October 30-November 1, 2011 [4]. This conference had about 250 attendees from 17 countries and has become the annual flagship IEEE conference showcasing the activities and research being performed to address the various UN Sustainable Development Goals.

The IEEE HE programs have been consolidated under the umbrella of the IEEE Humanitarian Technology Board [5] and offer various forms of funding to support HE projects through the IEEE Tech4Good program, the IEEE EPICS program, and the IEEE Smart Village program.

It is clear that ECE students who are interested in using their technical skills and knowledge for humanitarian purposes have a home within their professional organization to showcase their work as well as to obtain funding to support their projects.

ECE Curricular Elements for HE projects

Senior capstone projects in the ECE department at Villanova University are usually offered by the ECE faculty. Dr. Singh generally provides HE-oriented senior design projects. The ECE senior design curriculum at Villanova University follows a three-semester sequence. In the spring semester of junior year, students develop a written proposal for their project. Then, during the fall semester of their senior year, the students perform their project design work. Finally, in the spring semester of their senior year, the students prepare a written report and give an oral presentation on their project.

The main elements that have been incorporated into the senior design sequence for HE-oriented projects are communication with the in-country implementing partner as well as local, in-country advisors (as needed). During the spring semester, as the students are developing their proposals, a conversation is initiated with the in-country partner. These are typically done over Zoom and are used to ensure that they students (to the extent possible) get a good understanding of the context for their project design constraints and criteria. Following the end of the spring semester, the students may travel down to the project site to get a firsthand experience of the project site, interview local stakeholders, and get a better understanding of the local context. The students are always accompanied by Dr. xxx on these orientation trips. In addition to the communication with the local, in-country partner, Dr. xxx also provides cultural, geographical, and social background information about the community during the spring semester. Finally, if the project is a follow up to one conducted by a previous year's group, the new group is encouraged to meet with the prior group to understand their project development and what was accomplished and aspects that they were unable to complete.

During the senior year fall semester course, as the students are conducting the design work, they are encouraged to regularly meet with the project partner as well as any local technical advisors. This helps to ensure that the final design will be fit for purpose.

If possible, the students travel to implement their design during the spring semester of their senior year. Villanova University provides some funding to support the students' in-country expenses, but the students usually cover their own flight costs. Scholarships were offered to support student travel in case students were not able to pay for their own travel. The source of the scholarships were primarily donations from alumni and other benefactors to the program.

Faculty Workload and Administrative Support of HE Capstone Projects

Humanitarian Engineering type projects require a little more work (15-20% more) than traditional capstone projects in making travel arrangements, developing documents for the Risk Management office in the university, coordinating with in-country partners, and traveling to the project site with the students. Administrative support at Villanova University for helping with making student travel arrangements is coordinated through the Villanova Engineering Service Learning (VESL) program. In this program, a graduate student teaching assistant provides support to the student teams with both logistical arrangements as well as coordinating with the Risk Management office.

Project Examples

In this section, three different project examples are described.

Project Example 1: Connectivity Project in the Galapagos Islands

The Galapagos Islands are a renowned tourist destination for their unique flora and fauna. While 95% of the land mass on the Galapagos Islands is undeveloped and form the Galapagos National Park, 5% of the islands are inhabited and are underserved by the Ecuadorian government. Located about 1,000 km from the Ecuadorian mainland, there is no undersea cable connecting the islands to the mainland and connectivity is provided by satellite. Until recently, this O3B (other 3 billion) satellite link was the only means of connecting to the Internet and was very slow. The main source of electricity on the Galapagos Islands is through diesel generators (although a few solar plants and a wind farm now provide some of the islands' electricity). Because of the fluctuation in demand and lack of reliability of the power grid, smart grid technology (including smart meters) was implemented on each island connecting households, schools, businesses, etc. to a fiber optic backbone to monitor energy usage at each site. In June 2018 Prof. Singh took a group of four (all-female) computer engineering students to discover a potential senior design project to work on for their senior capstone project. After experiencing the difficulties of Internet connectivity at the schools, the students decided to design and implement a software/hardware system to provide access to educational materials at each of the schools on the island of San Cristobal. The materials were loaded onto Raspberry Pi servers and were connected to the schools through a local fiber optic connection at each school to the electricity company's (ElecGalapagos') fiber optic backbone. The students also provided other features such as a calendar scheduling app. In January 2019, the students traveled down to San Cristobal island and implemented the system with the help of technicians from the local electric company and a local Internet Service Provider. Figure 1 shows the students at the ElecGalapagos offices installing the Raspberry Pi servers in a server rack. The students published their work which was presented at the 2019 IEEE Global Humanitarian Technology Conference [6].

