2006-2388: INTRODUCTION TO ENGINEERING DESIGN THROUGH ENVIRONMENTAL ENGINEERING PROJECTS

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Introduction to Engineering Design Through Environmental Projects

Introduction

At Rensselaer Polytechnic Institute, Introduction to Engineering Design (ENGR2050) is a required course for all sophomore Engineering majors. Traditionally, this course has been taught in the context of Product Design and in small teams of 6 to 8 students. As depicted in Figure 1, this is a four-credit course, of which one credit is taught as Professional Development (PD1). The PD1 portion of the course is taught by instructors at the Archer Center for Student Leadership Development at Rensselaer. The mission of the Archer Center is to complement Rensselaer's educational mission by providing skill-based, leadership education to its students and community. According to the Archer Center: "The purpose of Professional Development 1 is to provide students with an introduction to a simulated professional environment where they can be exposed to the body of knowledge on effective teams." The material covered in the PD1 portion of the course consists primarily of skills-based learning meant to foster effective teamwork abilities. Skills and topics covered include: collaboration, effective communication and feedback, conflict management, team development, and ethical decision-making. The coursework and assignments help students gain topical knowledge, analyze and apply basic concepts, and expand written and oral communication skills. Instructors for the PD1 portion of the course work in close contact with the instructor in charge of the engineering portion of the course. Instructors work together to coordinate activities within each portion and confer with each other throughout the semester to address emerging issues and to optimize individual efforts. This collaboration is important as teams develop and internal conflicts appear. It is also important for the students to view this course as one entity and not two separate units.

The main focus of this course, however, is the design component. In the past, the design projects have varied annually, but they have usually involved the design of small objects such as cannons, ships, etc. The Environmental Engineering Program at Rensselaer, however, has delivered this subject matter in the context of Process Design for Environmental Systems. Before the first author joined this institution (Fall 2003), this course was taught as a hands-on Introduction to Water Quality with student teams focused on production of devices like portable (back-packing style) water filters. More recently, the author delivered this course in the context of Air Quality, where the projects often involved the design of air cleaner systems or aerosol laboratory instrumentation.

In 2005, the School of Engineering conducted a major re-structuring of IED and a renewed emphasis on hands-on projects was implemented. This new focus on project-based learning is in accordance with trends around the country [1]. The first author embraced some of the recent changes to the course and adopted additional ones to tailor the needs of the Environmental Engineering majors. In particular, the projects chosen for the Environmental Engineering section revolve around issues of Sustainable Development. The proposed overall project for this semester is to *design a system to provide potable water to poor communities in the developing* *world*. An additional change on this section, traditionally only open to Environmental Engineering majors, has been to open it to Civil and Mechanical Engineering majors as well. This change was in light of recent observations on the advantages of multidisciplinary teams in project-based learning environments [2]. The proposed project is intended to serve as a good introduction to issues of sustainability, to give students an opportunity to use their creativity under realistic constraints and to foment "global citizenship", as required by ABET. Projects dealing with construction of clean water and sanitation systems have been mentioned by proponents of project-based learning [3] as particularly appropriate choices for motivating engineering students since they have had great impact in increasing the life expectancy in the twentieth century [4].

In regards to the class format, at the beginning of each week, we conduct short discussions on topics of the day. Of particular importance are discussions on Social Responsibility and Sustainable Development. For example, on the first day of class, after administering the initial evaluation survey, we had an open discussion on *What do Engineers do?* Among the topics relevant to this discussion, the problem-solving aspects of engineering as well as decision-making and the collaborative nature of the work were discussed. In addition, the ethical dimensions of engineering and the responsibilities engineers have to uphold high standards of performance and execution are discussed [5, 6, 7, 8, 9]. Throughout the semester, students are encouraged to bring up their own topics for discussion. These discussions are conducted weekly and take place during the first 10 - 15 minutes of the class session.

