AC 2008-2954: ON PROVIDING ENGINEERING STUDENTS WITH CULTURALLY-APPROPRIATE DESIGN EXPERIENCES IN DEVELOPING COUNTRIES

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Abstract

Academic institutions are encouraged to instill "the impact of engineering solutions in a global and societal context." This paper summarizes the structural, planning, and logistical aspects of offering senior-level capstone and underclass extra-curricular design projects targeted for developing countries. These projects engage the students in year-long design and fabrication, and culminate in taking students to foreign soil for delivery and installation. The necessary infrastructure and culture at the academic institution, relationships with appropriate intermediaries, and the role of a receptive national host that needs engineering services are identified. The goal is to continue an on-going collaborative relationship that takes students and faculty abroad annually, who in turn help to identify new projects for future teams. The criteria by which projects are selected and staffed (*i.e.*, academic merit, field need, and student interest) are discussed.

A case study is presented that evaluates our pilot program. The projects that were selected focused on an organization's infrastructure that provides mechanical services (*e.g.*, electric power generation, water, and sanitation) to support a radio station, a hospital, a school, and a host of Non Governmental Organizations. Additional projects were focused on needs of rural people. The results of our first team, which traveled to Liberia, West Africa in May 2007 are documented. They successfully installed a student-designed cooling system for diesel-powered generators, built a medical waste incinerator for the hospital, and distributed solar-powered reading lamps to rural dwellers. They also began a new senior capstone project—to improve the water distribution network—by collecting appropriate data and preparing CAD drawings of the facilities.

Overnight trips to remote villages provided engineering students and faculty an opportunity to see how the rural dweller lives. These experiences provided rich insight for the students to see basic needs of people on a new level, and how they might develop engineering solutions which blend into the culture.

Introduction

This paper presents a model that was used to give our engineering students an opportunity to design culturally-appropriate technical solutions to technical problems in a developing foreign country, and to travel to the country to implement them. After a faculty survey trip in 2006, the first team of engineering students produced their designs during the 2006-07 school year and traveled to West Africa in May 2007. Their major engineering accomplishments include the following:

- designed and installed a cooling system for institutional power generators
- built a medical waste incinerator
- surveyed and measured the performance of an over-utilized water distribution system
- designed, built, and delivered solar-rechargeable reading lamps.

We hope that this paper will be helpful to other engineering faculty seeking to establish a similar program at their institutions.

Background

Academic institutions are encouraged to instill "the impact of engineering solutions in a global and societal context."[1] In particular, the Department of Engineering and Computer Science at our university has a stated educational objective that graduates "will be knowledgeable of opportunities to serve in and support Christian ministries both in their communities and around the world." Furthermore, trends show that today's college-age students are globally-minded and seek to make a difference.[2]

There have been other efforts to give engineering students a global perspective or integrate engineering design projects with international humanitarian needs. Some of the previous work has been done at faith-based institutions with engineering programs. Vanderleest and Nielsen[3] describe a course offering which integrated "global engineering and the liberal arts by immersing the students for one month in the engineering, business, and cultural aspects of a foreign (European) society." In 2002, Duda[4] described groundwork being laid at Grove City College for international humanitarian capstone design projects in electrical or mechanical engineering. This included faculty survey trips, identification of likely projects, and plans to address challenges such as ensuring educational merit and providing for additional costs.

Green, Wood, Vanderleest, Duda, Erikson, and Van Gaalen,[5,6] (2004) presented parallel papers discussing common key elements among international humanitarian design projects which had run at the following faith-based institutions: Calvin College, Grove City College, Messiah College, and Dordt College. The key elements were 1) team formation, 2) project selection, 3) funding, 4) obstacles identified, 5) deliverables, and 6) teaching and mentoring. The projects included designing a women's hospital, a crop irrigation system, a dolly-mounted solar power module for remote areas, and an ultraviolet water purification system. Most of these projects were senior capstone design experiences. Several included international implementation. At Messiah, the Dokimoi Ergatai[7] student organization has facilitated using appropriate technologies for several projects on foreign soil over several years' time.

Liberia is a resource-rich country on the Atlantic coast in western Africa which has been decimated and impoverished by a military coup in 1980 followed by bloody civil wars in the years 1989-1996 and 1999-2003.[8] As a result, much technical expertise has been drained from the country at the very time in which rebuilding is crucial. Recognizing this need, Ray Hutchison, an experienced missionary to Liberia, approached the authors about establishing an on-going collaborative relationship that takes engineering students and faculty to Africa to work on projects and provide engineering services to help the Liberians—both those responsible for the physical plant at an established institution and to help the rural dweller.

Liberia is located on the SW coast of West Africa.

Infrastructure
There are several institutional and cultural factors which serve to make such an effort possible. First, there must be an academic institution that supports the concept. The institution can facilitate such efforts by providing an office experienced in preparing students and faculty for overseas travel. Such an office can aid the students with writing letters to potential donors who can help fund the trip, coordinating immunizations with a student health care facility, obtaining airline tickets, and providing travel support such as getting passports, visas, emergency insurance, and rides to the airport. The institutional support office should also maintain travel policies that will help prevent travelers from getting into trouble. For example, dating foreign nationals on such trips should be strongly discouraged.