Figure 1: Senior Computer Engineering Students Installing Raspberry Pi Servers in a Server Rack

Subsequent to this senior design project, four additional teams have worked on extensions of the project to extend connectivity to all the schools on Santa Cruz Island, the most populous island of the

archipelago and the island of Isabela, the largest of the Galapagos Islands. The Raspberry Pi servers have also been replaced by industrial grade servers with support from the local Internet Service Provider.

Project Example 2: Renewable Energy Project in an Island Community in Ecuador

A second project in which Villanova ECE students have been engaged is a renewable energy project on the island of Cerrito de los Morreños in Ecuador. The island community is located in the Gulf of Guayaquil along the Guayas River about 20 km from the city of Guayaquil. A picture of the island is shown in Figure 2. In 2010, the European installed solar home systems for each of the approx. 90 homes on the island.

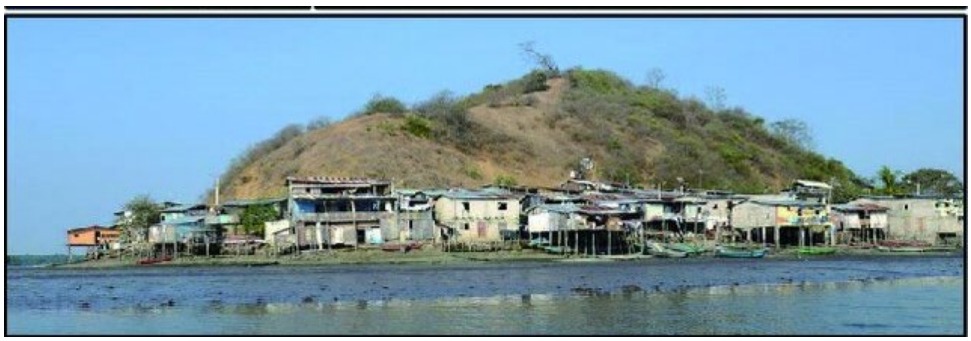

Figure 2: Island of Cerrito de los Morreños

However, by the time our team visited the island in May 2018, none of the solar home systems was working. In each case, the battery was not working and some of the power electronics components were not working either. Furthermore, the community members had not been trained to maintain the systems. While all the solar panels were still working, they needed to be cleaned and objects/dirt removed from them.

The team of ECE students from Villanova University and a partner Ecuadorian university based in Guayaquil, Escuela Superior Politecnica del Litoral (ESPOL), prepared a set of educational materials to teach the community members about basic electricity and solar energy and how solar electric systems work and how they should be maintained. Funding was obtained from the IEEE Humanitarian Activities Committee (HAC)/Special Interest Group on Humanitarian Technology (SIGHT) to rehabilitate the solar home systems and the requisite batteries and power electronics components were ordered by students from the IEEE Student Branch at ESPOL.

