Service-Learning Approaches to International Humanitarian Design Projects: A Model Based on Experiences of Faith-Based Institutions

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Abstract

Recent curriculum advancements in engineering education highlight the value of a healthy synergy from including applied mathematics and science, industrial work, and need-based projects. In light of the growing interest in globalizing engineering education, a service-learning approach to globally-based humanitarian projects is an effective approach to help in achieving this balance. The importance of integrating both globalization and social needs into the engineering curriculum is acknowledged by the ABET criteria. Human need is also a clear priority of engineering as a profession and of major world religions. It is not surprising, therefore, that faith-based institutions place a high value on such projects. This paper presents the methods and conclusions of design projects from four faith-based institutions that exemplify the successful integration of both globalization and humanitarian interests. The presentation focus is a model for conducting such projects. Particular results, within the context of these projects, include specific characteristics and insights for designing, selecting, and executing international humanitarian design projects within the undergraduate engineering curriculum.

Introduction

Engineering educators are increasingly recognizing the value of exposing students to need-based engineering problems and pedagogies [1, 2, 3, 4]. Another area of growing interest is the globalization of engineering education [5, 6, 7, 8]. These important topics may be concurrently addressed with a service-learning approach by involving students in international humanitarian (IH) design projects [9, 10, 11]. This approach addresses key ABET criteria by integrating both globalization and social needs into the engineering curriculum. Additionally, social needs are a clear priority of engineering as a profession (as indicated in the NSPE creed[i]) and of major world religions (as indicated by their international outreach). It is not surprising, therefore, that

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[i] "As a Professional Engineer, I dedicate my professional knowledge and skill to the advancement and betterment of human welfare …" (NSPE Code of Ethics for Engineers)

engineering departments at faith-based institutions place a high value on such projects. This paper presents the methods and conclusions of design projects from four faith-based institutions that exemplify the successful integration of both globalization and humanitarian interests into the curriculum. The resulting model for IH design projects should be applicable to any accredited engineering program, from state to private universities, and from faith-based colleges to secular-based institutions.

To develop a model for international humanitarian projects, data are collected from the four participating institutions, where this data is presented in a common framework. Each of the four project examples from the four institutions is preceded by the general context of the host institution and design class, including the general approach to team formation, project selection, funding, deliverables, and teaching/mentoring. Following this general context are the specific details of each project. Projects presented include the design of (1) a women's hospital in Nigeria by senior engineering students at Calvin College, (2) a crop irrigation system in support of a Honduran community development organization by Dordt College students, (3) a modular and scalable solar power system providing economical power to remote areas by electrical engineering seniors at Grove City College, and (4) a water purification system in Guatemala by Messiah College students. The presentation focus is the development of an underlying model for successfully conducting such projects. Success in this context involves achieving goals that may be categorized as educational, humanitarian, and spiritual. The focus here is on educational and humanitarian objectives; spiritual aspects are discussed in a parallel paper to appear in the 2004 CEE conference [12].

Methodology for Developing an IH Project Model

Our educational research seeks to present guidance for the successful implementation of IH projects in engineering curricula. The research approach to address this goal includes the following steps: (1) selecting four exemplary projects, (2) reviewing design reports, publicity articles, and student responses, (3) compiling a summary of each project, (4) reviewing the project summaries and identifying a list of "key elements" thought to be instrumental to project success (team formation, project selection, funding, overcoming obstacles characteristic of IH design projects, deliverables, and teaching/mentoring), and (5) comparing similarities and differences of these common elements across the projects. Each example project description concludes with a table summarizing how the key elements were executed. The paper ends with a discussion organized around these key elements and suggests insights thought to be generally applicable for successfully designing, selecting, and executing IH design projects.

The key elements compared across projects were chosen based on both previous experience with student design projects and a review of critical aspects across the four projects presented here. For example, the influence of design team formation on the success of a design projects is well documented. In the experience of the author's, selecting an appropriate project is important to project success, and presents a special challenge for IH projects. Funding is an important concern due to the greatly increased learning which often results when students build prototypes and delivery a working device to the customer. In the case of IH projects, international travel can be an important, and costly, element of a successful project. The category of "obstacles characteristic of IH design projects" was used to note special challenges which arose such as language barriers. Deliverables are critical to the execution of any service-learning or humanitarian project, since this is the only outcome the "customer" receives. A special challenge of IH projects is scoping deliverables that are realistic for a team to deliver with quality, while giving adequate attention to pedagogical objectives of the project. Finally, the aspects of how teaching/mentoring was carried out are noted for each project due to the importance this has to student learning.

Institution I: Senior Design at Calvin College

Calvin College offers a general B.S.E. degree with concentrations in chemical, civil, electrical & computer, and mechanical engineering. The program emphasizes the integration of religious faith and learning, the value of the liberal arts, and design. Approximately 70 students graduate from the program each year. Design projects are assigned starting with service learning projects in the first engineering course and culminating in a two-semester senior design projects course involving students from all concentrations. The senior design course has involved a number of international humanitarian projects.

Team Formation. For the senior design course, teams are self-selected with some guidance from the faculty. Teams usually have four members, sometimes all from the same concentration, but often multidisciplinary in nature. Some teams also work with students in other departments, such as business or computer science.

