Session 2260

Student Design for the Developing World

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Design that Matters

I. Introduction

The Electrical and Computer Engineering (ECE) Department at Worcester Polytechnic Institute (WPI) has instituted a sophomore-level course entitled "ECE Design" to focus on teaching design as a process, with the specific intents of better preparing students for their senior capstone design projects, and at the same time assessing their ability to apply fundamental knowledge in a design context. The ECE Design course[1,2] is run as a simulated business, with faculty serving as "Engineering Managers" who teach the process of design and manage the learning experience. The students work in three-person design teams to design a viable product, from market research through to demonstration of a working prototype. The student teams keep extensive engineering notebooks, report out their work to the faculty and external evaluators in technical Design Reviews, and submit formal design reports.

In a recent offering of the course, WPI faculty collaborated with Design that Matters™ (DtM), a nonprofit organization that acts as a bridge between students of design and underserved communities around the world[3]. Students work in collaboration with DtM to create products and services to address unmet needs in those communities. The students in the ECE Design course were given two design challenges that address the problem of adult literacy in areas of Mali that are without electrical infrastructure. DtM has developed a prototype portable library and projection system called the Kinkajou Microfilm Library[4] to be used in Mali; the system runs on 12V automobile batteries, the most common source of electrical power in many areas of the developing world. The first challenge presented to the WPI students was to design a "universal charge controller" to allow the charging of 12V automobile batteries from various sources including bicycle-powered generators and small solar panels. The second was to develop a highly efficient power supply for the Kinkajou projector, building on two previous design cycles that had been completed by mechanical engineering students at MIT.

This paper will describe the experience of WPI faculty and students in addressing a design problem embedded in a cultural context from the developing world, as well as the experience of Design that Matters in working with sophomore-level design students to develop products to bring to market abroad. In addition to describing the results of the design work, we will discuss the social and economic considerations that emerged from the student designs, as well as the perspectives of the involved faculty members and DtM staff.

II. The ECE Design Course at WPI

All WPI undergraduates must complete three degree-required projects. These projects are not part of any course; they involve individuals or small teams of students engaging in independent, inquiry-based work under faculty direction. One of these projects is a three credit-hour capstone experience in some area of the humanities and arts; one is a nine credit-hour interdisciplinary project addressing a problem that has both technical and social aspects; and one is a nine credit-hour senior year project in the major field. Called the Major Qualifying Project (MQP), this final project serves as ECE students' capstone design experience.

The ECE Design course was originally motivated by assessment[5] indicating the need to improve students' understanding of the process of design in preparation for the MQP. A second objective for the ECE Design course is to assure that students, who typically take the course at the end of the second year, are able to apply the fundamentals of ECE in the context of an independent, team-based design project. The course takes place roughly midway through ECE students' undergraduate careers, and is intentionally a *formative design experience*, rather than a summative capstone design project. At the point when students take ECE Design, they typically have a five or six course background in ECE, consisting of DC and AC circuit analysis, physical principles of ECE, basic digital circuits and computer engineering, and continuous-time signal and system analysis, plus either microelectronics circuits or embedded computer systems.

The ECE Design course puts small teams of students through a complete product design experience. They begin with an open-ended problem statement, and must conduct market research to determine customer requirements for the product they are to design. From their research, they derive a technical specification for their product, and brainstorm design approaches. Using product criteria to choose a design concept, they go through a formal design process involving analysis, simulation, synthesis, construction, testing, and demonstration of a working prototype.

The course itself helps guide the students through the design process. Students are not "taught" how to do their designs, but rather learn about the process of design and the many ancillary issues to which designers must attend: economics, schedules, teamwork, brainstorming, ethics, aesthetics, and more. They develop a sense of how to make tradeoffs between cost, quality, and schedule, and the role of quality, reliability, and manufacturability in design. They become familiar with issues related to intellectual property and patents, regulations and standards, and the manner in which large and small engineering design enterprises are organized and managed.

III. Presenting Engineering as a Helping Profession

The ECE Design course was developed and, for the first few years, taught by a team of faculty members with extensive engineering design and management experience with large corporations.

Accordingly, the perspective from which the course was presented reflected product design as it occurs in a corporate setting. Students learned about corporate organization and processes, and made business cases for their products based on a corporate model. The design challenges were developed by the faculty, and typically fell into the category of consumer electronics.

The authors decided to approach the course from a somewhat different angle, for a variety of reasons. First, an increasing number of electrical and computer engineers spend a significant part, or even all, of their careers outside of large corporations. Many BS graduates now start with mid-sized or even small companies, and a significant number of engineering graduates find their way quickly into other fields for which engineering is useful preparation, including management, education, law, medicine, and public service. Second, in keeping with WPI's mission to educate "technological humanists", the authors had a desire to challenge future electrical and computer engineers consider the ways in which technology can be of more direct benefit to society and communities than through the economic stimulus resulting from the design of consumer electronics. Third, WPI's extensive experience with project-based learning has made clear that enhanced learning typically results when students are given a meaningful "real world" problem to solve for some external organization, rather than a problem fabricated by faculty. An opportunity for teaching design through real-world problem solving and presenting engineering as a socially relevant profession appeared in the form of Design that Matters.

