International Humanitarian Capstone Design Project Option: a Model for Success

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Introduction
Capstone engineering design is intended to prepare students for new challenges beyond their academic curriculum, with a focus on balancing engineering science and engineering practice to enable a successful school-to-work transition\(^1\). Ideally, capstone projects should be based on real-world problems to provide students with industry-level skills that have been defined by ABET in the a.) through k.) criteria (team work, design with realistic constraints, etc.)\(^2\). Up until the 2012 – 2013 academic year, Virginia Tech (VT) met these outcomes through a combination of faculty and industry-sponsored design projects that served the needs of a class of over 300, with 41 unique projects. However, after that year, an increase in the senior class size to 344 students resulted in a need to look elsewhere for project options and so an international humanitarian (IH) project option was created.

Since inception of the option in 2013, 101 students have worked on 16 projects in four countries. This exciting new option has immersed students in unparalleled situative learning environments, where cross-cultural competency skills and global preparedness are integrated with engineering-focused course learning objectives. A conceptual framework, implementation of the option within the capstone course, and exemplar student projects are presented. Ultimately, this paper aims to serve as a tool for other institutions to become involved in international capstone project collaborations.

Mechanical Engineering Senior Design at Virginia Tech
Virginia Tech’s design sequence formally starts at the sophomore year when students take an Introductory Design class that covers basic elements of the design process as well as topics associated with the engineering profession. Customer needs, target specifications, concept generation, preliminary design and detailed design are covered along with communication (oral and written), intellectual property, ethics in engineering and engineering economy. With this preparation, project-based learning does not progress significantly until the senior year when the capstone course is offered.

In the senior year, students take a two-semester, six-hour capstone design course sequence. Prior to the start of the Fall semester, enough projects are assembled to support student teams of four to eight students, with some larger projects that take up to 25 students each (Formula SAE and Baja, for example). Projects can be sponsored by faculty or industry, where faculty receive course credit through advising (their own projects) and industry sponsors pay a fee that conveys intellectual property to the company (and students must sign an agreement supporting this, otherwise they can sign up for a non-industry sponsored project).

An associate professor co-teaches the class with a professor of practice, delivering two one-hour lectures per week to the team facilitators (one for every team). The lecture is recorded and viewed by the remaining students asynchronously as a means of accommodating the large class size. An additional member of the core faculty team is an instructor, who, along with the professor of practice, advises the industry-sponsored teams. The associate professor advises his/her proposed projects in addition to the international humanitarian (IH) projects. For the 2016 – 2017 academic
year, 418 senior engineers were registered and 51 projects were needed to accommodate these students; seven of the projects were classified as IH.

In the first week of the Fall semester, students select their top choices of design projects and along with a resume review, they are sorted into project teams. A team facilitator is chosen who will submit team assignments (and attend the lectures), while individual assignments such as logging hours and keeping up-to-date notebooks are individual students’ responsibility. Graduate teaching assistants working with the core faculty grade student performance weekly. Major milestones during the Fall include a concept review with the client (advisor or industry liaison), midterm presentation and report, preliminary design review, and the final presentation and report. The Spring semester does not have a lecture component, allowing students to spend the first seven weeks finalizing the design, fabricating parts, writing code and assembling the product. A dedicated 3,100 ft² machine shop and fabrication space is available to the seniors for this phase of work. The second half of the semester is the evaluation and testing phase where performance metrics are compared to target specifications written during the Fall semester. Milestones during the Spring include the critical design review, midterm “rollout” presentation, a final presentation and an ASME conference-formatted final report. Students also attend an exposition where they present a poster and display their products for judging in three categories (best design, most creative design and best poster).

With this background, international humanitarian design addresses ABET objectives, demonstrates situated learning benefits and provides opportunities for students to develop cross-cultural competency. The IH option is adding a layer of maturity for the students that is rarely achieved in other projects as they work across physical and cultural boundaries to deliver a functioning product. The outcome is an engineering graduate who is not only sensitive to cultural issues but also empowered in both domestic and international communication. How we carry out a successful IH design program is modeled on community-based participatory research theory.