Project Selection. The teams are allowed to choose their own project, and many have already selected a project at the time the class officially begins. The faculty provide suggestions for teams that are looking for a good project. Projects must show significant design, i.e., they cannot be entirely analytical, nor simply an integration of off-the-shelf parts. Normally a prototype must be constructed to validate primary aspects of the design. Over the years, many of the teams have picked a humanitarian design project, such as a water supply system for a village in Ecuador, low cost modular housing using local materials for Haiti, or a solar-powered, battery-backed incubator for premature infants born in developing countries.

Funding. Teams are provided with $500 to use towards supplies, prototype parts, and so forth. If the project requires further funding, the team must obtain the funds through grants or donations. Many teams have been successful in obtaining additional funding from local industry, state or federal grants, or sometimes through humanitarian aid agencies when the project is mission-related.

Teaching and Mentoring. A group of four faculty team-teach the course, one representing each concentration. The faculty give lectures on various concepts important in completing successful engineering projects, such as team dynamics, conflict resolution, communication, project scheduling, etc. Each team is assigned one of the four faculty members as an advisor. The advisor guides team members with suggestions but requires the team to make all design decisions. A few major milestones are required of each team (such as a problem statement, task specifications, project schedule, feasibility study, and so forth), while other deliverables are specific to each team. Each team member is required to give an oral presentation to the class sometime during the two semesters. A public presentation is made in May during an open house project night, attended by 300-500 people.

Figure 1: Calvin Students Performing a Site Survey in Nigeria

Empirical Data Set I: Design of a Women's Hospital in Nigeria (Calvin)

During the 2002-2003 academic year, a senior design team worked with Engineering Ministries International[13] (EMI) and the Worldwide Fund for Mothers Injured in Childbirth[14] (WFMIC) to develop a women's hospital in Jos, Nigeria. The focus of this center would be to treat vesicovaginal fistula[ii] (VVF). Victims of VVF are often social outcasts because of the resulting urinary incontinence and associated infections. The goal of the project was to design a culturally appropriate, cost-effective hospital complex (including the hospital, patient hostels, and staff housing) capable of serving the needs of 1,000 to 1,200 women suffering from VVF per year. The hospital was designed to have a communal setting that would be open and inviting to the women coming for surgery.

A Nigerian hospital team of five students, all from the civil engineering concentration, was formed and had selected a project before the course officially began. Because they wanted to complete a mission-related design project, one of the team members contacted EMI three months before the class began in May, 2002 to discuss cooperation on a project. EMI had already made a preliminary investigation of the proposed location and worked with a local contact on preliminary specifications. The Calvin team then joined the effort in September, agreeing to produce structural, water, and wastewater design plans. Project deliverables were a project manual (detailed design specifications including a complete set of design drawings), a cost estimate, and design notebooks (providing design calculations). The team visited the site in October, 2002 for one week. The cost of the trip was covered by fund-raising the team carried out over the previous summer. During the trip, the team surveyed the site, tested soil samples, met with local contacts involved with the project, and interacted with local residents. Normally an off-campus experience by Calvin students would be supported by our Off-Campus Programs office, which helps with travel visas, passports, trip itineraries, and so forth. In this case, however, the US State Department had issued a travel advisory for Nigeria. College policy

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[ii] VVF afflicts around 2 of 1000 women after childbirth in developing countries. It sometimes occurs after prolonged labor, causing a small hole between the bladder and vagina.

prohibited official college travel to locations under advisories. The course instructors assured the students that they could complete the project without the trip, but the students were intent on going, and the college asked them to sign liability waivers before they traveled to Nigeria. The college health services office provided the appropriate inoculations for the trip.

The student design team split up the project into various functional areas, with one team member responsible for each. They reviewed each other's work periodically. The design included basic engineering assessments of environmental conditions (soil, weather, elevations, water quality, etc.), engineering analysis (e.g., live and dead load computation, shear calculations, expected water demand, water pressure), and design decisions and implementation (e.g., material selection, truss design). The team advisor for the Nigerian hospital team was a licensed professional engineer with extensive civil engineering industrial experience. The team also received advice and guidance from an EMI project manager. An outside industrial consultant was brought in once each semester to review the team's design.

The students emphasized the value of a large project as a way to put their technical learning into perspective. Here are some quotes from the team's final design report, emphasizing their reaction to a faith-based project in their engineering studies:

> *"The actual visit to the site location gave us the ability to fully grasp the Christian responsibility we have in designing this hospital complex."*
>
> *"Over the course of this semester there was a lot of time spent designing every civil engineering part of the complex. From the drawing of the plans, to doing the calculations to writing the specifications, to writing the report the team put in well over 1500 hours on this project and during that time we kept our focus on the overall purpose of our project. Our purpose was to help others…. We persevered because we remembered what we saw in Nigeria and what we saw in the eyes of those women and girls. We do not have it that bad and given the opportunity to make someone else's life better we took the opportunity with open arms."*
>
> *"From the details of designing a water storage tank to the structural design of a truss we can use our talents as Christians to serve the people of God's kingdom whether it be abroad or at home.*"

Table 1 summarizes the key elements extracted from this Calvin College project. This table includes important facts extracted from the Calvin College data. These data, in their elementary form, provide interesting clues to the successful result obtained from the project. For example, Calvin College formed a balance in responsibilities between student investment (Team Formation, Project Selection, Funding) and outside assistance (Mentoring & Teaching).