III. Design that Matters and the Kinkajou Projector Projects

Design that Matters™ (DtM) is a nonprofit organization located in Cambridge, Massachusetts. DtM helps to improve quality of life for underserved communities by working with university students to create products and services that meet needs identified by the communities. DtM also works with non-governmental organizations, corporate partners, and local entrepreneurs to help bring promising student innovations to market in the form of products and services for communities in need. Since its launch at MIT in 2000, DtM has worked with over 300 university engineering and business students to develop dozens of prototypes that promise to improve thousands of lives.

Part of DtM's strategy is to capitalize on ABET EC 2000, which they see as creating a need for real world problems to be solved by engineering students. In doing so, they expose the students to the challenges and needs of underserved communities. Design that Matters develops "Design Challenge Portfolios" containing problem statements and the contextual information students need to develop appropriate technology to address the problems. The topics involve areas such as infrastructure and healthcare, renewable energy and economic development, education and capacity building. The portfolios connect the underserved communities to the student designers, by articulating community needs to a technical audience in a position to make a difference while learning and growing. DtM nurtures promising student-developed prototypes and facilitates the process of bringing the technology to bear in the target communities.

One of the challenges facing nations in the developing world is a low rate of adult literacy. In the African nation of Mali, over 60% of adults cannot read; this often prevents them from participating in the economy. Nighttime adult literacy classes have been established, but many areas suffer from lack of books and other basic resources. Furthermore, many of these classes occur in areas without reliable electrical infrastructure, and are hampered by lack of electrification. In response to this challenge, student teams working with Design that Matters developed the concept of the Kinkajou Portable Library and Projector.

The Kinkajou concept combines a microfilm-based library with a low-power projection system that requires only a 5-Watt white LED and cooling fan. Two teams of mechanical engineering students developed the alpha prototype of the Kinkajou, which was brought to Mali by DtM to get feedback and ideas for further design cycles. One challenge with the Kinkajou system is the need to power the LED efficiently and reliably, since the device is often powered from automotive batteries. The power supply in the alpha prototype was not designed for the Kinkajou application, and it suffered from light intensity fading due to thermal shutdown of a voltage regulator. Another related problem is that, for regular use of the Kinkajou, communities need a regular mechanism to recharge the automotive batteries. Currently, this involves carrying the battery to the nearest battery charging facility, often 10 to 20 kilometers distant from the village in question.

Two design challenges related to the Kinkajou Portable Library were developed collaboratively by WPI and DtM and presented to the student teams as follows:

<u>A 12V Universal Battery Charger:</u> Design a universal 12 Volt battery charger that can take various forms of electrical energy and charge a typical 12 Volt lead-acid (automotive) battery. The charger must be able to handle the following inputs: a solar panel, a pedal generator, and standard AC power (both American and European standards). The charger must not overcharge the battery, and must indicate the state of charge. In addition, the circuit should not drain the battery. The charger must be affordable in the community it is used in, and should be suitable for applications such as the Kinkajou Projector. Prototype cost should not exceed $50.

<u>High-Efficiency Kinkajou Driver:</u> You are to design the power supply for the Kinkajou Projector. The power supply must provide a constant current to the 5W white LED inside the projector, as well as run a small DC cooling fan. The input to the power supply will be a nominal 12 Volts from either a typical automotive battery or a 12 Volt battery pack. The circuit must be as efficient as possible to extend battery life. In addition, the circuit should indicate when battery voltage is low and shut itself down if the voltage drops below a certain level. The circuit must be integrated into the Kinkajou Projector and not add more than 10% to the production cost. Prototype cost should not exceed $50.

Each design challenge was taken on by nine teams of three students each. The DtM staff played an active role as members of the teaching team. They visited an initial meeting of the ECE Design course to describe the underlying problems in Mali, discuss the work done to date on the Kinkajou Portable Library and Projector, and present the specific design challenges. The students were given access to DtM's Kinkajou Design Portfolio, including field journals giving specific information about the potential users in Mali, their concerns and living conditions, and how, where, and by whom the projector might be used.

During the term, the students conveyed requests for additional information to DtM, who served as a "client" for the designs. For example, the students designing the battery charger wanted specific information—preferably exact technical specifications—about the bicycle generators, solar panels, and electric grid in Mali. Although DtM was able to respond promptly with some useful information from their contacts in Africa, and later provided some specific examples of equipment that might be used, the fact that there were no simple, readily available answers to these questions was in itself a valuable part of the learning process for the students. They were required to do additional research, and to make and clearly state some reasonable assumptions. This is just one example of the richness of educational experience that came from these messy, real-world design challenges.

