Design of Sustainable Water Pumps for Burkina Faso

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Abstract

The Department of Engineering at Messiah College has partnered with the *Handicapės en Avant*, (a center for rehabilitation and education of handicapped persons in southeast Burkina Faso) for over a decade. One of the enduring student-faculty projects spawned from this relationship is the Modified Rower Pump Project. The long-term vision of this project is to provide a sustainable design, including construction methods, allowing local manufacturers to build water pumps as part of their businesses. The present goals of the project are to quantify the pump's performance, to improve the pump's durability, to reduce material and construction costs, to develop more reliable construction techniques, and to create a versatile handle design that accommodates a variety of operator positions. The project exposes students to the challenges of solving an urgent, real problem within the constraints of a depressed economy, severely limited resources, and cultural preferences and biases. This paper summarizes the project's origins, the iterations of previous pump designs and installations leading to the current pump design, and the issues encountered while designing solutions for use in developing countries.

Introduction

In January of 1996, two Messiah College faculty, and two students participated in a survey trip of Serving in Mission (SIM)[1] facilities in West Africa. The purpose of this trip was to look for potential areas for project collaboration between SIM and the Messiah College Department of Engineering. *SIM was a logical partner for our department because of their long-term commitment to aiding developing countries and experience in supporting overseas projects.* The immediate result of this trip identified a need for electrical power at a medical dispensary in the rural village of Mahadaga, Burkina Faso. In January of 1998, a team of faculty and students returned to Mahadaga to install a photovoltaic solar array. In the course of the visit, the team discovered a second area for project collaboration *with SIM*: irrigation of the vegetable gardens and mango orchards that provided a source of income for *Handicapės en Avant (HeA), an SIM-sponsored* center in Mahadaga that helps persons with disabilities to be accepted by their families and provides physical therapy, education, and job training services. Further examination of this matter led to the conclusion that the *HeA* would greatly benefit from a hand-powered pump that was designed to be operated by the center's clients and built from locally available materials by the center's maintenance personnel. This was the genesis of the Modified Rower Pump project.

Context

Burkina Faso is one of the poorest countries in the world. The combination of being landlocked, having a high population density, and possessing few natural resources creates a very poor economy. About half of the population lives below the poverty line[2]. The current per capita annual income is about $400 US[3]. About 90% of the population works in subsistence agriculture which can be greatly affected by drought. The median age is a little less than 17 years and the average life expectancy is only 53 years. The risk of infectious diseases in the country is "very high." Malaria, yellow fever, bacterial and protozoal diarrhea, hepatitis A, and typhoid fever are quite common[4]. While polio has been eradicated, its effects are still apparent. Many of the clients at *HeA* are disabled because of this disease[5]. Clearly, our department's ongoing relationship with *HeA* has the potential to benefit some of the world's most needy and disadvantaged people.

Initially, the students (engineering and non-engineering) working on the Modified Rower Pump project were volunteers. Although Dr. Vader provided leadership and direction for the project, the project participants did not receive academic credit and relied on mutual accountability to ensure that project milestones were met. While student volunteers still play an important part in the project, the department of engineering encourages its students to make the project work a credit bearing activity.

Engineering students have earned academic credit for working on the project via two distinct modes. During the first several years of the project, students progressing to the senior year could choose to work on developing various aspects of the pump for the two-semester Senior Project sequence. During the 2006-2007 academic year, the Integrated Project Curriculum (IPC) for engineering majors replaced the Senior Project sequence[6]. The rationale for implementing the IPC was the benefit of long-term student commitment to projects (like the Modified Rower Pump) and vertical integration of student ranks. The IPC is delivered by a series of project and seminar courses throughout the sophomore, junior, and senior years. Generally, each student works on some aspect of the same ongoing project during the entire IPC project sequence. *As a result, the student develops expertise in the project's management and designs which can be passed on to succeeding student generations.*

While site visits to install the project designs are an essential part of the engineering process, these trips are not required to fulfill the IPC sequence. Site teams are selected from qualified students (engineering and non-engineering) who pay their own expenses. Students do not receive academic credit from the Department of Engineering for participating on a site visit.

Project History[7]

The initial constraints of the project were to create a hand pump that could be operated by the center's clients (persons with physical disabilities and blindness) and built by local crafters using local materials. The first efforts focused on developing a submerged metal treadle pump because of the treadle pump's well known design and high mechanical efficiency.

In 1999, two engineering students made the pump the focus of their Senior Project[8]. They soon concluded that the metal components of the treadle pump would be impossible to manufacture at the *HeA* and abandoned that design and focused on pumps made from PVC. The team produced and tested a single piston pump, a double piston pump, and modified rower pump.

In the summer of 2000, the team installed the prototypes at *HeA*. During this trip, the team became aware of a necessary design change in all of the pumps: the wooden ground supports were impractical because of the termites. Most of the work during the succeeding year focused on eliminating ground-contacting wood from the pump designs and improving the pump lever and bearings. *Discussions with pump's users during a* follow up visit in the summer 2001 revealed that the clients preferred the modified rower pump design.