ECE students and professors from Villanova University and ESPOL traveled together in January 2019 to the island and gave workshops on the basics of electricity and solar electric systems. A picture of the students and professors conducting the workshops is shown in Figure 3 (Note the students are wearing IEEE SIGHT t-shirts). Following the workshops, the students and professors worked with the local community members to rehabilitate the systems at each of the households. There were two additional trips made to the island to complete the project. This project was not a capstone design project but rather a student volunteer project. It was particularly attractive to ECE students since they could relate their real-world experience to their course work in their major. It is notable that the group of students was about 50% male and 50% female, despite the enrollment in the ECE program at Villanova University being about 75% male/25% female. By the end of the visit, the community members themselves were

performing the rehabilitation of the systems. A picture of the students and community members engaged together in a system rehabilitation is shown in Figure 4.

Figure 3: Workshop on Basic Electricity being delivered to community members by ECE students from Villanova University and ESPOL.

Figure 4: Community members participating in the practical rehabilitation of the solar electric system

Project Example 3: Community Network for a Kenyan Village

A third project example is designing a community intranet network for a village in Kenya's Maasai Mara National Reserve. This was another senior capstone design project. The design goal was to implement an offline intranet to widen the availability of educational resources from the Maa Empowerment Hub, a local educational hub of the Maa Trust, non-governmental organization (NGO) to schools in the surrounding area. The four schools to be included on the Intranet are Olkuroto Primary School, and the Talek Primary and Secondary Schools (two schools, one boy's school and one girl's school), all within line of sight of the Maa Empowerment Hub and located within a few kilometers of the hub.

The students divided the project into two parts, the communications part and a renewable energy part (the village does not have access to grid electricity). A block diagram of the students' design is shown in Figure 5. This project design took place in Fall 2020 and the students, unfortunately, did not have the opportunity to visit the site because of Covid travel restrictions. As a result, the design was done through communication with local partners and without firsthand experience of the project site.

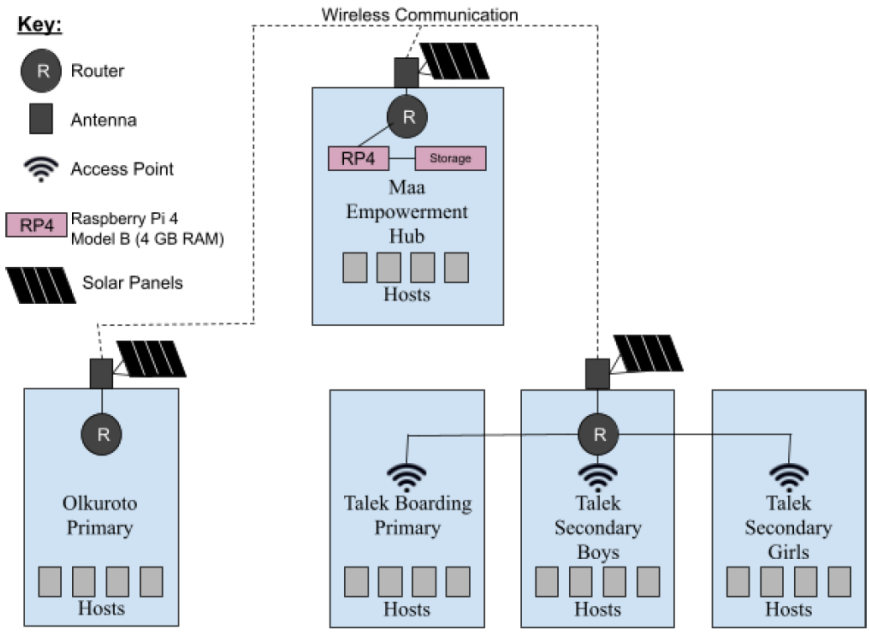

Figure 5. Block diagram of the design for the Maasai Mara Reserve Intranet

The students again chose to use the Raspberry Pi microcomputer configured as a server for the system. The communication modules for the scaled design and testing of a single link that was built and tested at Villanova University comprised two Ubiquiti Edge Router Xs, one Ubiquiti UniFi AC Lite Access Point, and two Ubiquiti Rocket Dish airMAX 2x2 PtP Bridge Dish Antennas. Additionally, the following software tools were used in the design implementation: Raspberry Pi OS, Win32DiskImager, Nextcloud, and Apache HTTP Server. Nextcloud is a free and open-source software utilized for creating and using file hosting services and Apache, a free and open-source web server software, was also downloaded onto the Raspberry Pi. A picture of the physical networking hardware (without the antennas shown) is shown in Figure 6.