If international travelers do not have help in communicating and working within a foreign culture, they could be hampered by cultural blunders which could make them appear insensitive —and thus minimize effectiveness. Therefore, a liaison who is experienced living in and communicating within the host country would be one means by which a team could be educated. The liaison should be able to communicate well with the students and faculty in order to provide cultural orientation—preferably before the trip. It is helpful if the liaison is flexible so that unexpected technical delays will not cause frustration for the travelers. Our team found the regional director of an organization that is working in Africa to be an excellent liaison.

It is also important that there be a host organization in the target country that has technical needs. The national host should be flexible in accepting the uncertainties of foreigners providing technical solutions to their problems with limited material resources available. The host should also be aware and tolerant of cultural mistakes the travelers commit. In addition, the host should have sufficient resources of personnel and facilities so they can help coordinate the transportation, housing, medical attention, and meals for the visitors. The host should also enable the team to communicate with the home country. There should be good and frequent communication between the host organization and the engineering team before, during, and after the field trip. Going to a foreign country to help a host organization legitimizes the engineering team's presence in the eyes of foreign officials.

Case Study
This case study illustrates the following: the necessary groundwork, the survey trip taken in 2006 to identify projects, the project selection, the team formation and preparation, and two of the five projects from the field excursion with eight students in the summer of 2007.

A. The Groundwork
Our liberal arts university currently enrolls 3000 undergraduate students; 10% of them are engineering majors. It has been sending student teams into cross-cultural short-term experiences since 1970. Over 5000 students have traveled to 89 countries to participate in humanitarian, cultural, sports, youth, music, drama, and ministry-related programs. So, taking a team of engineering students to do some engineering-related work in Liberia was well received when we first proposed it. The university also hosts a conference every year on campus. About 100 guests come to participate in campus-wide activities, speaking in daily chapel and evening services, conducting workshops, displaying their organization's outreach worldwide, and meeting

with students to discuss short- and long-term service opportunities. During one of these conferences we met Mr. Ray Hutchison, the regional director of an organization that is working in Africa.

He began by telling us about what a group of engineering students from Messiah College was doing in Burkina Faso. Every summer a group would go over and work on solar-electric and mechanical engineering projects. He suggested that we consider doing something in Liberia. Since he had lived in Liberia with his family before the 14-year civil war ravaged the country, he had some connections already established, and from his recent trip to Liberia knew that there were tremendous needs that might appeal to our engineering students. As a result of his patient encouragement, we agreed to go on a survey trip with him in 2006.

In addition to the university support, the Engineering Department began a new student organization called Society of Engineers Aiding Missions, or SEAM. This group of students meets regularly and takes on projects to help others, typically in developing countries, with engineering and technical services.

In summary, the groundwork consisting of institutional support, identifying a liaison, and targeting a specific country and a specific need were completed. A student organization was established that identified engineering students interested in using their technical skills to help others who are overseas; this group would become instrumental in providing the pool of students who would eventually go overseas on department-sponsored trips. The next step was to get some engineering faculty over to Africa to get a first-hand look at the situation.

B. The Survey Trip

We took a survey trip to West Africa in May of 2006 to evaluate engineering project possibilities, the nature of the projects, the political stability in a country that just came through a 14-year civil war, the nature of accommodations, health care, food and water, the receptiveness of the national hosts to foreign engineering students, transportation, and to discern the nature of the cross-cultural experience our engineering students would get. Of the 10 days, four were consumed by travel leaving only six in-country working days. The primary focus of our work would be to help the ELWA campus recover from the devastating civil war. ELWA represents the call letters of the radio station that began broadcasting in the 1950s. As a result of the radio station, a hospital and school were established in the 1960s. Presently the 134-acre campus comprises many residential homes and Non-Governmental Organizations. Since there is no power grid in Liberia today, ELWA must generate its own, and provide water and sanitation utilities to those who live and work there. Because of the civil war, many of the trained technicians are no longer there, leaving a struggling handful of workers to maintain operations. Now that the war is over, and 15,000 UN peacekeeping forces are occupying the country, efforts are underway to

Our trip upcountry included travel over many dirt roads and log bridges. This photograph shows our first encounter with a log bridge.

rebuild Liberia. However, with 85% unemployment, reconstruction is moving at a very slow pace. Thus, there are many opportunities for engineering students to work on a variety of projects.

We met with the administrative team of ELWA on the first day to tour the facilities and hear their needs first hand. During the next few days we walked around, took pictures, and talked to many of the workers, toured the supply shops in Monrovia, and met again with the administrative team before we left, primarily to update our project list and get a sense of priority from their perspective. Tops on their list was engineering help to provide relief from their task of generating electricity; they were paying upwards to $0.60 per kilowatt-hour in diesel fuel costs alone. With a very low budget, they acquired three mis-matched used generators and were struggling to cool them with their damaged cooling system. It was not uncommon to have the power go off several times during the day. Power generation was shut down at night to help conserve fuel.