In the fall 2001, a senior project examined the head seal and check valve designs and measured the energy losses though these elements[9]. Concurrently, volunteers experimented with PVC forming techniques and redesigned the lever bearings. The entire pump team graduated in the spring of 2002, requiring a new team to be recruited in the fall. The new team made limited progress during the 2002-2003 academic year due to inadequate documentation of the previous teams' work.

During the 2003-2004 academic year, a senior project focused on modeling the pump lever's kinematics and reducing the pump's Burkina Faso construction cost[10]. The project found optimum lever geometry for reducing the transmission angle between the pump rod and connecting link. The project also succeeded in reducing the in-country cost of the pump from $120 US to $90 US by replacing a solid pipe frame with a rebar truss and reducing the amount of concrete used in the frame's foundation. During this year, volunteers redesigned the piston valve, head seal, and foot valve improving the ease of construction and allowing better water flow through these elements. The volunteers also developed an instrumentation system to measure pump lever forces, piston displacement, and output flow rate. The updated pump was installed during the summer of 2004 and received favorable feedback from its users.

The following year, volunteers developed a construction manual for the pump and analyzed the lever arm in a further attempt to reduce overall cost. The previous summer's installation gave the project a false of completion, and the team began to shift its attention to other water access issues, such as well-drilling and irrigation. However, a site visit during January of 2005 revealed that the pump had durability issues with some components.

Spurred on by this development, another senior project formed, focusing on durability testing, redesigning the pump frame for easier construction, modifying the pump handle geometry to accommodate a wider range of users[11]. The durability testing focused on the foot valve and pump seals. The senior project team constructed an automated testing apparatus and established new designs for these elements based on durability and efficiency. In addition, the team redesigned the rebar truss, reducing its overall size and eliminating complex weld angles. The team also made fixtures for the pump seals and rebar truss to reduce construction time and to provide more repeatable construction process. The updated design was installed at *HeA* in the summer of 2007. The 2006-2007 academic year also marked the implementation of the Integrated Project Curriculum (IPC) for engineering majors at Messiah College.

During the fall of 2007, IPC students began work on creating a construction document and building new fixtures (the originals were left in Burkina Faso). Considering the difficulties of maintaining a working relationship with Burkina Faso, the project contacted Educational Concerns for Hunger Organization (ECHO)[12] in North Fort Myers, FL as an additional installation site. The team installed a pump at ECHO during the summer of 2008, providing another user to give feedback about pump performance and a dissemination point for the design. During 2008-2009, the project focused on completing the construction document, installing a third pump of the current design on the (college name) campus, and designing a new system for measuring lever input force, piston displacement, and output flow rate. As had happened several times before, the most experienced members of the pump project team graduated, leaving a "leadership vacuum." *However, the lull in productivity lasted only single semester, in part due to better project documentation and communication between the team members.*

During the current academic year, the project has identified several areas of the construction document that must be improved: consistent use of SI measurements, more detailed illustrations of the frame construction, and modifications of the overall height of the pump frame. In addition, the team has recalculated the current Burkina Faso construction cost to ensure that recent changes in the pump design and economic conditions have not radically changed the pump cost. (The estimate of the current cost for the pump and fixtures for a six meter well to be $85 US.) By the end of the academic year, the team will have made sufficient measurements and calculations to be able to compare our pump design's performance with more widely used hand pumps.

Discussion

The narrative of this project's history clearly demonstrates that the student's participation helps satisfy the general ABET Program Outcomes[13]. All of the senior projects required designing experimental apparatus, developing a plan of study, and inferring the necessary changes in the pump design (Outcome b). The 2006-2007 project is the best example of satisfying this outcome. The students constructed a test apparatus and performed over 450 hours of automated pumping for durability testing. The team tested several variations of three distinct piston seal designs and analyzed the results to find the best combination of longevity and efficiency.

Any student designing or redesigning a subsystem of the pump must consider limited materials, tools, and the physical abilities of the user to ensure that the pump meets the constraints of the project (Outcome c). In addition, the economic, social, manufacturability and sustainability issues present in Burkina Faso force the student to generate creative solutions to meet these constraints and broaden the student's understanding of the factors that limit a solution. The redesign of the wooden pump support structures to counter termite problems is an example of this practice.

Generally the first iterations of a solution utilize all skills and tools available- computer simulation and modeling, the resources of the mechanical and electrical workshops, and data acquisition tools (Outcome k). The 2003-2004 and 2005-2006 senior projects used finite element truss analysis to find acceptable designs for the rebar truss pump frame. Although the project is relatively low technology, the use of modern engineering tools is still needed.