**Conceptual framework for humanitarian design: community-based participatory research**

Several significant challenges threaten successful project implementation in international, collaborative design settings, including technology adoption and dissemination barriers. Arguably the most significant challenge for international collaborative design projects is design sustainability. Recognizing the unique challenges of international, collaborative design—particularly design for low resource settings—experts across many disciplines have established guidelines for working with communities towards design innovations. These guidelines collectively emphasize the importance of involving community stakeholders in every phase of the design process, including understanding local availability of resources, identifying needs of local significance, and most importantly, asking appropriate questions to illicit appropriate design feedback. Though these guidelines have been traditionally targeted towards design of health technology, they provide critical insight into sustainability of design projects in every area. Therefore, these guidelines were adopted as the guiding principles—the conceptual framework—of the international humanitarian project option in the senior design course. The following section outlines the principles of community-based participatory research, highlighting their relevance for the capstone project option.

The basic premise of community-based participatory research (CBPR) is to partner community members’ practical knowledge and experiences with methodological and theoretical skills of researchers. In recent years, many design initiatives in the public health sphere have begun to
emphasize CBPR in an effort to encourage genuine, collaborative partnerships between researchers and communities\textsuperscript{10-12}, and increasingly other disciplines have begun to implement CBPR principles as well. One of the most widely utilized definitions of CBPR was put forth by the W.K. Kellogg Foundation in 2001, defining the research method as:

“a collaborative process to research that equitably involves all partners in the research process and recognizes the unique strengths that each brings. CBPR begins with a research topic of importance to the community with the aim of combining knowledge and action for social change…”\textsuperscript{10}

The primary purpose of utilizing CBPR as a conceptual framework for the engineering design process is to empower community members as agents of change, building upon community assets in every phase of the design process in order to develop appropriate, sustainable solutions\textsuperscript{10, 12}.

Importantly, shown in Figure 1, CBPR proposes a paradigm shift in the traditional attitude and methods of engineering design\textsuperscript{10, 13}. CBPR challenges the model of traditional engineering design in which a team of engineering “experts”, most often from outside the community where design implementation will occur, are solely responsible for making decisions throughout the design process. These decisions, including assessing local assets of communities, prioritization of local needs, and selection of appropriate engineering design interventions, are of critical importance to both short term outcomes, such as design functionality, and long-term outcomes, such as design sustainability\textsuperscript{10}. Translated to the engineering design, CBPR emphasizes the importance of equitable collaboration during every phase of the engineering design process. Though CBPR consists of nine key principles\textsuperscript{12, 14}, six of the principles are particularly salient to the engineering design process. These six CBPR principles, and their implications for the engineering design process, are outlined in Table 1. In an effort to promote design sustainability, these principles serve as the conceptual framework for all projects undertaken through the Virginia Tech international humanitarian design project option.

**Implementation of international humanitarian engineering capstone projects**

The delivery of successful IH projects requires advocacy from community members, the University, and in-country partners, as well as a funding model and careful student vetting. All VT projects to date have grown out of prior international partner relationships through student involvement (club or personal), or research projects on campus. In the case of existing research activities, mechanical engineering applications are common and it may be possible to reach out to colleagues engaged in an ongoing research project and offer support through a capstone design project. This is an easy way to find a project: a quick review of international activities and a call to the PI can result in several good project ideas. Students also feed great project ideas through their experiences abroad, either sponsored by the University (Engineers without Borders) or through clubs and organizations that they have traveled with in the past.
For IH projects, community members are most keenly aware of what problem needs to be solved; however, since community members are often abroad for the duration of IH projects, it is often helpful to have domestic partners provide expertise for projects, particularly for handling day-to-day project questions. Communication with in-country partners can be accomplished via Skype™ or WhatsApp™. However, it is important to be cognizant of the communication infrastructure challenges, particularly for partners in developing nations. The bandwidth limitation can be traced to Internet service but also in-country partners who are using personal devices with limited data plans, as employer-sponsored hardware is rarely available.

