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On Providing Engineering Students with Ministry and Culturally-Appropriate Design Experiences in Developing Countries

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Abstract

The Bible gives mandates to subdue the earth and to make disciples in "all the nations." This paper describes our pilot program for engaging undergraduate engineering students to enable and encourage African believers in their ministry of meeting humanitarian needs and propagating the gospel in Liberia. This program helps undergraduate students discern God's call on their lives as they complete engineering projects targeted for a developing country. Important components for the program's success were: 1) infrastructure and culture at the academic institution, 2) relationships with appropriate intermediaries, and 3) a receptive national host that needs engineering services. These components were similar to those identified by others in recent literature.

A case study is presented that evaluates our pilot program which took a team of students and faculty to Liberia, West Africa in May 2007. ELWA Ministries comprises a Christian radio station, a Christian hospital, and a Christian school; the 134-acre campus is also home to many families and provides housing for Non-governmental organizations. Four projects were selected focusing on ELWA's physical plant that provides mechanical services. The team successfully installed a student-designed cooling system for diesel-powered generators and built a medical waste incinerator for the hospital. Students also prepared CAD drawings of the campus and documented the water system by taking many measurements. An additional project helped rural pastors; the students designed and distributed solar-rechargeable reading lights.

Overnight trips to remote villages provided engineering students and faculty an opportunity to see how the rural dweller lives. These experiences provided the students intercultural worship opportunities and insight how to develop engineering solutions which blend into the culture. The ELWA services personnel and Liberian pastoral leadership expressed profound gratitude for the team's ministry; student assessment also confirmed the value of the experience.

Introduction

This paper presents a model that was used to give our engineering students an opportunity to design culturally-appropriate solutions to technical problems in a developing foreign country, and then immerse the students in 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. They worked with ELWA Ministries near Monrovia, Liberia in a strategic partnership intended to help spread the gospel. ELWA is a private organization that runs a radio station, hospital, and school. Of the eight projects completed, the team's major accomplishments were to:

- design and install a cooling system for institutional power generators,
- build a medical waste incinerator,
- survey and measure the performance of an over-utilized water distribution system, and
- design, build, and deliver 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 an appreciation for "the impact of engineering solutions in a global and societal context."[1] In particular, the Department of Engineering and Computer Science 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, studies show that today's college-age students are global-minded and seek to make a difference.[2]

There have been a variety of efforts to give engineering students a global perspective or to 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 to identify 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) deliver-ables, 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 been using appropriate technologies for several projects on foreign soil over several years.

Liberia is a resource-rich country on the North Atlantic coast in west 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] Rebels with guns looted at will to the extent that anything of value that could be removed from ELWA was stolen and sold on the street. The medical staff bought back their own drugs off the street. If personnel had not moved back onto the campus, the rebels would have removed the roofs from the buildings to sell on the street. It was anarchy. Anyone who had leadership responsibility had reason to fear for their lives. As a result, technical expertise was drained from the country, and is now really needed at the very time in which rebuilding is crucial.

Recognizing this need, Ray Hutchison, an experienced missionary who lived in Liberia before the civil wars, approached Drs. Zavodney and Thompson about establishing an on-going collaborative relationship that takes engineering students and faculty annually to Africa, to work along side with the Africans, and help them rebuild from the war, find solutions to technical problems, and encourage the Christians.

Liberia is located on the SW coast of West Africa.

A Short History of ELWA [9,10]

What began as a dream for three Wheaton College students in the early 1950's continued as a challenge and prayer as they and others envisioned a radio station in Liberia. An initial invitation from President Tubman of Liberia followed by a providentially-arranged meeting with Postmaster General DeShield, continued fulfillment of the dream as West Africa Broadcasting Association (WABA) began to put roots down into Liberian soil. In 1952, the government granted the permit for broadcasting.

After several months, WABA joined Sudan Interior Mission (SIM), an organization with many established works in Africa. Together they were able to acquire 180 acres of unclaimed land along the ocean, only 12 miles from the capital Monrovia. The government granted duty-free privileges which allowed expensive equipment, needed for the station's establishment, to enter Liberia without greater expense. The call letters assigned ELWA—Eternal Love Winning Africa—expressed the vision and challenge of SIM, "that all may hear the propagation of the tenets of the Christian faith by means of broadcasting."

In amazing ways funds, equipment, Liberian laborers and staff, foreign missionaries and technicians came together at strategic times and places to begin broadcasting ELWA's first program in 1954, desiring to spiritually bless millions of Africans. They faced the obstacles of 28 languages, a mix of religions (paganism, Christianity, Islam), thieves, and heavy rains daily for six months of the year. Many helped hand-clear land, form and lay block, weld sky-scraping towers, gather and safely store necessary equipment to set up and sustain the "big voice" calling out to Africa. Their purpose was to "minister to and encourage believers, as well as to witness to the unsaved and unreached with the gospel message by spoken word, drama and music." They desired to educate and rekindle hope, helping heal and strengthen scarred and broken lives. The "voice under every palm" from the "box that catches it" broadcasted preaching, drama, children's programming and reading as well as news, government notices, public announcements and music.