Included in our six days in Liberia was a two-day overnight trip to a village 100 miles north of Monrovia. This village was accessible only by foot path or canoe. We drove all day mostly on dirt and muddy roads (rainy season), struggled to cross two log bridges, and reached the end of the road much later than planned. We waded through swollen streams and crossed single-log bridges at night, and rested in the first village. Half a dozen river crossings and an hour later, we came to an extremely swollen river. Our guide crossed first but could not find the path on the other side; at the deepest part, he was up to his chest in water. We returned to the village near the end of the road and spent the night there. The village chief welcomed us and invited the men in the group to sleep in the open community hut, which sheltered us from the rains.

We saw how the rural villager lives in Africa; many small villages have neither electricity nor wells, so they drink "so-so" creek water and get "runny tummy." Many small villages do not have roads to provide vehicle access, so everything has to be carried in on foot. During our two days of travel, we talked to nationals about some of the needs of the rural dwellers. It was indeed a very insightful experience.

Some of the projects are listed in the next section. They include projects for ELWA such as solar-power generation, a cooling system for their generators, hot water for their hospital, good water pressure throughout their campus, and projects for the rural dweller such as solar-rechargeable reading lights.

C. The Project Selection Process

Of the two dozen projects on the list, we selected half a dozen of them for two target groups of students: those working on capstone senior mechanical engineering design projects and those working on extra-curricular projects, comprised typically of underclass mechanical, electrical, and computer engineering students. The project descriptions were drafted such that the scope was targeted for completion in one academic year. The criteria for selection included appropriate academic merit, the field need, and student interest. Senior design projects must include course work in the curriculum, but also require that the students learn something new in order to complete the project. The projects that did not have as much academic merit were not considered for senior design, but if they met the next criterion—whether the project meets a real

humanitarian need—they were presented to the students for consideration as extra-curricular. The mechanical engineering faculty reviewed the African's project list for suitable senior design projects. For the first year the list included the following:

- Solar electric power generation
- Solar panel manufacturing in Liberia using locally available materials
- Alternative power generation; from the ocean there is a steady breeze and lots of waves
- Solar powered security light
- Cooling system for the diesel power generators
- Muffler for the generators
- Improving the water system on campus (Phase I, II, and III)
- Portable well-drilling machines that can be carried by foot to remote villages
- Scarecrow hawk for farmers

The extra-curricular projects on the list from which the underclass students could chose consisted of the following:

- Solar-rechargeable reading lights
- Alternative well-drilling methods
- Hospital medical waste incinerator
- CAD package suitable for Liberia
- Mapping the campus in a CAD package
- Low-cost water filters for individual families
- Playground equipment that pumps water

Surprisingly, for the seniors choosing capstone projects, designing well-drilling equipment that could be carried in on foot was the most popular, even competing with the SAE Formula race car project. Although the cooling system for power generation was lower on the list, we made an administrative decision to work on an ELWA project (vs. a project for the remote dweller) the first year, partly to encourage the ELWA team since they hosted us on our survey trip, and also because we recognized the significant importance of developing the infrastructure of ELWA—they needed reliable electric power generation, and the cooling system they had was destroyed in the war. Also, when we asked to see an engineering drawing of the ELWA campus, they did not have one. We put CAD on their project list.

D. The Team Formation and Preparation

While having a list of projects, a liaison, a receptive group in a developing country, and a supportive academic institution is necessary, the most important part is a team of willing students to go over and do the work. To this end we advertised the opportunity to all of the engineering students, starting with the students in SEAM. At one of their regularly scheduled meetings, we gave a 2006 trip report, showing slides of the facilities, the excursion up country, crossing the log bridges, wading through water at times up to our waist, and then talking about the projects that they could work on during the year. There was an enthusiastic response.

The SEAM students decided to adopt the solar rechargeable reading light project for the rural dweller, especially for those who need to read and study at night. Four seniors chose to design a

cooling system for the power generators for their capstone project; one of them went over to help install the system. Two students were interested in helping with the incinerator project for the hospital; another student keen on computers wanted to help find a suitable CAD package, learn how to use it, and then began transferring the information we did have into the computer.

By the time the deadline arrived, we had eight students who committed to going. In addition to one senior who was on the cooling system design team, another graduating senior wanted to go and help with the cooling system. One of the strategic elements in getting a team interested in going was having a well-defined list of achievable projects that were clearly seen as viable, necessary, and helpful to the people we were serving in Africa. They all required various levels of engineering—whether it was analysis, design, or services. Once that hurdle was crossed, the next one was learning about the culture.

One of the important resources mentioned earlier was the role of a receptive host in the country. For us, our hosts were the ELWA administrators and the SIM personnel on the ELWA campus; they provided transportation to and from the airport and provided meals and lodging during our stay for a nominal fee. We had to coordinate all of the logistical issues related to our trip, including the work projects and tools that were needed to complete our projects. For example, we had to purchase a surveyor's level and tripod (on eBay), grade stick, measuring tape and measuring wheel to conduct our survey of the site. The biggest expense of this trip was the airfare. The total expense per student was $3200.