Table 1: Model Summary - Design of a Women's Hospital in Nigeria (Calvin)

Team Formation	Before the semester began, this team formed with the goal of carrying out a mission-related project. All team members were students in the civil engineering concentration.
Project Selection	The team contacted Engineering Ministries International, a non-profit international engineering and architecture firm.
Funding	In addition to the $500 provided, the team raised funds before the class started to cover a one-week trip to Nigeria.
Obstacles Identified	The US State Department had issued a travel advisory for Nigeria, and college policy prohibited official college travel.
Deliverables	Design specifications, drawings, and cost estimates addressing: structural, water, and wastewater aspects of the hospital.
Mentoring & Teaching	The faculty mentor was a Civil PE with extensive industrial experience. An EMI project manager also provided guidance. An industrial consultant provided end-of-semester reviews.

Institution II: Dordt College Engineering Program

Dordt College is a fifty-year old Christian liberal arts college located in Iowa. The engineering program was first implemented in the early 1980's with general engineering. This general engineering major offers mechanical and electrical emphases to an engineering student body of about 90 individuals across all levels (freshman to senior). About 20 seniors complete the program each year. Design projects play a role in many engineering courses, in freshman through senior years. The design curriculum concludes with a two-semester course sequence that allows teams of 3 or 4 students to work with a faculty mentor and a client on a selected project.

Senior Engineering Design Project Management. The two-course senior design sequence begins with a fall semester class in which the faculty member and students discuss design project management and teamwork principles, engineering economics, and statistics. Discussion of possible design projects also begins early in the fall, with a goal of having teams and projects identified by mid-semester. Project ideas come to the course instructor by way of industry contacts, department colleagues and the students themselves. As these ideas develop, project options are discussed and approved by the Engineering Department.
Team membership is somewhat self-selected based on individual student interest in the various projects. This team formation process can be somewhat chaotic at first, but generally works out well with some facilitation by the instructor.

An engineering department faculty member is assigned to mentor the project team into and through the second semester, where weekly written reports and meetings with the mentor are required. A design review session involving the whole class is conducted about 3-4 weeks into the second semester so that all classmates can ask questions and observe each team's progress. Most of the projects involve the construction and testing of some type of prototype. A written report and a public oral presentation of each project are required near the end of the spring semester.

Figure 2: Dordt Students Installing a Crop Irrigation System in Honduras

Empirical Data Set II: Design of a Crop Irrigation System in Honduras (Dordt)

Design Problem Statement and Project Initiation. The irrigation system project was an answer to the needs for greater food security and for improved health of the 300 indigenous Tolpan people in the village of San Juan in the Montana de la Flora region of Honduras. These needs were communicated to Dordt College via the Luke Society[15], a Christian society that builds and financially supports medical and dental clinics in disadvantaged areas of the U.S. and in developing countries around the world. The Luke Society also provided logistical support for the student team's investigation and construction trips.

Dordt College's involvement with the project began in the spring of 2000, when a member of the department became interested in the project through personal contacts with members of a Luke Society volunteer brigade that had recently traveled to the La Joya region of Honduras to build a clinic. While visiting Honduras, brigade members investigated other possible projects in the area, including irrigation of cropland for the Tolpan people living nearby. As a class design assignment, a faculty member asked his fluid mechanics students to study the problem and its constraints, and to create an initial plan that might be used as background if the project was to proceed. Over the following summer, through the efforts of Dr. Bryn Jones, a Luke Society member and volunteer team leader, major funding for the project became available through the Luke Society, and Dordt College was asked if a team of seniors could be involved in the design and installation of an irrigation system.

Problem Approach. The senior student team became involved in the project in the Fall semester of 2000 and immediately began investigating possible solutions to the problem. Under the direction of Dr. Jones, who represented the client and arranged for logistical support, and the mentorship of a faculty member, the four students each took primary responsibility for one of the following aspects: Water Diversion, Holding Tank and Filtration, Transportation and Distribution (pipe layout), and Application. In January 2001, with Luke Society funding and in-country logistical support, they traveled to the site with a Dordt College agronomy professor and a volunteer licensed civil engineer, as well as several other Luke Society personnel. They spent 10 days in Honduras, with overnight lodging at the site in the school building in the village. They surveyed the site to determine the topography of the fields and the small streams that were chosen to be the water sources. On this first trip, they developed an initial irrigation piping layout and even helped to install small diversion dams (with bypasses) on the two streams.

The student team returned to the U.S. with significant topographical data and with enough mountain jungle experience to realize some of the challenges that would await them. The team began to design and plan for the installation of the irrigation mainline and laterals into some 25 acres of mountainside fields involving an 80-foot elevation drop from top to bottom. As analysis progressed and decisions were made about the layout of the project, needed piping and other equipment were communicated to the in-country personnel who purchased the PVC pipe and directed the villagers' work to clear brush and dig the necessary trenches for approximately 6,000 feet of buried mainline and laterals. Some of the necessary fittings and stainless steel filtering screens for the filtration tanks were brought in from the U.S. by the installation brigade.

In March 2001, Dr. Jones led a 10-day Luke Society volunteer brigade of 40 persons, including the team and its faculty mentor, to Honduras to install the system. Travel and lodging expenses for this trip were raised by the students and by each volunteer through requests to friends, family and home church communities.