In addition to involvement from community members, the most successful projects have been based on a triad consisting of the senior design team, the in-country non-governmental

Table 1. Implications of CBPR Principles for International Humanitarian Design Projects

<table>
<thead>
<tr>
<th>CBPR Principle12,14</th>
<th>Implications for International Humanitarian Engineering Design Projects</th>
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<tbody>
<tr>
<td>1 CBPR identifies and builds upon assets within the participating community. By identifying and strengthening existing strengths and resources of communities, community members and engineers work together to develop solutions.</td>
<td>The engineering design process should begin by working with communities to assess community assets. These assets may include, but are not limited to, knowledge and skills of personnel, locally available material resources for developing engineering solutions, and community partner organizations.</td>
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<tr>
<td>2 CBPR is collaborative, meaning that all parties are equal participants in every phase of the design process.</td>
<td>Decisions throughout the design process are made collaboratively between all partners. Each partner’s voice is valued equally during the design process. Decisions are not made by engineering teams alone, but instead engineering teams and community partners collaboratively work to make design decisions.</td>
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<td>3 CBPR promotes reciprocal transfer of knowledge by promoting a co-learning environment.</td>
<td>Community partners and engineering design teams are actively engaged throughout the design process, emphasizing a reciprocal transfer of knowledge. Engineering design teams recognize and deeply value the unique expertise of community members, including but not limited to practical knowledge and experiences.</td>
</tr>
<tr>
<td>4 CBPR is an iterative, cyclical process incorporating research, reflection, and action.</td>
<td>Designs are not “unveiled” to partners at the end of the design process, but rather constant feedback from partners is collected throughout the design process.</td>
</tr>
<tr>
<td>5 CBPR includes dissemination of results and knowledge gained to all partners in a method that is respectful and understandable for all involved.</td>
<td>Design progress and results is shared between community partners and engineering design teams throughout the design process.</td>
</tr>
<tr>
<td>6 CBPR necessitates long-term commitment from all partners.</td>
<td>Engineering design projects are chosen based on a minimum one-year commitment from senior engineering students and community partners. When possible, projects continue for multiple years.</td>
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</table>
organization (NGO) or responsible party, and a subject matter expert that has years of experience in the country and is available domestically to answer questions quickly and even attend design reviews. Fortunately, this model has been available for many projects.

Travel is an important aspect of the program and a unique opportunity for engineering students who typically do not see other cultures or experience resource-limited environments in which they must improvise to bring a design to successful operation. Usually, partners are a tough customer: they expect everything to work once it is delivered. But since no testing was ever performed in the true operating environment, modifications are always needed. Knowing something about the supply chain before arrival is helpful—hardware store locations and fabricators are particularly important. A project team may consist of five to eight students; however, travel is usually limited to a subset of the team. These students are carefully chosen for their interest in both the project and the culture they will be experiencing. It is imperative that students selected for project travel are comfortable with social interactions and reaching out to new acquaintances, as it will greatly expand their foundation for success.

Funding for travel has been accomplished through a variety of sources on campus and with industry partners, allowing the students to travel without a financial burden. This is unlike study abroad programs where students typically cover their own expenses.

**Design Intent**

Through the CBPR model, each project starts with interviews of users of the technology to identify a need that will be addressed by the design team. Importantly, the CBPR dictates that the agreed upon design need should be a priority of the community and not an imposed “need” from the design team. In most cases, a trip to the country has already been made by a faculty member or student to collect this information. The projects focused in low- and middle-income countries address one of the following areas: healthcare, agriculture, water or sanitation. A “simple but elegant” design made from locally available materials and using local fabricators is the best and a goal for the student design teams. Design considerations include ability to be maintained using locally available resources, intuitive operation with operation manual, and affordability. Systems that have built-in capability for manual or powered operation, or even multiple means of manual power (crank and pedals, for instance) can greatly expand application, particularly in settings where access to the electric grid may be limited.