IV. Designs for the Developing World

All nine student teams designing battery chargers and all nine student teams designing power supplies were able to demonstrate successful operation of at least some significant portion of their prototypes. The majority of the teams had circuits that were judged to be between 80% and 100% functional. Most of the battery charger circuits accommodated at least three of the four inputs (110VAC, 220VAC, solar panels, and bicycle-powered DC generators) and incorporated three- or four-stage charging circuits. Most of the power supply designs incorporated DC-DC conversion circuitry using feedback to provide a constant current to the Kinkajou Projector's 5 Watt white LED under varying operating conditions.

All of the teams had to deal with cost/performance tradeoffs, and perhaps more significantly, all had to consider issues of how the circuits might be repaired in Mali, and what the most likely failure modes were. Many teams specifically chose design concepts based on their research into parts availability in Mali, and most designs had multiple features and user interfaces driven by consideration of the users' technical background and level of literacy. Although microcontroller-based designs are typically popular in the ECE Design course, only one team out of 18 made the design decision to incorporate a microcontroller. Most teams developed designs with readily available replacement parts.

A fundamental design consideration was, of course, how practical the devices would be for the Kinkajou application in Mali. Determining this required the students to consider issues of product portability, waterproofing, and performance in extreme weather. The students also had to consider how much charging time would be acceptable in various modes (solar panel and bicycle generator, in particular) given the expected usage of the Projector.

Below is given an example set of customer requirements for one team's battery charger design. Most of the customer requirements were derived from research into the DtM field journals from Mali.

"Based upon our market research we have generated the following list of user requirements with a brief explanation. Below is the composed list:

- Portable – able to be carried easily, since most 65 % of all transportation is done by foot.
- Affordable – needs to be inexpensive. Annual income of households is typically under $500 American.
- Efficient – will charge the battery without wasting electricity from the input especially if they use a pedal generator (which research indicated they would), since it is unreasonable to assume they can pedal for more than a few hours.
- Durable – it will be subjected to a wide variety of conditions. Temperature ranges from 30 degrees F to 120 degrees F. Climate ranges from Desert in the northwest to tropical in the South East. Rainfall ranges from less than 12 inches a year to raining every day.
- Safe – because we are dealing with electricity, we need to keep consumer safe
- Low maintenance – does not have to be repaired often, deals with price and cost of repair.
- Repairable – if it does break it needs to be easily fixed, taking into account the customer technical expertise. The equivalent technical expertise there is to be assumed equivalent to a WPI sophomore EE major. (Given in class)
- Easy to use – 81 % of Mali is illiterate. The product must be easy to operate.
- Aesthetically pleasing – if it is used in a classroom then it should look nice.
- On/off switch – to have more control over battery charging.
- User feedback – a display indicating the sate of charge of battery.
- Able to take multiple inputs – different forms of electrical energy, given in the problem statement, as well as research indicated there was no national power grid, so alternate sources of power need to be used to charge a battery."[6]

V. Results and Discussion

The WPI faculty members involved in this offering of the course were struck by the level of commitment demonstrated by the students. It is typical for about 10% of the students in this demanding course to either drop the course or be "fired" from their team by the faculty "Manager" due to lack of contribution. Remarkably, all 54 students remained in the course for the entire term, contributed actively to their team's work, and successfully completed the course. For one faculty member, this was the first course in 17 years of fulltime teaching in which no students failed to complete a course he taught. The support, engagement, and enthusiasm of Design that Matters as a "design client" with a compelling, real-world problem clearly provided the students with high levels of interest, motivation, and pride in their work.

In an anonymous end-of-term survey, with 45 of 54 students responding, 76% of respondents reported investing an average of over 20 hours per week in the course, and 40% reported investing over 25 hours per week. WPI students typically take three courses per quarter, with an average total workload of about 15 hours per week per course. 93% of respondents either agreed or strongly agreed that they had solidified their understanding of previous courses, and 96% agreed or strongly agreed that they had learned to apply previous knowledge to a challenging problem. Several of the teams volunteered to continue working on their devices for use by DtM after the course was completed, and about 20% of the students indicated interest in continuing their work with DtM as part of a subsequent design project.

Design that Matters enjoyed working with WPI's enthusiastic and talented students, and believes that the designs generated by the students will lead to a viable beta prototype for the Kinkajou Projector in the next year. DtM and WPI are currently working together to arrange a follow-on project in which a single team of WPI students will, as their senior-year design project (MQP), perform the next design cycle for both the battery charger and power supply circuits, with the goal of integrating them into the Kinkajou Projector for the next stage of testing in Mali. We are also now planning the next set of design challenges for the ECE Design course, in order to provide more engineering students with examples of how engineers can improve lives worldwide.

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