Eventually ELWA, with 70 missionaries and over 100 Liberians, used its transmitters to send radio to all of Africa, South America, parts of Europe and the Middle East. Their programming could be heard in 42 languages for hundreds of hours per week. In the privacy of his own home a person could hear what his heart longed to know, and could be linked, without fear or prejudice, to countless listeners around the globe.

Value of Immersion Experiences for Engineering Students

A cultural immersion experience for engineering students is beneficial because true solutions to problems must always harmonize with the culture into which they are applied. Culture may be defined as the collection of social customs, communication media, and ways of living that characterize a connected group of people. Engineering design is the application of physical principles and models to solve problems and create opportunities for people. Since an engineering design will only be effective if it blends with the culture, it is important that the engineer be intimately aware of not only technical but also social customs and cultural issues. For example, it might be possible to design a device to grind corn more efficiently, but if this device would preempt the social custom of village women gathering to socialize while they grind corn, it might either have detrimental cultural outcomes or never be adopted. Because cultural differences alone do not make one culture superior to another, engineers should take care not to unwittingly despise or diminish a culture by introducing inappropriate designs.

While it is certainly possible by reading literature to increase one's understanding of and sensitivity to such cultural differences, a cultural immersion experience is usually the most effective way to change engineering students' attitudes towards and appreciation of other cultures. By living for a time in the culture, the student gets to experience first hand the comforts, the discomforts, the joys, the sorrows, the music, and the sights, sounds, and smells of that culture. They get to sit next to, work alongside, and form friendships with the people. They can feel the climate and explore resources and techniques.

As a result, the students will be enriched not only as engineers, but as global citizens. They might be able to borrow ideas or designs and methods from other cultures. For example, in many cultures, heavy loads are carried on top of the head. This technique could be adapted to create a device which reduces back strain or even exercises the spinal musculature. As the engineers return home to practice engineering they will be able to create designs which are sustainable in view of the world of cultures. They may also retain an enduring desire to help those who have fewer resources.

Institutional Infrastructure

There are several institutional and cultural factors which serve to give students cross-cultural immersion design experiences. First, there must be an academic institution that values cross-cultural immersion experiences for students. Institutions that favor such often have policies to help protect students and have support staff to help with the many logistics. An example of a policy might be that dating foreign nationals would be strongly discouraged.

We found that having a liaison who lived in the country and had already established connections was indispensable. If international travelers do not have help in communicating and working within a foreign culture (especially if language is a barrier), they could be hampered by cultural blunders which could make them appear insensitive. The liaison should be able to communicate with the students and faculty in order to provide cultural orientation—preferably before the trip.

It is also important to have a host organization in the target country which is aware of technical needs which must be met. The host should have sufficient resources of personnel and facilities so they can help coordinate the transportation, housing, emergency medical treatment, and meals for the visitors. And it is equally important that we communicate to the host institution that they are helping us by enabling us to see and learn about their culture, their customs, and their way of life. Going to a foreign country to help a host organization helps to legitimize the engineering team's presence and enhance the credibility of the host organization in the eyes of foreign officials.

Case Study

This case study consists of a summary of our groundwork, our survey trip taken in 2006 to identify projects, our project selection process, team formation and preparation, and the field excursion with eight students in the summer of 2007.

A. Groundwork

Our university, that presently has 3000 undergraduate students, has been sending student teams into cross-cultural short-term immersion 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.

Our university sponsors a conference every year. About 100 guests come to participate in campus-wide activities, speaking in daily chapel and evening services, conducting workshops, displaying their organization's work worldwide, and meeting with students to discuss short- and long-term service opportunities. During one of these conferences we met Mr. Ray Hutchison, a regional director of SIM, an organization that is working in Africa, Asia, and South America.

He began by telling us about what an engineering professor and 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 civil war ravaged the country, he had some connections already established, and from a recent trip to Liberia in 2005 knew that there were tremendous needs that might appeal to our engineering students. As a result of his patient encouragement, the cessation of the civil war and presence of 15,000 UN Peacekeeping forces, we agreed to go with him on a survey trip.

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

B. Survey Trip

We took a 10-day survey trip to West Africa in May of 2006 to evaluate the following: 1) engineering project possibilities, 2) nature of the projects, 3) political stability in a country that just came through a civil war, 4) accommodations, 5) available emergency health care, 6) food and water, 7) receptiveness of the national hosts to foreign engineering students, 8) available transportation, and 9) to discern the nature of the cross-cultural immersion experience our engineering students would get. Of the 10 days, four were consumed by travel leaving only six in-country working days. As a result of the survey trip, we concluded that working on projects in Africa with ELWA and ECUL (the Evangelical Church Union of Liberia) would be a good experience for our students and that the primary focus of our work would be to help the ELWA campus maintenance services group recover from the devastating civil war.

Presently the 134-acre campus comprises many residential homes and Non-governmental organization (NGO) offices such as Living Waters and Samaritan's Purse. Since there is no power grid in Liberia today, ELWA must generate its own, and also 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 handful of workers to maintain operations. Now that the war is over, efforts are underway to 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, toured their facilities, and heard their needs first hand. During the next few days we walked around, took pictures, 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 kW-hour in diesel fuel costs alone. With a very limited budget, they had three mismatched 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 conserve fuel.