During the Fall semester, students are in contact with in-country partners and any subject matter experts that they have identified so that early prototype concepts can be evaluated and modified as needed. Sketches and scale models of the systems are provided for evaluation and to elicit preference from the partners. Fabricators may be contacted to provide samples of welded parts and also make suggestions on material type and fabrication methods. Cost analysis is performed and supply chains and services are identified early to prevent designs from stagnating once they are deployed. A note about supply chains: raw material transportation costs frequently dominate the cost of a complete system; therefore, community partners often express that sourcing local materials should be a design priority.

**International Humanitarian Capstone Projects to Date**

Since the inception of the international humanitarian project option in fall of 2013, 101 students have participated in projects, all of which emphasize principles of CBPR through international design collaboration. As shown in Figure 2, partners have included organizations and institutions in four countries: Malawi, Peru, Senegal, and Rwanda. In 2013, the international humanitarian
project option was piloted with two initial projects in Malawi and Senegal. One of the initial projects was focused on designing improved infant resuscitation equipment. This project partnered five mechanical engineering seniors with several rural hospitals in northern Malawi, the Virginia Tech Carilion School of Medicine, and the Pediatric Medical Device Institute, a 501(c)3 organization devoted to improving medical equipment for pediatric patients. The second initial project challenged students to design mechanical equipment for silage production in Senegal, with the intent to prolonged food storage and increase food security in the local community. The silage project partnered senior students with faculty in the VT College of Agriculture (via the Education and Research in Agriculture, USAID-funded project), farmers in Santamba Village, Senegal, and Ecole Nationale Supérieure d'agriculture (ENSA) in Senegal.

![Figure 2. Since 2013, 101 students have participated in 16 projects in 4 countries. Due to space limitations, 12 of 16 most recent projects are shown.](image)

In the first year of implementation, both projects received substantial interest from students; the large number of students interested in the international humanitarian project option led to a competitive selection process and contributed to the high caliber of the pilot year projects. The success of the first two projects warranted departmental and college-wide buy-in to the new design concept, cementing the international humanitarian project option as a permanent addition to the mechanical engineering capstone course. Importantly, CBPR serves as the foundation for the project option during every phase, including project initiation, design, and implementation. Since 2013, every project that has been undertaken through the mechanical engineering capstone course has been a community-led idea. In other words, the primary responsibility of the program director is to facilitate authentic connections with community leadership, local non-governmental organizations, and other experts who will remain intimately involved during the entire life cycle of the project. This is critical for both project outcomes and student learning outcomes.

Table 2 provides a summary of recent projects, particularly emphasizing how principles of CBPR have been used to promote sustainability and long-term success of projects. A common theme among all projects to date is the necessity of developing long-term relationships with community leadership in order to appropriately understand, define, and prioritize needs relating to engineering design.
Table 2. Summary of select international humanitarian projects

<table>
<thead>
<tr>
<th>Project</th>
<th>Location</th>
<th>Description</th>
<th>Community Partners (CBPR Principle 1)</th>
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<tbody>
<tr>
<td>Pediatric IV fluid delivery regulation pump</td>
<td>Southern Malawi</td>
<td>A regulator to control intravenous fluid for safe infant rehydration</td>
<td>Zomba Central Hospital, Domasi Rural Hospital, southern Malawi</td>
</tr>
<tr>
<td>Desludging pump for pit latrines</td>
<td>Northern Malawi</td>
<td>A device for pumping sludge from full pit latrines</td>
<td>CCAP SMART Centreer for Excellence in (WASH, ) Mzuzu, Malawi</td>
</tr>
<tr>
<td>Locally manufactured cargo bicycle</td>
<td>Senegal, Malawi</td>
<td>A low-cost cargo bicycle designed for production in Sub-Saharan Africa</td>
<td>Sakaramenta – a fabricator in Blantyre, Malawi</td>
</tr>
<tr>
<td>Passive infant warming device</td>
<td>Southern Malawi</td>
<td>An environmental enclosure designed to protect infants during transport to a hospital</td>
<td>Kamuzu Central Hospital, Domasi Rural Hospital, central-southern Malawi</td>
</tr>
<tr>
<td>Deep water well drilling system</td>
<td>Northern Malawi</td>
<td>An optionally powered drilling system capable of 80 m depth</td>
<td>CCAP SMART Centre for Excellence in WASH, Mzuzu, Malawi, CCAP SMART Center (WASH) Mzuzu, Malawi</td>
</tr>
<tr>
<td>Cervical cancer screening table</td>
<td>Cusco, Peru</td>
<td>A portable examination table for cervical cancer screening in rural Peru</td>
<td>CerviCusco, Cusco, Peru and Augusta University, Augusta, GA</td>
</tr>
<tr>
<td>Manually powered washing machine</td>
<td>Southern Malawi</td>
<td>A washing machine for bed linens at a clinic that has no laundry capability</td>
<td>Domasi Rural Health Clinic, Hospital, Domasi, Malawi</td>
</tr>
<tr>
<td>Pit latrine assistive technology for rehabilitation center</td>
<td>Southern Malawi</td>
<td>A device to assist disabled patients with toileting</td>
<td>Kachere Rehabilitation Centre and, Malawians Against Physical Disabilities, Blantyre, Malawi U. of Delaware Physical Therapy</td>
</tr>
<tr>
<td>Pit latrine design</td>
<td>Rilima, Rwanda</td>
<td>A new latrine design based on a collection system and central decomposition processing</td>
<td>The village of Rilima, Rwanda</td>
</tr>
</tbody>
</table>