In addition, we scheduled orientation time with the team and our liaison, who was an American who lived in Liberia before the civil war and was well acquainted with the Liberian people and our host in Liberia. He provided cultural and social sensitivity orientation during our layover at Brussels, since the team was not fully assembled until we rendezvoused in Washington DC en route to Belgium.

Student assessment after the trip confirmed that the students felt that they were adequately prepared to mix with the people in Liberia, and work effectively with them.

E. The Field Excursion

Having completed the project designs and necessary preparations for the trip, the next task was to get the team to Liberia. Because the shipping container that had our high-temperature mortar was delayed, we had to carry (in our luggage) 100 pounds of high-alumina mortar to construct the incinerator. In addition we carried 30 pieces of two-foot long by two-inch diameter PVC Schedule 40 pipe with three dozen caps and ten solar rechargeable lamps with their charge-regulating circuits.

Project Descriptions

The following discussion will provide details of the senior design project and one of the underclass extra-curricular design projects, and how they provided design constraints not encountered in the USA. The other projects are just briefly mentioned.

A. Diesel Generator Cooling System

The diesel generator cooling project had sufficient academic merit that it was run as a senior capstone design project. What makes a "developing country" criteria different from criteria for a design in the United States is

- lack of capital
- limited building materials
- level of technical training of the end user (*i.e.*, the maintenance personnel)
- cultural appropriateness
- acceptance by the local people

The cooling pond as it was in 2006 without the cooling tower. Technicians pumped water out to the pond and sprayed it through rather large holes in PVC pipe. The water squirted out about a foot or two before returning to the pond. Light colored algae can be seen floating on the surface.

Whatever we designed and built would have to be understood by the end user, and be able to be fabricated and maintained by them.

The senior design team reviewed the literature and identified the four most popular methods that would be suitable for construction in a developing country. We chose four since there were four students on the team; each student would design a functioning prototype of their system, and the team would provide a comparison of the four different systems, including original capital cost of materials and equipment, cost of construction, and cost of operation. The basic idea of cooling the engines consisted of exposing the hot water coming from the diesel engines, typically at 150 °F to cooler air that was as high as 90 °F. To properly design the systems, the students had to determine how much heat had to be dumped.

This task appeared to be quite simple, but proved to be a challenge. The data that we were given from the field for temperatures and flow rates were not correct, causing our cooling systems to be significantly oversized. It turned out that it was not until we obtained more accurate temperatures that we were able to properly size the cooling systems.

The four different systems consisted of a wet natural-convection tower, a wet forced-convection tower, a dry tower, and a wet natural-convection fountain spray system. The ELWA campus has used wet natural convection towers and fountain spray systems. The generators came from the manufacturers with a dry cooling system mounted on the frame. However, because it is so hot in Liberia (7° north latitude), the radiators would inefficiently dump the heat into an already hot engine room. Hence, the radiators are not used as supplied by the generator manufacturer.

The additional constraints placed on the design team included the proximity to the ocean and the corresponding corrosive environment caused by the salt-enriched air and high humidity in the rainy season. Fuel costs for generating electricity range between $0.50 - $0.60 per kilowatt hour, so any solution that also used electricity would add additional operational cost.

Dry Cooling Tower. The dry cooling tower would be fabricated from truck radiators that were readily available from shops in nearby Monrovia, the capital of Liberia. The advantage of the dry tower was that there would be no loss of water due to evaporation during the dry season, and chemical additives could be added to the cooling water to enhance cooling performance. The disadvantage was that the corrosive coastal environment typically erodes the cooling fins in heat exchangers that face the ocean within three years.

Wet Cooling Towers. The wet cooling towers would require a superstructure filled with baffles that allowed the falling water more "air" time. For both wet-tower systems, water was pumped to the top and allowed to fall freely over lattice obstructions that allowed cooler air to pass through and eventually up and out. The forced-convection design had a large fan and motor oriented horizontally so that it pulled the air up through the center and out. The naturally convected tower requires a tall chimney to help create a density difference that would naturally circulate the warmer and less dense moist air inside the chimney. The air intake was positioned such that it faced the ocean so the natural breeze would assist the natural convection. Both tower designs required building a superstructure that did not exist. The forced-convection system required a motor and fan whereas the naturally-convected system required a tall chimney.