Included in our six-day visit was a two-day overnight trip to a remote village 100 miles north of Monrovia. This village was accessible only by foot or canoe. We drove all day mostly on dirt and muddy roads (we were in the rainy season), struggled to cross two log bridges (one vehicle got stuck on the first bridge and one vehicle could not cross the second bridge), and reached the end of the road much later than planned. As a result, our two-hour hike through the jungle was attempted at night. Half a dozen river crossings and an hour later we came to an extremely swollen — and hence impassible — river. We returned to the village near the end of the road and spent the night there. The village chief welcomed us; the men slept in the open community "palaver" hut, which sheltered us from the rains while the women slept in one of the villager's huts. We saw how the rural villager lives in Africa; many small villages do not have wells, and none have electricity. 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 and the highlight of our trip.

Our trip upcountry included travel over many dirt roads and log bridges. This photograph shows our encounter with our first log bridge. Our other vehicle could not get over the second log bridge.

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, providing hot water for their hospital, providing good water pressure throughout their campus, and projects for the rural dweller such as solar-rechargeable reading lights.

C. Project Selection Process

Of the two dozen projects on the list, we selected half a dozen of them for two 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 selection criteria included appropriate academic merit, the field need, and student interest. Senior design projects at Cedarville must build on the core curriculum, but also require an independent research element that stretches the students in new areas in order to complete the project. The projects that did not have sufficient academic merit were not considered for senior design, but if the the next criterion was met—whether the project meets a real humanitarian need—they were presented to the students for consideration as extra-curricular.

The faculty reviewed the project list and decided which ones were suitable for 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 waves,
- Solar powered security light,
- Cooling system for the diesel power generators,
- Improving the water system on campus (Phase I, II, and III),
- Portable well-drilling machines that can be carried by foot, and
- 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, and
- Muffler for the generators.

Surprisingly, for the seniors choosing capstone projects, designing well-drilling equipment that could be carried into remote villages on foot was the most popular, even competing with the SAE Formula race car project. Although the cooling system for diesel power generation was less popular, we made an administrative decision to work on an ELWA project (vs. a project for the remote dweller) the first year 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 during the war. We also discovered that they did not have any engineering drawings of their site or facilities. We put CAD on their project list, recognizing the importance of having engineering drawings of their site. In so doing we realized that we would have to persuade them of the value of the drawings, and would have to provide training on how to prepare CAD drawings themselves.

One of the strategic elements in getting students interested in working on these projects and then in going

overseas 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. It was clear that they all required various levels of engineering—whether it was analysis, design, or services.

D. Team Formation

While having a supportive academic institution, a liaison, and a receptive group in a developing country is necessary, an important part is assembling a team of the right kind 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 report of our 2006 survey trip, showing photographs of the facilities, the excursion up country, crossing log bridges, and wading through water. We showed them the projects that were begging for solutions—and we got an enthusiastic response.

The SEAM students adopted the solar rechargeable reading light project for the rural dweller. Four seniors chose to design a cooling system for the power generators for their capstone project. Two students were interested in helping with the incinerator project for the hospital; another student keen on computers wanted to help with the CAD project. By the time the deadline arrived, we had eight students who committed to going. Another graduating senior wanted to go and help with the cooling system, and one of the students helping with the lights wanted to go.

E. Team Preparation

Preparation for the trip included weekly one-hour meetings that dealt with trip logistics, historical background about the country of Liberia (PBS documentary "Liberia—America's Step Child"), meetings with Liberian nationals, meetings with people who had worked in Liberia, planning the work they would be doing in Africa, and raising funds to pay for their trip expenses. Most of what we did was funded by ourselves and donors. The total expense per student was $3200, the biggest portion being the airfare.

Each member of the team needed a current passport, visa, and immunizations and accompanying yellow card and malaria medicine. These details were handled by the Missions Involvement Service (MIS) office and the University Medical Service (UMS) office. Health risks, including AIDs which is epidemic in Africa, were handled in our weekly team meetings by the faculty advisor. Health care issues available while in Africa were also discussed and conveyed to the parents. For our work mainly on the ELWA campus, there was a hospital with an American doctor available. The MIS office also screened each of the student applicants; they sent out email to the faculty and staff asking for any character feedback that might preclude a student from participating on this trip. At each weekly meeting progress on a variety of tasks was noted, including parental concerns.

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 purchased a surveyor's level and tripod, grade stick, measuring tape and measuring wheel to conduct our survey of the site and determine the locations and elevations of the water lines.

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 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. He also helped lead our daily team meetings in Africa. These meetings were often less than 20 minutes long, but helped us focus our energies and see where help was needed for a particular day; they also provided a structured forum for the students to share anything that happened the day before or how they might deal with a particular situation that developed. 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.

F. 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 (gray powder) to construct the incinerator. Additionally, we carried 30 pieces of two-foot long by two-inch diameter PVC Schedule 40 pipe with three dozen caps for the cooling system, and ten solar rechargeable lamps with their charge-regulating circuits.