Discussion and Future Work

The IH option for capstone design has been successful for showing engineering students the need to consider cultural factors and also understand an aspect of engineering design (functionality in harsh environments) that is rarely experienced in a standard curriculum. Just as some mechanical engineers are attracted to automotive engineering, there is a reliable group within the senior class that is attracted to humanitarian engineering projects to support international development. There has never been a design option for these students until now. In a comparison of performance between student groups for the current year (Table 3), the humanitarian teams worked more hours with better teammate cooperation. However, lower scores were linked to early communication of their designs, possibly a result of cultural factors that were not fully understood by the evaluators.
Whereas engineering design is difficult because of its ill-defined nature, cross-cultural design is completely unrecognizable by most engineering students. These projects represent a bold step in further expanding the design domain.

Application of the CBPR principles serves to guide engineering towards a successful outcome when designing for out-of-country use. We believe that a close connection with the end users of the technology is required for adoption, and as future communication options expand, our students will be better positioned to gain early feedback in the design cycle.

The timing of travel has varied for reasons unrelated to the needs of the project (student and professor availability, rainy vs. dry season, class schedule), and with limited data we have found that travel during the U.S. summer is best, primarily since students have a difficult time missing up to two weeks of class. Given this schedule, it is advisable to set up projects by May and solicit interest among the rising seniors so that future team members can travel and meet their in-country stakeholders. A few graduating team members are usually available to deliver and demonstrate final products was well.

Virginia Tech will continue to grow the program through new mechanisms of funding and outreach – as a University that has targeted global systems science as a destination area, this program fulfills required elements in cross-cultural competency for the engineering program. Future work will include assessing student learning outcomes for those who participate in international humanitarian projects vs. domestic projects. Figures 4a and 4b shows two designs that have reached implementation phase with in-country partners.

Table 3. Grade comparison for humanitarian vs. non-humanitarian project teams

<table>
<thead>
<tr>
<th></th>
<th>Non humanitarian</th>
<th>Humanitarian</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fall</td>
<td>Spring</td>
</tr>
<tr>
<td>Peer review</td>
<td>87</td>
<td>88</td>
</tr>
<tr>
<td>Work hours</td>
<td>92</td>
<td>86</td>
</tr>
<tr>
<td>Notebook</td>
<td>93</td>
<td>89</td>
</tr>
<tr>
<td>Prelim des. review</td>
<td>85</td>
<td>n.a.</td>
</tr>
<tr>
<td>Final fall pres.</td>
<td>85</td>
<td>n.a.</td>
</tr>
<tr>
<td>Critical des. review</td>
<td>n.a.</td>
<td>90</td>
</tr>
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Figure 4a. The latrine pit desludging system used in Mzuzu, Malawi (above).

Figure 4b. The silage chopping system used in Senegal (above).
Bibliography