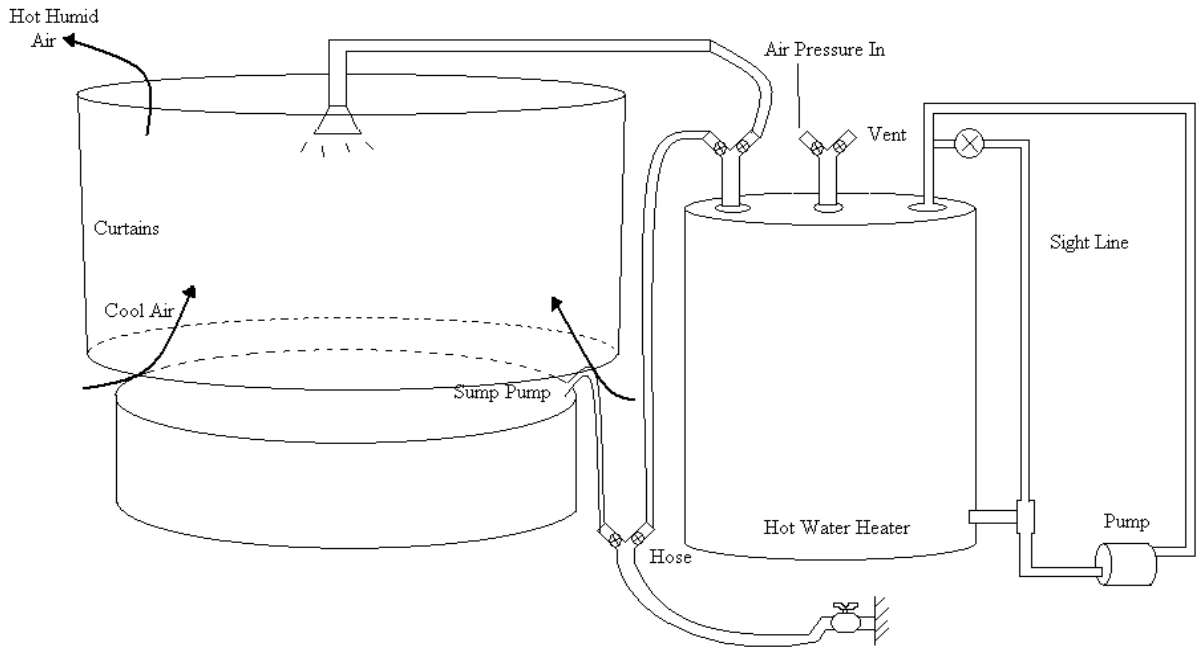
Fountain Spray System. The fountain spray system consisted of specially designed spray heads that would provide as much surface area per volume of water as was possible. The big advantage of this system was that a 20-ft by 30-ft cooling pond was already in operation and water lines were already in place. The disadvantage was that the spray heads were relatively expensive, and for three generators, we would need two dozen of them. Also, the small holes could clog easily.

The Final Selection Design Process

The four prototype solutions were presented to the ELWA Technical Services team with a cost comparison. We set up a website that allowed our Liberian customers to download the report and see our cost estimates. After they evaluated the different designs, and considered their own manpower and technical expertise, they chose the fountain spray system. This system was not the system recommended by the students. Furthermore, once the fountain spray system was chosen, the recommended solution was not chosen. They preferred three separate cooling lines, each with its own set of spray heads instead of a single spray system that just cooled the pond water.

The second semester was devoted to designing the fountain spray system. The team divided into a mathematical modeling group and an experimental verification group to test the model. This refined model was much more sophisticated and accounted for the heat transfer and water loss due to evaporation. Simulations were run for the wet season and the dry season. Students accessed the weather METARs at Robert's International Airport to track the wet and dry bulb temperatures, the winds, and the variations during the wet and dry seasons.

An experimental apparatus was set up in the laboratory. An electric hot-water heater was used to provide hot water. Various spray heads were tested in both elevated positions spraying down and low positions spraying up. The test area was cordoned off from the rest of the lab with a plastic curtain to set up a natural convection draft. A child's swimming pool collected the water which



Laboratory setup to verify the mathematical model and to compare the efficiency of spraying from top down vs. that of spraying from bottom up. With a full hot water heater, we were able to get about a five minute test run during which a steady-state natural convection was established. Temperature and humidity were measured at the air inlet and exit areas. We also measured water temperature at the nozzle and just before it fell into the pool at the bottom. Water pressure was easily controlled with compressed air and an air pressure regulator.

was pumped back into the 80-gallon hot water heater for the next test. Temperatures and pressures were varied and a set of performance curves were generated. When we exhausted the height range of the laboratory ceiling, we moved the spray head outside and took more measurements.

From these measurements we were able to corroborate the model predictions and we were able to specify the ideal nozzle spray head for Liberia. Unfortunately, none were available off the shelf. Since the cooling pond was 30 feet long, it was desirable to stack 10 spray heads on one 30-ft line. To maximize the spray area, we designed an oval spray pattern. To achieve this, the students drilled 78 holes in four rows using four different angles in two-inch PVC plastic caps. The caps were screwed onto adapters glued onto the ends of an elevated pipe. The heads were elevated to give the water more air time before landing back in the pond. The two-foot elevation was chosen for several reasons—one being that it was the maximum dimension of our largest suitcase. The other reason was that during the many thunderstorms, the wind velocity can be substantial. These pipes were held up with just a few supports. The PVC caps provided a low-cost solution that was understood by the Liberians. The screw heads provided a means of aligning them and removing them for service.