Project Descriptions

The following discussion provides details of how one senior design project and one extracurricular underclass design project were designed, and brief summaries of the other three major projects. We discuss some of the cultural constraints that are not typically encountered in the USA. Factors which differentiate "developing country" and "cultural issues" criteria for engineering design from criteria in the United States are:

- lack of capital,
- limited building materials,
- level of technical training of the maintenance personnel,
- cultural appropriateness, and
- acceptance by the local people.

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

A. Diesel Generator Cooling System

The diesel generator cooling project had sufficient academic merit that it was run as a senior capstone design project. The senior design team reviewed the literature and identified four popular methods of cooling water that would be most suitable for construction in Liberia. We chose four since there were four students on the team; each student would design a functioning prototype of a different system, and the team would provide a comparison of the four systems, including estimated original capital cost of materials and equipment, cost of construction, and cost of operation. Details of the different engineering systems and some of the constraints are published in a companion paper presented at the recent ASEE 2008 conference.[11]

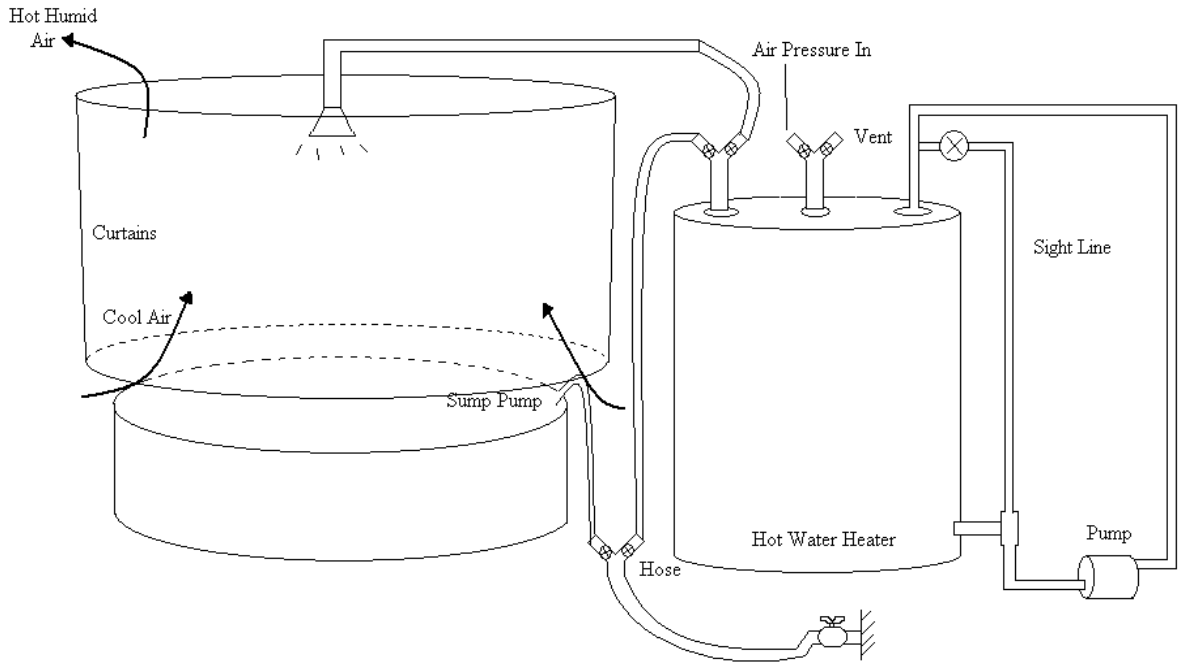
The four prototype solutions were presented to the ELWA Technical Services team with a cost comparison. We set up a website that allowed our Liberian partners to download the preliminary report and see our cost estimates. After they evaluated the different designs and considered their own manpower and technical expertise, they chose the fountain spray system.

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.

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. The model was developed further 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 in Liberia to track the hourly 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 to cool. 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. A child's inflatable swimming pool collected the water which 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 to study performance and observe spray patterns in light winds.



Laboratory setup to verify the mathematical model and to compare the efficiency of spraying from top down to 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.

From these measurements we were able to corroborate the model predictions and we were able to specify the nozzle spray head. Unfortunately, none were available off the shelf. Since the cooling pond was 30 feet long, we stacked 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 PVC caps provided a low-cost solution that was easily understood by the Liberians. The screw-on heads provided an easy means of aligning them, removing them to clean out the algae, and replacing them.

The heads were elevated to give the water more air time. The two-foot dimension 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 thunder-storms, the wind velocity can be substantial. These pipes were held in position with just a few supports, so extra length would have exposed more pipe to the fierce winds.

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 to form a parallel line in the event that the tiny 0.043”-diameter holes got clogged by the algae in the pond water.

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

We purchased the 2-inch 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. American students are not used to bartering.

B. Solar Rechargeable Lights

As its service project for the 2006-07 school year, the students in SEAM chose to help 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.

While the entire nation of Liberia feels the effects of the conflict, the people who feel those effects the greatest are the rural-dwellers. ELWA Ministries is located near the capital city Monrovia, the hub of the nation, the place where the greatest help from the U.N. peace-keeper and economic development programs as well as the services from many NGOs is available. But the people who live the rural areas do not have as much access to the benefits these Christian and other philanthropic organizations can provide. But they can listen to radio programs. They are served primarily by ECUL (The Evangelical Church Union of Liberia), which is a loose association of over 100 like-minded churches scattered primarily over western Liberia.