The narrative also provides insight into the challenges of working on a long-term project with students. Students, especially those taking the Senior Project sequence, tend to limit the scope of the project to what can be finished before they graduate. As a result, work on the pump progressed in a piecemeal fashion- focusing on performance, then cost, then reliability. Ideally, these factors should be accommodated in a single design cycle, but the two semester limit of the Senior Project course over focused the student's scope. When combine with inadequate documentation and communication, a narrow set of design criteria sometimes led to "re-inviting the wheel" or undoing a previous project's advances.

While the IPC is still in its early phases, some advantages to this mode of offering academic credit for project experiences are already visible. As illustrated by the project history, a typical senior project resulted in significant advances, followed by an academic year of minimal progress the succeeding year. The graduation of the team's most experienced personnel left inexperienced first-year and sophomore volunteers to provide student leadership. In the IPC, knowledgeable sophomores and juniors are available to take over leadership positions. The vertical integration of class ranks[14] and improved documentation embedded in the IPC also contribute to reducing the productivity lull to a single semester. Students working through the Senior Project sequence usually develop a compartmentalized view of their work- the project ends at graduation. The IPC mode continuously reminds students entering the final semesters that the project will continue after graduation. This promotes transmission of a project's knowledge base and purpose from one generation of students to the next. In addition, the academic credit earned by IPC participants provides faculty with leverage to encourage adequate documentation at all stages of the project.

Furthermore, this project also helps Messiah College meet Program Outcomes beyond the general ABET outcomes that we have defined for graduates of the Engineering Program. The outcome to "work toward integration of Christian faith, learning, professional life" is difficult to satisfy through classroom instruction. The Modified Rower Pump project places its team members at the intersection of extreme human need, academic performance, and engineering practice. Our students have responded in the short term with quality designs and some have committed their professional careers to address similar human needs. Three of the project's alumni have chosen to work in Burkina Faso to promote the economic development of the

Mahadaga community. Such responses represent the highest level of learning in Bloom's taxonomy[15]: evaluation and commitment.

Based on these observations, the Modified Rower Pump project is already a successful instrument for engineering education. As the design reaches maturity, and transitions from an engineering project to microenterprise/sustainable development project, we will be able to assess the merits of the pump as a water access device.

Conclusions

1. **Partnering with clients in developing countries provides students with experiences that satisfy the general ABET Program Outcomes [a-k].** While most engineering science courses contribute to the outcomes relating to technical expertise, several outcomes are difficult to satisfy with projects confined to these courses. The Modified Rower Pump project places students in a context where issues relating to these outcomes arise organically. *Students are exposed to development and sustainability issues, preparing our graduates to practice engineering within sound global and environmental constraints. Our partnership with an established NGO has proved invaluable, allowing our students, alumni, and faculty to focus on the technical aspects of the project.*
2. **The benefits of long-term projects outweigh the challenges.** Although long-term projects are more difficult to start and to maintain, there are distinct advantages to this approach. Obviously, more complex and difficult problems can be addressed. In addition, the students are more likely to recognize the need for effective communication and documentation to aid current and future project participants. These practices become internalized habits, not just a concession to faculty demands.
3. **The Integrated Projects Curriculum alleviates the discontinuity caused by graduation.** While the Modified Rower Pump project invariably experiences lulls after losing experienced members to graduation, the down time is reduced with the IPC project structure due to vertical integration and improved documentation practices.

Endnotes and Bibliography

1. SIM (Serving in Mission) is an organization committed to meeting the spiritual and physical needs of disadvantaged peoples. http://www.sim.org/index.php/content/our-purpose provides a more detailed description of this organization's purpose and values.

2. CIA – The World Factbook- Burkina Faso. https://www.cia.gov/library/publications/the-world-factbook/geos/uv.html.

3. Personal communication, Matthew*Handicapės en Avant.*

4. CIA – The World Factbook- Burkina Faso.

5. Personal communication, Matthew Walsh, *Handicapės en* Avant.

6. A brief description of IPC can be found at http://www.messiah.edu/departments/engineering/program/ipc.html

7. For this narrative, "team" refers to all students involved in the Modified Rower Pump project and "project" refers only to students receiving academic credit.

8. Heisey, Stuart J. and Brian Ondrasik. *West Africa Pumping Project*. Grantham,PA: Messiah College Department of Engineering, 1999. A full report is available upon request from engineering@messiah.edu.

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12. Visit http://www.echonet.org/content/whatWeDo for a complete description of this organization.

13. Criteria for Accrediting Engineering Programs: 2009-2010 Accreditation Cycle, Engineering Accreditation Commission (ABET). http://www.abet.org/Linked%20Documents-UPDATE/Criteria%20and%20PP/E001%2009-10%20EAC%20Criteria%2012-01-08.pdf.

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15. Bloom, Benjamin S. and David R. Krathwohl. *Taxonomy of Educational Objectives: The Classification of Educational Goals, by a committee of college and university examiners. Handbook I: Cognitive Domain*. New York: Longmans, Green, 1956.