Project outcomes. On March 20, 2001, after five days of intense effort from sun-up to sun-down by everyone involved, the dams and filtration boxes and valves were operated and checked, and the irrigation mainlines were flushed. The potential energy of water in the mainlines, coming down from the storage tanks upstream, "powers" this gravity-flow system, so no electricity or other power supplies are needed to irrigate the fields. One of the hand-moveable, pressure-regulated sprinkler lines was assembled in one of the fields for testing. Tolpan villagers and North American volunteers celebrated the success of the irrigation system that operated as planned in such a steep and challenging terrain. A small drip irrigation system to water a vegetable garden plot at the top of one of the hillside fields was also installed for demonstration purposes. After saying their goodbyes to the Tolpan people, and a day of sightseeing in the capital city of Tegucigalpa, the student team and the other volunteers flew home to the U.S. and Canada on "World Water Day," March 22, 2001.

Besides these desired engineering outcomes, a number of cross-cultural, socio-political, and international affairs lessons were learned by the team. One memorable aspect of the installation trip was the presence of seven armed members of the National Police and the Honduran army, who accompanied the large volunteer brigade the entire time that it was in the area of La Joya and San Juan. This escort was deemed necessary because of earlier incidents by a group of 'banditos' who had noticed increased activity of the in-country volunteers in the area during the preceding two months. Another more important lesson for the Dordt students involved is that the people they assisted and worked with are not poor due to any lack of industriousness! The Tolpan people worked very hard in advance of the brigade and alongside them to carry the pipe up the mountain and to help install the system. Though there was a language barrier for many of those involved, there was a great deal of communication of positive intent and respect as people from vastly different cultural backgrounds worked and relaxed together during the installation phase of the project.

Conclusions. One of the lessons learned by the department is that this project could not have been carried out without the extremely focused planning and diligent logistical support of the Luke Society leadership both in the US and in Honduras. Because of this support, it seems that similar projects of this magnitude would only be undertaken by the department every few years at best. Though it was (and continues to be) a successful project for the Tolpan people and for the design team, it appears obvious that future international humanitarian projects should be smaller in scope and involve fewer people in travel if the engineering department is going to provide the main logistical support.

Table 2 summarizes the data from this Dordt College project. This table includes important facts extracted from the Dordt College data. For example, Dordt College formed a working relationship with an external society (Project Selection, Funding, Mentoring & Teaching) to act as a student resource and handle important logistics.

Table 2: Model Summary - Design of a Crop Irrigation System in Honduras (Dordt)

Team Formation	Four self-selected students formed a team based on their interest in the project, with some instructor facilitation.
Project Selection	A faculty member had personal contact with the Luke Society, and Dordt was asked if seniors could participate in the project.
Funding	The Luke Society provided funding for the irrigation piping, fixtures, and tools. The student's first trip (surveying and initial irrigation layout plan) was funded by the Luke Society. For their second trip (system installation), the students raised their own travel and lodging funds from friends, family, and their churches.
Obstacles Identified	The (large) project required extensive planning and logistical support from the Luke Society. Travel to the site was critical to allow the team to perform work and have enough mountain jungle experience to design the installation.
Deliverables	Design plans and installation assistance for: water diversion, holding tank and filtration, mainline pipe layout, and an irrigation sprinkler system.
Mentoring & Teaching	A faculty mentor and a client both worked with the team, as well as Luke Society personnel.

Institution III: Engineering Design at Grove City College

Grove City College Background. Grove City College (GCC) is a four-year, independent college located in Grove City, PA with an enrollment of 2,200. Although the school is primarily a liberal arts college, it has ABET accredited electrical and mechanical engineering programs. Each program has its own department chairman. There are six electrical engineering faculty and eight mechanical engineering faculty. The electrical engineering majors can pursue a concentration in either "classical" electrical engineering or a concentration in computer engineering. The 15-25 electrical graduates each year are typically split equally between each concentration. The 25-35 mechanical engineering graduates likewise can pursue options including fluids, machine design and thermal.

Grove City College has a fine history of supporting science and technology. One of its founders, J. Howard Pew, also founded Sun Oil Company. Emphasis is placed not only on a quality technical education but also on the underlying characteristics of ethics, personal and community involvement and development, and community leadership. Many of its graduates have served as CEO's of technology based companies such as Motorola, Alcoa, U.S. Steel, and Tyco. One of its graduates, John Breem, recently was chosen as the new Tyco CEO to lead them to fiscal recovery.

The college has recognized the importance of providing its students an opportunity to study in developing countries or to participate in aiding their development. The college's academic structure recently has been reorganized with a greater emphasis placed on external studies. A new dean's position has been created, "Dean of International Studies, Graduate Advancement and Faculty Development." Faculty members also have been supported through faculty development funds to (1) travel to developing countries to investigate potential engineering projects, (2) attend conferences such as the Christian Engineering Educators Conference[16] (CEEC) in order to share like experiences, and (3) participate in the development of a possible new cooperative study center in Uganda, East Africa.

Senior Design. The electrical engineering students are required to take a three-hour course entitled "Introduction to Design" during the first semester of their senior year. They are taught the design process as well as soft science subjects such as ethics, professionalism, and communication skills. About half way through the course, they form groups of 3-5 students. At this time, the groups propose their design projects that they will develop during the remainder of the semester and during the second semester prior to graduation. They are required to complete lab work on their projects during the last third of a three-hour lab the first semester, and complete the project during a two-credit lab course the second semester. The college normally funds $300-$2000 for each senior project. The projects are student driven with faculty input in the form of recommendations and assistance with problem solving. Although GCC has both electrical and mechanical engineering departments, the students from both departments have not yet collaborated on projects.