Liberian hunting and farming villages are small, tight-knit communities without easy transportation access to neighboring villages. Many do not have pastors, but having spiritual guidance and solid biblical teaching is vital to the spiritual health of the Liberian Church. Those congregations that do not have pastors are much more susceptible to discouragement and false teaching. Pastors who are committed to helping meet the spiritual needs of these congregations face huge challenges. Rustic accommodations and lack of employment are among them. In addition to these, lacking basic services such as electricity and water add to the burden of staying upcountry and shepherding their flock.

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.

Liberian pastors can meet spiritual needs of villagers using fewer resources than foreign missionaries, but they need help, training, and encouragement. They typically farm 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 expensive, but there are usually a few

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

hours of daily sunlight during the rainy season. These factors made a solar-rechargeable reading lamp technically feasible and culturally strategic.

SEAM designers found a circuit design[12] on the Internet, performed tests, and made modifications so that the user would gradually become aware of the fading batteries. They fabricated their own enclosure design, which was 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.

Once in the country, we tested the recharging circuits. After the lamps were left "on" for 30 hours, the lamps were placed in the sun to recharge. As was hoped, the recharge rate was at least as fast as the discharge rate. A Liberian ELWA technician was able to troubleshoot and repair two lamps that malfunctioned due to assembly errors.

The lamps were received enthusiastically by the Liberians. The solar lights allow these rural pastors to stretch their days so they can prepare to feed spiritual food to their flocks. The solar light project also provides the potential in the future for some of these men to support themselves and families by building, selling and maintaining these solar units for others to purchase. This would be a great incentive for pastors to remain in the rural areas to serve their churches rather than migrate to the capital city where there are more opportunities for employment.

One version of the solar-recharged 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.

Not only rural dwellers, but also those who lived around Monrovia saw the value of the lamps—and offered reasons why they could use one. They 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. 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 sharps and infectious waste that needs safe disposal. From our literature survey we learned that D. J. Picken had developed a low-cost but effective incinerator. After evaluating the design using the criteria mentioned above, we chose the DeMontfort Incinerator[13] design. We proposed the design to the ELWA administrators and the hospital staff. They agreed that the Mark 8a or Mark 9 model would be a good solution.

The DeMontfort design has been used in many developing countries and has been shown to be a good moderate-temperature incinerator. These incinerators were designed specifically to be built in almost any developing country, can be made from readily available materials, are effective, and can meet the criteria of a temperature above 800 °C with a residence time of over 1 second. They require a fire to be started using some combustible materials, such as paper or wood, which are readily available in Liberia.

One feature of this design that makes it particularly suitable for Africa is that with this design, the loading door can be out of tolerance by almost an inch and still provide a good air-tight seal. The seal around the loading door is accomplished by placing sand in a "U"-channel; the loading door has a knife edge around the sides that cuts into the sand about an inch. Since ELWA is right on the ocean, sand is plentiful and

cheap. The only way combustion air can enter is through the air inlet opening above the ash door, and that location provides an air blast that fans the fire and helps to increase the incinerator temperature.

The fire brick liner of the medical waste incinerator nearing completion. We chose the DeMontfort design and used fire brick obtained from an abandoned iron-ore mine. This liner was reinforced and protected with a cement block perimeter. The ash door (shown in this picture) and steel top loading door and frame, were made by Peter, an African metal worker and welder.

Two students were interested in building the hospital incinerator. The Liberians were able to obtain fire brick from an abandoned iron ore furnace, so the students prepared CAD construction drawings of the incinerator design using their exact brick sizes, showing each layer step by step. The students also prepared drawings of the steel work which was fabricated by a Liberian metal worker in their metal shop. The dimensions were specified on the drawings prepared by the students. The steel stock purchased in Monrovia consisted of angle iron, steel plate, and steel reinforcing bar. The parts made of steel were the ash clean-out door, the loading door, and the chimney. The angle iron was cut by hand with a hacksaw, and the plate steel was cut by chisel.

One question in our minds was whether or not the African workers would hold tolerance on the steel work, which had to precisely fit the openings on the brick incinerator. We chose to communicate with the Africans with technical drawings prepared beforehand, and then with additional sketches in the field. We stressed the importance of being square and uniform, and within tolerance. One African made the comment that "precision is only important when making a piano!"

The almost finished incinerator with the second layer of cement block and steel top loading door installed and painted. The chimney was installed after we left.

In our case, the steel door had to fit inside the opening in the brick liner, and the top frame had to fit in its precise opening—it could not be too large or too small. When the steel parts were made, the dimensions of the steel work were held to within a 1/32 of an inch; we were quite impressed and pleased.

The students helped to scrounge around the scrap pile looking for suitable chimney stock. Several steel pipes, presumably light poles at one time, were welded together to make a chimney. Eyes were welded onto the chimney near the top to attach stabilizing cables. Since the chimney was not installed until after we left, we were unable to actually start a fire to see it in operation.

D. Water System Assessment and Upgrade - Phase I

During our 2006 survey trip, we noticed that the water pressure dropped off sharply when the generators were shut down at midnight. Because of the high cost of power generation and low water pressure, the ELWA managers asked us to help them improve their water system.