There was one problem. When the cooling system for the big generator was turned on for the first time, the water spray was only a few inches above the spray head—not the expected five feet. The water pressure coming from the pump was too low, so a 1.5-Hp pump from another

The fountain spray cooling system designed and built by seniors for their capstone design project. Ten spray heads on a 30' line was sufficient to dump more than 60 kW of heat. Each head was machined with 78 holes of 0.043" diameter at four different angles to get an oval spray pattern.

unit that had an inoperable motor was put on the ¾-Hp electric motor. The picture shows the result.

The team of two graduates, with help from a Liberian helper, assembled the system in less than two weeks. We chose to leave their present system operational and installed "T's" and valves in the line in the event that the tiny 0.043"-diameter holes got clogged by the algae in the pond water. We had to purchase the 2-in PVC ball valves and CPVC cement locally. Just purchasing the items was a cultural experience; the first store wanted $15 for one ball valve, the next store wanted $25, and the third wanted $35. USA students are not used to negotiating their purchases.

B. Solar Rechargeable Reading Lights

As its service project for the 2006-07 school year, the Society of Engineers Aiding Missions (SEAM) chose to help enable Liberian pastors who live in the bush to read and study at night. We learned of this need while *en* route to the Liberia bush during the 2006 survey trip. Seeing villages first-hand at night made this need obvious.

Liberian hunting and farming villages are small, tight-knit communities without easy transportation access to neighboring villages. Pastors of churches in such areas typically work an occupation such as farming during the day, so any study and preparation time is forced to the evening hours. However, because of its location near the equator, the Liberian sunset consistently occurs around 7:30 p.m. Fuel to power kerosene or propane lights is scarce and cost-prohibitive, but there are at least a few hours' daily sunlight during most of the year. These factors made a solar-rechargeable reading lamp technically and culturally feasible.

As for the SEAM organization, it needed a project which could involve the electrical, computer, and mechanical engineering members. The solar rechargeable lamp circuit was a design which could harness the upper-class EE leadership, and the lamp's protective housing and light distribution design could be done by several ME's. The cost of a few lamps would fit into the organization's limited budget, and the device was small enough to carry to Liberia. Because of these factors, SEAM members chose to design and build ten solar-rechargeable reading lamps as its service project.

The student-designed reading light provides ample light on dark nights. The 9-LED light head draws so little current that a fully charged battery will last up to 60 hours.

SEAM engineers divided the lamp design into two subsystems: the electrical consisting of electronics, solar panel, and battery; and the mechanical, consisting of the housing and the light distribution apparatus. The electronic circuit had to provide light sufficient for reading, hold charge for several evenings' use (in case of rainy days), have robust recharging properties, and be simple to operate. On the internet they located an existing LED circuit design which served as a starting point. They estimated that each unit could be built for $40 to $50. Costs were minimized where possible while meeting the device's specifications. They raised $500 to fund their project.

After searching and selecting a battery and solar cell which fit the amp-hour requirements, tests were performed. Sealed lead-acid battery voltage was found to drop off fairly linearly over an extended time period, until the voltage curve reached a shoulder where it dropped off more severely. After much deliberation, the team decided to eliminate a voltage controller from the original design so that the user would gradually become aware of the fading battery instead of experiencing a sudden blackout. The control circuits were soldered on small circuit boards by several members of SEAM at a "soldering party."

One version of the solar-powered lights. This light had the light head inside the box mounted on a microphone gooseneck. The solar array is mounted on the top of the box, which being open, is not visible. These boxes were coated with polyester resin to help protect against against the high humidity, termites, and rough treatment.

SEAM designers wanted a housing which was resistant to a severe environment and treatment. They required that the light would be rain resistant, termite resistant, and abuse-resistant. They also required that it could project light onto the desk in a convenient manner. After searching for existing economical blow-molded and injection-molded housings, the team finally decided to build the housing of plywood protected with a coating of polyester resin. The final boxes were approximately 13" x 7.5" x 4" and featured an inner enclosure for the battery. There were three separate variations for the door and light head position. Most of the lamps had a hinged door which held the 5.5" x 6", 18-volt solar panel behind a Plexiglas cover. Inside the box was a goose neck (used for microphones) which served to position the light head, which was made of UHMW plastic and held a small circuit board with nine white LED's protected by a small Plexiglas cover. Some boxes had no hinged cover, so the LED's were directly mounted behind Plexiglas in the box's wall.

Solar lights being recharged in the sun. One hour of sunlight will provide one hour of use.

The assembled lamps were carried to Liberia in our luggage. Once in the country, the lights' recharging circuit was tested. The lamps were left "on" for 30 hours, causing the battery voltage to drop about half way to the necessary recharge voltage. The lamps were placed in the sun for several hours to recharge. As was hoped, the recharge rate was at least as fast as the discharge rate. However, due to

assembly errors, two of the lamps did not recharge properly. A Liberian ELWA technician was able to troubleshoot the problem and repair those lamps.

The lamps were received enthusiastically by the Liberians. Not only rural dwellers, but also those who lived around Monrovia saw the value of the lamps and gave informal feedback about the lamps' function. The light's intensity was more than sufficient considering the dark nights in rural Liberia. Concerning the configuration of the light head, one national leader felt that simplicity trumped convenience, so the in-box LED configuration was as good as any.