Figure 3: Prototype of a Solar Power System for Remote Areas

Empirical Data Set III: Design of a Solar Power System for Remote Areas (Grove City)
Problem Statement. Throughout the world, situations arise in which conventional access to power grids is not available. Many people live in remote areas that do not have the infrastructure of power transmission systems or, if the system exists, it is unreliable. This scenario is common in Africa and areas of South America. The inaccessibility to electric power prevents people in remote locations from using everyday appliances, clean water, vital medical equipment and everything in between on that spectrum. One solution to this lack of available electrical power is solar energy. Solar systems that currently exist are usually rigidly mounted at a fixed location. If the system is needed at another location, it would be very difficult to move. If more or less capacity is needed, it would be difficult to change the capacity. It is likewise very difficult to monitor the reserve capacity of the system. The decision as to whether to draw from the charged batteries often is made without knowledge of the reserve capacity and, later, the system has no charge remaining when it is needed.

There thus exists a need to develop a scalable, modular solar power system that is easy to use, portable, and reliable. Products that partially meet this need currently exist on the market. However, there is no one system that is scalable and portable and has a reliable monitoring system built-in. In general, companies do not provide integrated systems that are easily reconfigured and include the solar cell, charge controller, battery, battery monitor, and inverter. Thus, consumers with little or no technical knowledge face a real challenge in solving this problem. The Scalable Portable Solar Power System project sought to provide a portable power system that eliminates this difficulty of setup and integration in current systems, while supplying reliable battery monitoring capabilities.

Project Selection. The need for a portable scalable solar power system originally was identified by a faculty member who had worked on missions related projects in Africa. He observed first hand the large number of solar power systems being installed in Uganda. Many were being donated by church groups and service organizations like the Rotary. A church diocese in Pittsburgh had recently installed their one thousandth solar system in Uganda. The faculty member observed the difficulties in using the solar systems and depending on them for critical electrical power. A second faculty member recognized the same need during a separate college funded trip to Africa to identify electrical engineering projects. The need also was confirmed by a medical doctor in Kenya who depended in part on reliable solar power for his medical work.

The general project idea was presented to all the upcoming seniors at the end of their junior year. The value of the project was strongly supported by both faculty members. The group of four students that tackled the problem included two students who had chosen the "classical" concentration and two students who had chosen the computer engineering concentration.

Design Approach. The students first identified the sub-components necessary to meet the objectives for the solar power system. They determined that they needed a solar panel, inverter, battery, charge controller, and system state monitor. The two "classical" students concentrated on the "power" aspects of the project and worked on the solar panel and battery specifications. The two computer engineering students concentrated on the system state monitor and the charge controller. The battery, inverter and solar panel were bought from commercial vendors according to the design team's specifications. The charge controller was modified from a circuit that they found in the literature. They made a printed circuit board of their final design. They researched the literature and found two promising theoretical approaches for the system state monitor. They settled on one of them and implemented its algorithm using an embedded controller. Part of this process required the students to develop a data acquisition system to measure operating parameters and to develop a database. The system sub-components were integrated, and the complete system was mounted on a dolly structure for portability. The total cost for the project was $1,700. The major purchases were $500 for the solar panel and $200 for the batteries.

The teaching staff checked the sizing to specifications of the major components before they were purchased and the initial use of the solar panel after it arrived. The staff also checked the modified design of the charge controller and guided the students in making the printed circuit board. Initially, the teaching staff guided the students in their search for a feasible system state monitor. After a promising approach was found in the literature, the students were instructed to verify the claims made in the paper, determine how to implement the concepts in their system, and then verify the operation of their system.

Project Results. The project required an understanding and application of circuit analysis and design, data gathering and analysis, embedded system programming, and system integration, construction and verification. The team designed, analyzed and implemented on a PCB a charge controller. The battery monitoring algorithm involved mathematical analysis techniques. The technique the team settled on is based on the techniques developed by Aylor, et al. [17] originally created for wheelchair users. The technique involves two measurements of the electrical condition of the battery. One is the open-circuit (or unloaded) voltage across the battery terminals and a coulometric measurement which tracks the current discharged from the battery. This technique was implemented using a Motorola 68HC11 to execute the required switching of the loads, the analog to digital conversions, the managing of the databases and the execution of the algorithms. The HC11 was also used to control the user display. The team had to determine reasonable specifications for the solar panel array and the inverter. Finally, they located manufacturers of scalable individual components, purchased the components, and installed them on a dolly structure.

The students were required to use a two channel data acquisition system for both the evaluation of the monitoring algorithm and the proof of performance of their integrated system. This step was an added benefit since they had just completed a senior lab in data acquisition, and they were able to use the system that they had designed in that lab.

In addition to the normal engineering required in a senior level project, the design team also had to consider the issues of ruggedness, adaptability to developing countries and sustainability. Although the students did not have the opportunity to travel to a developing country, the faculty member who had visited Africa gave them advice throughout the project.