The purpose of the water system assessment project was to measure the performance of the water distribution system on the ELWA campus in order to evaluate it during the following year and recommend improvements. The obvious problems were very low system pressure and no systematic water treatment program. The water pressure overall was low, and there was a variation around campus—caused by the 30-foot elevation change around campus. At some points air was sucked into the system when a faucet was opened. Negative pressure anywhere is serious because it provides an easy source of system contamination. The service technicians would occasionally (maybe once a month) pours

Students inspecting of one of many 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.

bleach (sodium hypochlorite) into a well to treat the water. Considering that many nearby villagers come to ELWA to get free water at the public access faucet, the very low pressure and randomly-treated water affected a large population.

During the 2007 trip, the students mapped the ELWA compound and searched for distribution boxes containing water meters which marked branches from the water mains into buildings. They measured and recorded pressures and flow rates at each of these branches. They used surveying equipment to measure locations and elevations. They also examined the 5000-gallon pressure tank and observed the pressure fluctuation during shutdown, and also noted the corrosion (*i.e.*, rust). The students measured the flow rate at the only working public faucet which ELWA provides for local villagers. The faucet is open non-stop because locals are continuously filling their vessels—and because the shut-off valve is broken. The students measured pressure and timed vessels filling to measure flow rate.

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.

The students also observed the pumps in operation. The pumps ran continuously during the 18 hours when power was on. They seemed to be operating chronically below their rated pressure. The students noticed and repaired a leak in the high-pressure line between the pump and the sand filter located in the pump house.

For their 2007-08 capstone senior design project, a group of five mechanical engineering students modeled the entire ELWA campus water system so they could understand operational problems and simulate the effects of specific improvements. Their model solved over 500 equations. They also designed and built an automatic injection system for disinfecting the water using sodium hypochlorite or calcium hypochlorite (chlorine).

E. Facilities Survey and CAD Documentation

The purposes of the grounds survey and CAD documentation were to supply ELWA with an up-to-date facilities map; the map was also needed to record the location of the water lines so we could document the water distribution network for next year's senior capstone project.

First, the appropriate software was sought out. To be economically feasible for ELWA, it had to be very low cost and have moderate computer system requirements, since most of the ELWA computers were of the older vintage. It also had to be easy to learn so that someone with a high-school education could learn and use the software. It had to have the functionality that makes features like buildings, roads, and electrical and water lines easy to represent, and

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. Here the students are discussing the next areas that need surveying.

layers so unnecessary information could be turned off. After examining several different codes, the software package Cadvance was chosen. There was an older version of the software available free of charge.

The ELWA leadership was very pleased with the resulting map, and when they saw how easy it was to use, they were eager to learn. We gave them several copies of the revised site map and installed the Cadvance source code on their computers. We have updated the map and posted it on our website for them to download.[14]

Ministry Excursions to the Bush

To enhance immersion exposure and participate in the spiritual ministry amongst Liberians, we worked into the itinerary an opportunity for each student to participate in an upcountry overnight trip to the bush. These trips were also great opportunities for team members to understand rural life and learn how engineering projects might improve it. On each trip, one professor and four students accompanied a church leadership training team that included our liaison going to remote locations in Liberia. Rural villagers showed us their farms, cooking methods, food drying, and construction materials and techniques for erecting buildings. 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 and/or corrugated galvanized steel or aluminum roofs. The floors are typically packed dirt. There is no electricity or running water. The towns we visited had wells, but half of the wells were not producing water because they were either dry or inoperative. Wells that were dry were typically dug in the rainy season. Future project ideas such as solar cooking were discussed. Due to time constraints, this informal process was not as comprehensive as a full participatory rural appraisal.[15]

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.

One team took a three-hour hike into the jungle to check out a potential site for a mini-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 team drove 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 on the second 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 Ray, who had lived among them 20 years ago, is something none of us will ever forget.

These excursions were not only for adventure and fact-finding. The Lord has gifted Ray Hutchison in the area of providing training for rural church leaders in conjunction with the leaders of ECUL. It is very effective for Ray to team teach the faithful ECUL rural church leaders in 1-2 day conferences. Taking students from the Cedarville- Liberia connection along on these trips is strategic for several reasons:

- It encourages the Liberian Christians who attend the conferences. Liberians are very hospitable people and they feel greatly honored to entertain guests – especially guests from the West.

- It helps the students better understand the transportation challenges in Liberia.
- It affords the students the opportunity to gain a different perspective concerning life in Liberia. While staying on the ELWA compound they stay in accommodations that are similar to what they are used to in the United States. Rural areas are more rustic and the amenities are much more Spartan. This experience enables the students to "rub shoulders" more closely with Liberians and experience the way most of them live, and affords the potential of discovering simple solutions to help improve the quality of life for Liberian people.
- It enhances the opportunity for the students to experience the culture of Liberia through conversing with Liberians and observing rural life during the "after conference" hours.
- It provides the opportunity for building relationships between Cedarville students and Liberians.