C. Hospital Medical Waste Incinerator

After the survey trip in 2006, we recognized the immediate need for a medical waste incinerator. The hospital, like others in Africa, deals with the AIDs virus and has infectious waste that needs safe disposal. We proposed building the DeMontfort Incinerator[4] to the ELWA administrators and the hospital staff. Two students were interested in building the hospital incinerator, so they prepared CAD construction drawings of the design using their brick sizes, showing each layer step by step. The students also prepared drawings of the steel work that needed to be fabricated.

D. Water System Assessment and Upgrade - Phase I

The purpose of the water system assessment project was to measure the performance of the water distribution system on the ELWA campus. The major problems were very low system pressure and no systematic water treatment program; at some locations, when a faucet was opened air was sucked into the system—which could easily contaminate the water supply. Considering that many villagers come to ELWA to get free water at the public access faucet, the water should be treated for harmful bacteria.

During the 2007 trip, two junior ME students, who chose this for their senior design project, mapped the ELWA water system. They measured and recorded pressures and flow rates at each

(left) ***The medical waste incinerator nearing completion. We chose the DeMontfort design and used fire brick obtained from an abandoned iron-ore mine. The fire brick liner was reinforced with a cement block perimeter. The top loading door was sealed with a sand trap. For 17 years the old medical waste incinerator sat unused after it was destroyed in the first wave of civil war.*** *(right)* ***Inspection of one of many water distribution boxes on campus. At these stations water pressure and flow rate measurements were taken and recorded. Occasionally budding engineers volunteered to help the students.***

branch. They also examined the main operative pressure tank and observed the pressure fluctuation during shutdown.

For their 2007-08 capstone senior design project, a group of five mechanical engineering students are modeling the entire ELWA campus water system so they can understand operational problems and simulate the effects of proposed improvements. They are designing and building an automatic injection system for disinfecting the water using sodium hypochlorite (*i.e.*, bleach). They are also developing an apparatus to produced sodium hypochlorite electrolytically from seawater using a 12-volt source such as an automotive battery.

ELWA provides free water to local area residents who come to fill up their water containers. In helping improve the water system, we are also helping hundreds of other people.

E. Facilities Survey and CAD Documentation

The purposes of the grounds survey and CAD documentation were to provide ELWA with an up-to-date facilities map so they could plan physical plant improvements, and to locate and document the water distribution network so that our students could perform their water system analysis and improvement. Our students surveyed the shareware, selected the best CAD package for ELWA, and then converted a 1980 drawing to electronic format.

Once on-site, surveying tools were used to confirm elevations and to locate newer structures. The Cadvance map was updated accordingly. The entire water system was also mapped and incorporated into the site map. The ELWA leadership was very pleased with the resulting map. We gave them several copies of the revised site map and installed the Cadvance source code on their computers.

The engineering students selected a CAD package and prepared current engineering drawings of the facilities. We took over surveying equipment to measure new facilities and verify critical dimensions. Next summer we will offer a course on engineering graphics using this CAD software. Here the students are discussing the next areas that need surveying.

Overnight Excursion into the Bush

Although not part of the engineering design projects that prompted our going to Africa, we worked into the itinerary an opportunity for each student to participate in an upcountry overnight experience. Basically, one professor and four students accompanied a national leadership training team that included our liaison going to three remote locations in Liberia. The students ate locally prepared food and lodged in rural dweller's homes. A typical rural dweller's home is made from bamboo-reinforced mud-filled walls covered by thatched roofs. The floors are typically packed dirt. There is no electricity or running water. The towns

Engineering students visiting a village that has a well. An NGO came in and installed this 75' deep well for this village. Each student had an opportunity to travel to the bush and spend a night with a rural dweller. Typical housing consisted of bamboo reinforced mud walls, thatch roof, and packed mud floor. None of the villages have electricity unless someone has a generator.

where we visited had wells, but half of the wells were not producing water because they were dry or the pumps were inoperative.

One team took a three-hour hike into the jungle to check out a potential site for a micro-hydro electric power plant. Our guide was an education victim of the civil war—he was 22 years old but had a 5th grade education. He worked as a diamond miner, and on the return trip took us by way of the site they were mining; he seemed honored to introduce us to his coworkers. We passed through his village and asked to see their well. It was 75 feet deep and was drilled by an NGO and capped with concrete. A robust manual pump drew the water.

This same team went further to the border of Sierra Leone and spent a second night in another village. The drive over treacherous dirt roads, through deep mud puddles, and over log bridges was an experience none of them will ever forget. When offered a chance to return to Monrovia after the first day with the other vehicle, none of the students wanted to return—they all wanted to venture further into the bush, knowing that they would be traveling in very cramped conditions. The reception the villagers gave our liaison, who had lived among them 20 years ago is something none of us will ever forget.