Conclusions and Lessons Learned. The project was completed on time according to the design specifications at a reasonable cost of $1,700. This result was quite an accomplishment in itself. The students did not have the assistance of an electrical/electronic technician since the electrical department was just recently given approval to hire one. They would have profited from the help of a technician in the installation, testing and integration aspects. This project was the first time that some of the students had the chance to work with currents over 1 mA. It was also difficult to evaluate and integrate the large area solar panel (25.4 lbs., 4.3 feet long, 2.2 feet wide, and 1.6 inches thick). The students also had to rely on the help of the mechanical engineering technician for the construction of the dolly system. (The mechanical technician had the responsibility to assist the mechanical engineering students who were also trying completing their projects.)

The students additionally had to consider the ramifications of the fact that the system would potentially be used in a critical life-threatening situation in a hostile environment. Although the monitoring algorithm worked adequately, the students eventually concluded that more work needed to be done as well as more proof of performance testing should be completed before the system was shipped to a third world country and put into operation.

Recently, an expert with shipping experience from a developing country evaluated the project and was pleased with it. He concluded that the system was indeed portable and scalable. In his opinion, the unit could be easily dismantled, shipped and then reconstructed. It could be easily moved once in the working environment. System components that met the student's specifications could also be readily purchased in the developing country.

Table 3 summarizes the data from this Grove City College project. This table includes important facts extracted from the Grove City College data. For example, faculty members had a personal interest due to their travels to Africa (Project Selection).

Table 3: Model Summary - Design of a Solar Power System for Remote Areas (Grove City)

Team Formation	A self-selected team of four students composed of two "classical" EE's and two from the computer engineering concentration.
Project Selection	The need was identified independently by two faculty members traveling to Uganda (one on a school funded trip to identify design projects). The need was confirmed by a medical doctor in Kenya. The project was presented to the class and one team volunteered to take it.
Funding	The college provided $1,700 which was primarily spent on prototype components.
Obstacles Identified	The team had to account for ruggedness, adaptability and sustainability appropriate for a developing country. Students were not able to travel to Africa.
Deliverables	Design specifications and a working system.
Mentoring & Teaching	The project was student-driven. Staff checked student work at critical points, and provided guidance searching for a system state monitor. Mechanical technician support and outside expert review was also provided.

Institution IV: Design as an Extra-Curricular Activity at Messiah College

Messiah College's mission is "to educate men and women toward maturity in intellect, character, and Christian faith in preparation for lives of service, leadership, and reconciliation". Messiah has a student body of 3,000 students, 160 of which are enrolled in the engineering program taught by eight faculty. Messiah employs summer work experiences and internships to provide valuable real world experience for their students in all disciplines. In addition, for many years the Engineering Department has been utilizing extra-curricular projects, both locally and globally, to help educate engineering students. Several local urban projects in Harrisburg, PA have included community gardens, building straw-walled sheds, and roof-top gardening techniques.

Many of the Engineering Department's global extra-curricular projects have been facilitated through Dokimoi Ergatai[18] (Greek for "Approved Workers"), basically a student run organization, which collaborates with faculty, staff, and the local community to initiate, nurture, and oversee the development of appropriate technologies for implementation in needy areas abroad. Some of the projects have included:

- Photovoltaic(solar) electric power systems for a medical dispensary in Burkina Faso and a hospital in Zambia
- Solar-powered drinking water pumps supplied to a school for persons with physical disabilities
- Human powered pumps to irrigate a micro-enterprise farm run by persons with disabilities
- Hand-powered tricycles which provide mobility and freedom to polio victims

Other projects with global interest have been sponsored by the Collaboratory for Experiential Learning program, a "hands-on" learning laboratory. Some of these projects include work on water purification and on landmine detection, removal, and detonation.

Figure 4: Prototype of a Three Filter Ultra-violet Water Purification System

Empirical Data Set IV: Design of a Water Purification System in Guatemala (Messiah)
Water for the World[19] is an interdisciplinary extra-curricular project started in January 2002, inspired by one man's concern to provide pure drinking water to the world. A simple two-fold mission was developed:

- Create an awareness in people that there is a need for clean drinking water (education)
- Create devices to provide clean drinking water to people groups at an affordable cost and who can be easily trained to maintain the devices (sustainable purification)

Presently there are 14 students, first year to senior year, from four of the five schools within Messiah College who are now committed to take part in this on-going project. Four teams have been established. An engineering team has built a small, three filter, ultra-violet light prototype purification system which can be powered by AC or DC electricity. A natural sciences team tests and documents the purity of the water being filtered. A business team has developed a marketing strategy for the device which was developed. A communications-education team has developed (and maintains) a website for the project [19] and has developed a brochure in both an English and Spanish edition and educational materials. Faculty advisors from each department/school were solicited and have been involved with the teams.

The teams meet bi-weekly together in a large meeting and as needed during the week to fulfill the objectives of each team. The man who inspired the project and an alumni advisor who is an environmental chemist come to most of the meetings, giving valuable input to the teams.

In addition the mechanics and chemistry of water purification techniques, teams have also learned team dynamics including: time management, project management, communications skills, division of labor, conflict resolution and the use of logbooks.

In August 2003, a scouting team of students and advisors visited a Kekchi Educational Center in San Juan Chamelco, Guatemala to investigate water needs of the school, find local suppliers of water purification materials and equipment, and field-test the prototype system mentioned above. All three objectives were met. Based on the scouting team's recommendation, the center has installed a system which saves the school $1,600-$1,700 per year in purchasing bottled water and firewood to boil water. Another system is being planned for a seminary in Guatemala City.