Unexpected Dessert

During our stay in Africa, the team of students, professors, and liaison were invited for meals into the homes of Africans, typically the administrators and workers at ELWA. We were served typical African meals — which means lots of pepper. After dinner, we interacted with the Africans, hearing presentations on topics such as AIDS in Africa. Some evenings we heard first-hand reports of survival during the 14 years of civil war that ravaged their country. It was difficult to fathom what it was like during those times when more than 200,000 people in a country of three million lost their lives. Shortages of food and fuel were rampant, as were accounts of barbaric raids by ruthless young men with guns.[16] 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!

Resulting Global Perspectives

This trip and the design experience leading up to it had a significant effect on the student perspectives regarding both ministry and engineering in the global context. Four of the eight students responded to a survey distributed 11 months after return from Liberia. For questions 1 – 3, the scale of 1 (very little) through 5 (profoundly) was used.

1. *How has this trip affected the way you look at the world?* The student responses averaged 4.3.
2. *How has this trip affected the way you think about engineering design?* The student responses averaged 3.8.
3. *How has the trip affected the way you pray?* The student responses averaged 2.8.
4. *How much have you communicated with friends made in Liberia?* The student responses averaged 2.0 on a scale of 1 (once or twice), 2 (from time to time), 3 (monthly), 4 (weekly), and 5 (daily).
5. *Has this trip increased your interest in serving overseas in the future?* The student responses averaged 4.8 on a scale of 1 (much less likely) to 3 (the same) to 5 (much more likely). The only student who did not answer "5" had made a prior decision to do so.

Ministry Perspective

[from R. Hutchison] It was a thrill for me to be a part of the Cedarville-Liberia connection. To serve the church and people of Liberia in a more effective way has been a dream for a long time. The partnership between SIM (the mission agency with which I serve), the Engineering Department at Cedarville University, and ELWA Ministries and ECUL in Liberia has been that dream becoming a reality.

I am excited to be a part of this joint venture because it brings hope and help to a nation and to a Church

that has suffered a great deal as a result of a long and horrific war. Through this arrangement very competent professors and students of engineering brought to bear their knowledge and experience on wide spread problems. Their completed projects brought a great deal of encouragement and hope to our partners in Liberia.

I very much enjoyed being a member of the first installment of this partnership. While I was able to use my expertise in bringing cultural insight to the other team members, I was thoroughly impressed with the magnitude of preparation each had put into this two-week venture. Each of my fellow team members worked very hard at accomplishing his projects but equally demonstrated his desire to build relationships with and learn from his new Liberia friends. Working side by side with Liberians as opposed to just by himself promoted mutual learning. Each one did his work well and used joint experience to foster mutual understanding and respect. My Cedarville partners did their best to stay within cultural parameters so as to not offend the people they came to serve. They readily accepted invitations to enjoy meals and hospitality in the homes of their new Liberian friends. They were respectful of one another, as well as their Liberian and expatriate hosts. They listened attentively as Liberians shared their stories of hardship during the years of war.

The projects that were chosen were strategic. Some were designed to meet felt needs in a land with many felt needs. Others focused on addressing real needs behind the felt needs. Some have the potential of being turned into micro-enterprise ventures which could train and employ Liberians who are currently suffering with an 85% unemployment rate. All the projects were pursued with appropriate technology and the availability and affordability of local materials in mind.

I enjoyed traveling with my Cedarville partners and our ECUL hosts in our excursions into the interior part of the country for pastor's training conferences and for a trip back to a village where my family and I lived and ministered during our days as missionaries in Liberia. Although the accommodations were sparse, my Cedarville partners graciously accepted the warm hospitality offered by our Liberian hosts. They took time to play with children. They asked good questions and did their best not to offend their hosts. They showed appreciation for all that was graciously offered to them and did not complain when hungry, tired and uncomfortable. Our trip into the rural areas provided the richest opportunity for culture learning for my Cedarville partners.

It was a great privilege to serve the people of Liberia with this first team from Cedarville University. I look forward to accompanying many more teams in future years in the Cedarville-Liberia connection.

Summary

[from L. Zavodney and T. Thompson] In this paper we have provided details of how we developed a program to give engineering students, as part of their engineering education, a cross-cultural ministry and engineering design experience that immersed them into an African developing-country culture. We have identified the necessary infrastructure and resources at the home institution and the receiving institution abroad. We have summarized the major logistical details of making such a program a success and have provided a criteria for choosing projects. We have also documented the results of our survey trip and our pilot program, which from our assessment, the student feedback, the response of the institution abroad, and our liaison, was very successful. The SIM host missionaries' nontechnical assessment of our work and the overall impression we made has been posted on their June 3, 2007 blog.[17]

The team of eight students and two faculty advisors, along with African co-workers, completed the following engineering design and service projects:

- designed and installed a power station cooling system, including a catwalk,
- designed, fabricated, and delivered 10 solar-rechargeable reading lights,
- chose a design and built a medical waste incinerator and dismantled the old one,
- evaluated and selected an appropriate CAD system for Liberia,

- transferred existing engineering drawings to CAD and updated them,
- surveyed and mapped the water system on the 134-acre campus (6+ miles of pipes),
- delivered the first laptop computer to the school principal, and
- conducted a hands-on seminar for high school students promoting engineering as a profession.