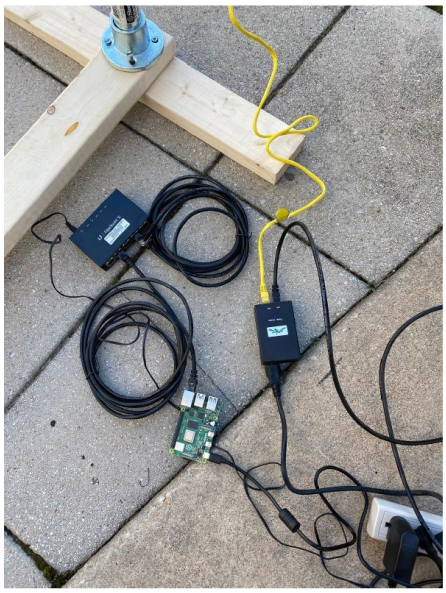

Figure 6. Networking hardware connected to the Raspberry Pi and routers

A picture of the power system incorporating the solar panel, charge controller, and battery interfaced to the antenna and networking hardware are shown in Figure 7.

Figure 7. Photograph of Power System Hardware interfaced to networking hardware and dish antenna

Student Feedback

All the students who were engaged in the ECE HE project work found the experience to be particularly rewarding compared to students who were working on non-HE type projects. The students who selected the HE-oriented senior capstone projects indicated that they selected the projects because of the impact that their projects could have on the underserved communities whom they were serving. The projects tended to attract some of the highest GPA students as well as female students. This is consistent with other studies [7,8]. The students displayed great enthusiasm for their projects.

One student who completed his BSEE and MSEE in four years indicated that "*this was the best experience of my four years at Villanova University*".

The students who were able to travel to the communities with which they worked found the projects to be especially meaningful because of the opportunity to experience the life of the community members and the challenges that they face.

Unfortunately, the formal course evaluations offered limited feedback because the capstone course as a whole was evaluated. Only in the Fall 2021 course did the students provide an evaluation of the quality of the course as a 5.0/5.0 scale and the only comment from one of the students was: "*I believe Dr. Singh was a great capstone advisor. He was always very understanding if we had questions about the material. He is also very knowledgeable about the subject matter, allowing us to learn a great deal during this semester.*" This comment did not specifically address the HE nature of the project.

ABET Outcomes

Senior capstone projects often meet many of the expected student outcomes of criterion 3 of the ABET accreditation criteria [9]. HE projects meet several of these outcomes in some depth. In particular, HE projects address criterion (2) "*an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors*", criterion (3) "*an ability to communicate effectively with a range of audiences*", and criterion (4) "*an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgements, which must consider the impact of engineering solutions in global, economic, environmental, and social contexts*".

Conclusions

Electrical and computer engineering students are often not engaged in humanitarian engineering projects because many of these projects are focused on provisioning clean water or building structures to communities. Yet, as we have demonstrated in this paper, ECE students are well equipped to contribute to addressing the UN Sustainable Development Goals through their knowledge of information, communication, and energy technologies. Several examples of projects, both senior capstone design projects as well as extracurricular projects have been described in this paper. Other projects that have also been conducted by ECE students in Villanova University include the establishment of information hubs/kiosks in Nicaragua, a telemedicine project also in Nicaragua, and communication devices for a physically handicapped client in the US. IEEE is supporting humanitarian engineering initiatives throughout the world and setting undergraduate ECE students on the path to be able to volunteer their technical skills to address many of the world's challenges is a very worthwhile endeavor.

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