Through this and other similar extra-curricular projects, engineering students have begun to fulfill the mission of Messiah College, "to educate men and women toward maturity in intellect, character, and Christian faith in preparation for lives of service, leadership, and reconciliation."

Table 4 summarizes the data from this Messiah College project. This table includes important facts extracted from the Messiah College data. For example, projects need not be associated with credit-based courses, but through established service organizations (Team Formation).

Table 4: Model Summary - Design of a Water Purification System in Guatemala (Messiah)

Team Formation	Students voluntarily participate in a student-run service organization. 14 students ranging from freshmen to seniors, from four different schools within Messiah, formed into teams: engineering, natural science, business, and communications/education.
Project Selection	The Guatemala site was suggested by the Mennonite Central Committee. It was selected by students based on the inspiration of a local philanthropist.
Funding	A local philanthropist purchased the equipment. Students raised their own travel funds.
Obstacles Identified	The cost of overseas travel for field-testing. The language barrier required a translator.
Deliverables	A prototype purification system with demonstrated effectiveness, a marketing strategy, and publicity through brochures and a website.
Mentoring & Teaching	Faculty advisors from each of the departments provided mentoring. The man who inspired the project and an alumni environmental chemist served as consultants.

INSIGHTS: Designing, Selecting, and Executing International Humanitarian Design Projects

Using the extracted data from the previous sections, insights may be derived through similarities, contrasts and distinguishing project features of the summary models of Tables 1-4. This section highlights these insights with the goal of elucidating approaches for successfully executing international humanitarian (IH) design projects in an engineering curriculum.

Team formation. The impact team formation has on success and learning during design projects is well documented [20,21]. It is notable that in all four of the exemplary projects presented, teams were composed primarily of self-selected students who chose the project because of their interest. It is well documented that self-selected project teams can have mixed results in success. In the case of these IH projects, the inherent need associated with humanitarian efforts appears to overcome (or at least temper) typical self-selected team problems.

As demonstrated by the four institutions, IH projects also foster interdisciplinary work. Structuring teams in an interdisciplinary fashion is not an afterthought, as in many efforts in academia. Instead, the projects implicitly call for interdisciplinary skills. These skills are a prerequisite to success.

Project selection is a challenge for successfully executing IH projects. Geographic, cultural and language barriers can all complicate the process of identifying and scoping a project (reference 10 discusses IH project selection in-depth). Perhaps because of these challenges, all four projects studied involved an outside person or organization already actively working to address a social need: EMI and WFMIC were working to assist injured mothers in Nigeria, the Luke Society was assisting the Tolpan people in Honduras, church groups and service organizations like the Rotary were installing solar system in Uganda, and MCC Missions was serving the Ketchi people in Guatemala.

An additional challenge is to choose meaningful projects that excite student's interest as well as provide a quality educational experience. In each example given, the faculty were actively involved in the project selection and specification. In several cases, the international involvement of faculty members led to identification of the projects and their inherent commitment to teams which chose the projects. In most cases, the faculty traveled to the developing country to see first hand the needs and obstacles.

Funding. Due to the importance of international travel and/or prototype delivery, IH projects may incur higher costs than normal course fee structures can support. In three of the projects the students traveled internationally to visit the site, and the Grove City team, which did not travel, relied heavily on the observations and experiences of a faculty member who had visited the site. In the case of the women's hospital design team and the water supply system design team, students worked to raise additional funds to cover travel and other project expenses. For the Water for the World project, the students and faculty raised their own funds for traveling, approximately $750 each. The equipment for the Kekchi educational center was purchased by the philanthropist who inspired the project.

While greater funds may be needed (in some cases), the likelihood to secure the appropriate funds also appears to increase significantly, compared with typical academic design projects. The willingness of philanthropists, foundations, certain government agencies, churches, and community groups to support IH projects is greater due to the inherent needs and potential payoffs.

A further consideration of the funding data also indicates that a wide range of project costs are possible. Low cost projects with existing technologies are possible, as shown by the Grove City College project. This project, while modest in terms of financial demands, presented significant technical changes to the students, drawing and extending their engineering knowledge.

Overcoming Obstacles Characteristic of IH Design Projects. Overseas travel was both desirable and a special challenge in the case of every project. One of the most difficult cases was the Calvin team which chose to visit Nigeria despite a US State Department Travel advisory. An email to the students read, "Although Calvin would prefer that you not go to Nigeria at this time, we of course wish you success in your project and safe and healthy travel." In this case, EMI provided some of the logistical support that the college normally would have supplied. Logistics must be well planned and scheduled to overcome these obstacles. External groups may be willing to assist with these logistics, as in the case of EMI with Calvin or the Luke Society with Dordt. Such partnerships are invaluable, and can be informally developed on an as-needed basis.

IH projects present potential problems with language barriers. In the case of the Messiah team trip to Guatemala, for example, a student majoring in Spanish was invaluable in translating discussions with local health officials and school personnel as well as written documentation during and after the trip. Most Ketchi people could communicate in Spanish, even though it was not the language most familiar to them.

Deliverables for the four IH design projects were similar to more traditional domestic projects: design specifications and prototypes. The unusual deliverables for these projects were the international on-site assistance; a survey of Nigerian terrain, and the installation assistance of 6,000 feet of irrigation piping in Honduras. The engineering outcomes included:

- Design specifications, drawings, and cost estimates were provided for a women's hospital in Nigeria.
- Design specifications, installation plans, and installation assistance were provided for 6,000 feet of irrigation piping in Honduras.
- A scalable solar power system suitable for shipment to Africa was designed and constructed.
- A water purification system was tested and recommended for installation in a Guatemalan school, saving $1600-$1700 per year.