We had only 10 working days to complete these projects. Our schedule was further complicated by the weather — we were there during the rainy season, and most of our work was outside. Each student and one professor was gone for at least two working days for a trip to the bush. We were asked to build the catwalk for the cooling system and conduct the "What is Engineering" workshop and live call-in radio show after we arrived. We also had eight group meals that included extended cultural or historical presentations and discussions.

[from R. Hutchison] The Cedarville-Liberia connection has provided a greatly needed shot in the arm of encouragement to the ELWA Ministries, the Christian organization with which SIM partners in their institutional work (radio station, hospital and school) in Liberia. The team from Cedarville provided much needed technological expertise in the areas of power generation, hospital waste disposal and water distribution. The team also brought along some much needed resources used in carrying out the projects. While competent in many areas and fully committed to the Christian purposes of Radio ELWA, ELWA Hospital and ELWA Academy, the leaders and workers face huge challenges in repairing, maintaining and expanding the infrastructure undergirding these ministries — ministries in Liberia which have a have a long history of providing excellent spiritual, medical and academic service to the people of that nation. Delivering messages of hope and salvation, and providing solid biblical teaching as well as public service announcements has been an important role for Radio ELWA. The ELWA Hospital has had a reputation of being one of the finest providers of medical care in the entire nation. And ELWA Academy is providing a great service to the nation of restoring the opportunity of education from a Christian perspective to a people which suffered the loss of the best and brightest and the disruption of the educational system due to many years of war.

In addition to supporting these ministries, the team from Cedarville provided something else that is at least as important. The members went to Liberia with open hearts and minds. While anxious to implement the projects they had worked on for an entire academic year they wanted to do so in a way that afforded them the opportunity to value and learn from ELWA ministries personnel. The students worked wonderfully side by side with their counterparts to learn from them and to listen to their stories of great trial through the years of war. The Liberian leaders and workers greatly appreciated the servant/learner posture of the Cedarville team while they, themselves, also obtained new knowledge and skills to better enable them to carry out their tasks.

Future Work

The model we have presented here lends itself to annual trips to Liberia. The intention is that each year the team will identify new projects for future teams. The survey trip in 2006 identified 14 projects; during our 2007 trip we started on six of them and completed five. During the 2007 trip we discussed new projects to put on the list and also identified the most urgent needs in their eyes. Two of the eight students who went in 2007 also went in 2008 and provided some continuity.

During the 2007-08 school year, a team of five seniors worked on the water system, including modeling the system, designing an automatic passive chlorine injection system, and investigated the feasibility of generating sodium hypochlorite electrolytically from the abundant supply of ocean water available to ELWA. Other students designed and built the next generation of solar rechargeable night reading lights for rural pastors enabling us to take over 50 lights this year. We also assembled and installed a computer network for the ELWA Academy and began working on a solar oven.

The 2008 team took over supplies to upgrade the water system; this included two deep-well submersible water pumps, controllers, most of the plumbing supplies, and strain gages to perform a stress test on their water storage tanks. They installed one new pump in an unused well, installed new plumbing, installed new electrical service in one pump house, and provided some much needed maintenance on the main water storage tank that was rusting and leaking. They patched over a dozen holes, pressured washed the inside, removed a lot of rust, and painted the support areas. The 2008 team also upgraded the incinerator and provided some training on how to use it, and performed some maintenance on the generator cooling system by removing the algae and unclogged some of the small holes on the spray heads. Overall, the system is working extremely well. We also met with the ELWA Administrative Team to discuss projects for next summer and after. The intent is to continue this wonderful relationship every summer working on projects suited for students.

Conclusion

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

In conclusion, we have provided our engineering students with an immersion cross-cultural ministry and engineering design experience as part of their undergraduate engineering education. The design experiences ranged from an upper-level (curricular) senior design capstone project to underclass (extracurricular) design projects. Unique to this design experience was that the engineering had to be put into a majority-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 education level of the end user and maintenance personnel constrained our many design options. What may have been the obvious choice based on technical merits alone played second fiddle to cultural considerations. (The recommended cooling system was not selected, nor was the recommended design of that cooling system.) If a design's operation is unclear to the recipients, or if it needs repairs they cannot perform, it will soon fall into disuse.

We also requested that Liberian workers work along side the students, assisting them and helping them find resources to complete their projects. The Liberians also taught them many things, such as how to mix concrete—without a mixing container. They taught one of our students how to stick weld. During those working hours, they talked about many things.

The students were motivated to go. They attended the weekly meetings to prepare for the trip, completed their projects in a timely manner, and helped each other. The planning that went into the trip was necessary to scope the projects, organize the work and schedule, and was crucial to satisfactorily completing all of the projects.

On the return trip home the students filled out an evaluation survey of their experience, including their assessment and recommendations. The unanimous highlight of their two-week experience in Africa was the overnight trip to the bush!

When asked if, knowing what they knew after the trip was completed, would they do it again, they all said yes emphatically! Two of the students returned 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. Further probing revealed 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 driving over the treacherous unimproved dirt roads and log bridges. There certainly was a sense of adventure.

We were extremely pleased 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. They went out of their way to interact with their Liberian co-workers, not only to teach them new things, but also to learn from them. Even though the food was often very spicy, they still received it with gratitude.

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