Unexpected Dessert

During our two weeks in Africa, the engineering team of students and professors were invited for dinner into the homes of Africans, mostly the leaders of the ELWA campus. We were served typical African meals. After dinner, we heard first-hand reports of survival during the 14 years of civil war that ravaged their country. It was hard to fathom what it was like during those times when 200,000 people lost their lives. Shortages of food and fuel were rampant, as were accounts of barbaric raids by ruthless young men with machine guns. At one point in the war, rebel soldiers occupied the ELWA campus and looted at will. Many people were forced to flee on foot with nothing but the clothes on their backs. These first-hand accounts of survivors of the war had a sobering effect on the students—and professors!

Summary

In this paper we have provided details of how we developed a program to give engineering students at both the under-class and senior capstone level an opportunity to experience cross-cultural engineering design as part of their engineering education. We have summarized the necessary infrastructure and resources at the home institution and the receiving institution abroad. We have discussed the elements and logistical details of making such a program a

success, and have provided a criteria for choosing projects that meet a variety of needs. We have also documented the results of our survey trip and our pilot program, and provided details of two of the projects we completed: one at the senior design level and one at the underclass level. From our assessment, the student feedback, and the response of the institution abroad, the experience was good and very much appreciated by the foreign institution. The foreign institution's nontechnical assessment of our work has been posted on their June 3, 2007 blog.[10]

The team of eight students and two faculty advisors, along with African helpers, completed the following projects:

- designed and installed a power station cooling system, including a catwalk
- chose a design and built a medical waste incinerator and dismantled the old one
- evaluated and selected an appropriate CAD system for ELWA technicians
- transferred existing engineering drawings to CAD
- surveyed and mapped the water system on the 134-acre campus (> 6 miles of pipes)
- delivered the first laptop computer to the school principal
- designed, fabricated, and delivered 10 solar-rechargeable reading lights to rural dwellers
- conducted a hands-on workshop for high school students who were considering engineering as a profession

Considering that we had 10 working days (two Sundays were used to attend church, visit with people, and play with the children on the beach) during the rainy season, and each student was gone at least two working days on an overnight trip to the bush, we were very fortunate. We also had eight group meals that included extended cultural or historical presentations an discussions with our foreign hosts.

Conclusion

In conclusion, we have provided our students with cross-cultural engineering design experience as part of their undergraduate engineering education. The design experiences ranged from upper-level senior design capstone projects to extracurricular underclass design projects.

Unique to this opportunity, compared to what is commonly provided to students in US institutions, was that the engineering design had to be put into a third-world developing-country cultural context. Probably the most obvious constraint was the limited choice of raw materials and very little in the way of funding for the projects. Also, the limited education of the end user and maintenance personnel constrained our design options. What was the obvious choice based on technical merits alone played second fiddle to cultural considerations. If the recipients cannot understand how it works, or if it needs repairing and they cannot repair it themselves, it will just be a matter of time before it is no longer used.

On the return trip home we asked the students to fill out an evaluation survey of their experience, their assessment, and their recommendations. What surprised us most was what they mentioned as being the highlight of the trip. And it was not just a majority, it was unanimous. The highlight of their two-week experience in Africa was the overnight trip to the bush.

When asked if they would do it again knowing what they knew after the trip was completed, they all said yes emphatically! In fact, two of the students are planning to return in the summer of 2008. When asked what they would change, the answer also surprised us; they did not want to split up the group on the out-of-town trips. On further discussion, what they really meant was that the group that spent two nights in the bush seemed to have had more adventure, and they wished that the other team members could have had a similar experience, especially driving over the treacherous unimproved dirt roads and log bridges. There certainly was a sense of adventure on that trip.

The engineering team from Cedarville University with the Liberian Services people. Wonderful friendships were begun between our engineering team and our Liberian counterparts as we worked together on a variety of projects.

We were overwhelmed with how well the students behaved on this trip—there was not a single complaint. There was a wonderful spirit of helpfulness and self-sacrifice that characterized the manner in which the team members conducted themselves. Even though the food was often much more spicy (*i.e.*, hot) than we are accustomed to, they still received it with gratitude. Our hosts said that they would welcome any one of the team members back at any time. Our new friends in the ELWA Services group were very appreciative of what we did and were also amazed at what got accomplished during our two-week visit.

Acknowledgments
This experience would not have been possible without the encouragement over the past eight years of our liaison Mr. Ray Hutchison, who served as a missionary with SIM in Liberia during the 1980s before the civil wars. He provided the preliminary cross-cultural orientation for the team and lead the team excursions to the bush. SIM provided the people to serve as our hosts in Africa—Dr. Rick Sacra and his wife Debbie—coordinating our meals and transportation in Africa. The ELWA management team, headed by Mr. James Kesselly, also welcomed us during our survey trip in 2006 to identify projects. Mr. Augustine Kollie, the Services Manager, provided all of the Liberian helpers who assisted and worked with us.

Logistical help with passports, visas, travel arrangements and tickets, immunizations, and travel to and from the airport were provided by the MIS and UMS offices. Dr. Peter Burban assisted the students with modeling the heat transfer in the cooling system. This trip could not have been possible without the generous support of many individual donors who provided the $32,000 to fund this trip.

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