Such outcomes represent tremendous results on the part of undergraduate engineering students. Such deliverables should instill a pride in the students, provide a word-of-mouth source of advertisement and publicity for future projects, and create an outreach avenue to an institution's local or extended community. These secondary outcomes are a critical aspect of an engineering student's education and an institution's mission.

Mentoring and Teaching Considerations. All four cases presented involved close faculty mentoring of student teams, and, in several cases, teams were assisted by subject-area experts. A summary of learning outcomes specific to IH design projects includes:

- Increased awareness of social (in this case Christian) responsibility
- Cross-cultural, socio-political, and international affairs lessons were learned by the teams (e.g. necessity of security, strong work ethic of poor farmers, camaraderie built across linguistic and cultural differences).

- Exposure to the issues of ruggedness, adaptability and sustainability for developing countries.
- Increased maturity in intellect, character, and Christian faith in preparation for lives of service, leadership, and reconciliation.

General Insights. A number of insights are apparent from these exemplary projects that cross the categories described by the IH project framework:

- Many of the customer needs and requirements of the projects extended the students' perspective and skill set beyond any coursework or typical industrial project. Needs related to power consideration, environment, ergonomics, and culture are unique, or the parameter ranges required are beyond those encountered when considering industrialized countries. These needs appear to naturally engage the students. They also call upon the students to independently investigate literature and other sources to extend their knowledge. Such research provides a foundation for life-long learning and education beyond the baccalaureate degree.
- In terms of creating a teaching model, external and invested personnel are essential to IH projects. The expertise provided by external sources must be balanced by the students' genuine interest and commitment to the project. The combination of motivated students and committed external personal appears to be a consistent factor of project success.
- IH projects may be solved through the adaptation of low to medium technologies. As demonstrated by all the exemplary projects (existing building and complex layouts, water purification technologies, water supply materials, and solar technologies), existing technologies are synthesized, in novel and creative ways, to solve real human needs. Technical expertise must be brought to bear by the student teams, but resources are readily available due to the technologies employed.

Implementing IH Design Projects. The four projects reviewed here illustrate how international humanitarian design projects can be implemented in an engineering curriculum. Six key elements for project success are highlighted and compared across projects. The above insights give additional guidance regarding how each key element may be successfully negotiated when implementing an IH project. Table 5 presents a summary of insights for each key element in the form of actionable guidelines. These guidelines, along with the data analysis above, provide a model for implementing such projects. Although the examples given are all in the context of faith-based institutions, the model developed is more generally applicable (provided differences among institutions are accounted for.) Table 6 suggests possible sources of IH design projects. Faculty who wish to implement domestic service-oriented design projects are referred to references 1 and 9.

Table 5: Model Guidelines

Team Formation	• Students should be self-motivated to tackle an IH project. • Self-selected teams may be appropriate, if united by their motivation. • IH projects may call for teams with interdisciplinary skills.
Project Selection	• Partner with individuals knowledgeable about the problem context. • Ideally, partner with individuals already involved with the problem. • Carefully scope projects for feasibility in consideration of the obstacles involved.
Funding	• Prepare for higher costs than traditional domestic projects. • Consider philanthropic churches, community groups, and individuals. • Students and their communities may be willing to help fund an IH project.
Obstacles Identified	• Plan in advance for international travel which is often critical and difficult. • Partner with knowledgeable individuals for help with travel logistics. • Insure students have an adequate awareness of special design constraints. Travel, contact with individuals, and supplemental lectures and research can help.
Deliverables	• Encourage or require delivery of a working design or actionable recommendations to provide motivation, satisfaction, and community rapport. • Avoid assuming that high-technology is required. Creative adaptation and synthesis of low to medium technologies may be appropriate.
Mentoring & Teaching	• Seek mentors with problem-related expertise, particularly if faculty lack it.

Table 6: Potential Sources of IH Design Projects

- Personal contact with individuals and organizations working in developing countries
- The Basic Utility Vehicle design initiative www.drivebuv.org
- Development by Design www.thinkcycle.org/tc-topics/
- Engineering Ministries International www.emiusa.org
- Design that Matters http://www.designthatmatters.org/

Conclusions and Future Work

The international humanitarian projects presented here were carefully selected for their exemplary success. This selection, and subsequent data analysis, has lead to an identification of how key elements were addressed in each project, highlighting notable similarities and differences among projects. These key elements provide a basis, at least in part, for including international humanitarian design projects in any engineering curriculum. With the inherent motivation from the reported projects, it is hoped that engineering faculty will internalize these key elements and guidelines, and initiate similar efforts at their home institutions. By so doing, faculty will encourage engineering students to embark on a learning journey harmonizing their technical studies with humanitarian pursuits, and thus engaging the intellectual, physical and spiritual aspects of their personhood.

While the model's assessments, as reported here, provide useful insights into successfully selecting and executing IH projects, future study of additional and perhaps less successful projects will underscore and expand these insights. Future work for this research may include monitoring future IH projects using the key elements identified here as a template for project documentation. Further study may also uncover additional key elements important to project success.

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