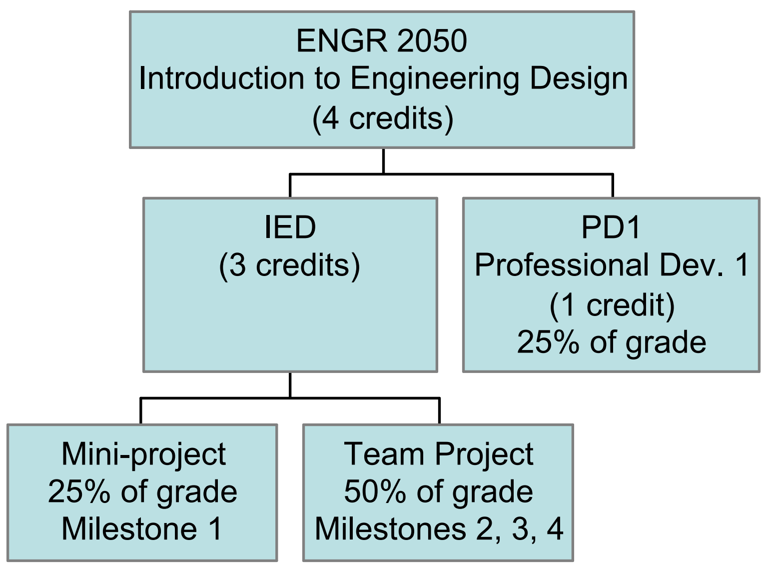

Figure 1. Organizational chart for Introduction to Engineering Design (ENGR2050).

The author's previous experience teaching this course revealed that students appreciate the opportunity to select their own design projects; however, they still require significant guidance when making their final selections. Consequently, last year's approach was to provide them with a list of possibilities and guide them through the selection process. The new format of proposing one multidisciplinary design project for all students has proven to be even more effective in getting the students started with their projects. As mentioned earlier, the format for all sections of Introduction to Engineering Design includes two phases: 1) a mini-project to be completed by each student individually within the first 4 weeks of the semester; and 2) a team project to be completed by the end of the semester. These phases are discussed in more detail in the following sections.

Mini-projects

For the Environmental Engineering section, the mini-projects involved *the design of simple systems to move water uphill from a spring near a small village in Africa where there is no access to electricity or other advanced technology*. Individual projects were approved by the instructor and small prototypes were built as part of Milestone one (Figure 1). Students had access to resources on the web as well as reference textbooks and journal articles [10, 11, 12, 13] provided by the instructor.

As part of their mini-project, students had to translate the customer needs into engineering specifications (i.e., power requirements to move a specified water flow based on water needs of 50 people). The instructor provided additional specifications (e.g., height that the water must be lifted) and involved students in the identification of other important design considerations. Students were able to explore past work, including patents. They were encouraged to consider competitor benchmarking and conduct a functional analysis. Specific outcomes for this exercise will included: identifying and defining the primary functional attributes of their design and quantifying a target value or specification for their design. They were required to identify any mathematical formulas that could be used in making these predictions and to propose how the target design specification would be measured. A one-page memo was due at this point.

Next, students learned about concept generation and selection methods, design communication and documentation. They were asked to develop a CAD model, system schematic or flowchart to clearly and accurately communicate their design concept. They prepared a five-page technical memo and a short (about 5 minutes) oral status report describing their design. As culmination of the mini-projects, students made project design review presentations and performance evaluations (Milestone 1). Students give an oral presentation and demonstrated that their design met the target design specifications as predicted. Students served as critical reviewers of each other's work and learned to give and receive constructive criticism.

As an additional, extracurricular activity, students were encouraged to enter a project in the *Change the World Challenge* competition, which is held at Rensselaer each semester. The *Change the World Challenge* is a Rensselaer initiative to "support entrepreneurship education and stimulate ideas to improve the human condition." The program is funded by entrepreneur Sean O'Sullivan '85 through a $1 million donation to Rensselaer as part of the *Renaissance at Rensselaer: The Campaign for Rensselaer Polytechnic Institute*. At the core of the challenge is an "idea competition" to be held each semester. Student participants select a topic from a list of challenges to use science and/or engineering to improve human life, and offer a solution to that challenge which is not currently available and is sustainable long term. The importance of engaging our students in projects that can positively affect humanity does not need to be explained. The intent of this exercise is to leverage all the resources and opportunities at Rensselaer to provide our students with the most rewarding and challenging curriculum. In particular, this exercise seeks to complement their academic curriculum with institutional initiatives that bring a global dimension to their training.

Team Projects

After the individual mini-projects were completed, students were organized in groups of four or five to work on their team projects. Each team initially evaluated the various mini-project designs developed by its individual members on the first part of the course as well as other available options. On this phase, students were instructed to consider additional systems that could include electricity generation. From these deliberations, they selected their preferred designs and moved to *develop a complete system for delivering potable water to a population of 500 people in a small village located 10m above the level of the water source*. To give students an idea of what these communities look like, students were invited to attend a video show presented by the *Engineers for a Sustainable World (ESW)* student chapter at Rensselaer. This video showed the water source in a small village in Nigeria that meets these specifications (Figure 2). The motivation for providing information about this actual community was to offer students the opportunity to view their projects as being relevant in a world that exists beyond their school or even their country.

At this point, students learned about drinking water standards and methods to determine water quality from an expert in the field. Students would have the opportunity to consult with this expert outside class and on a subsequent lecture once they have had an opportunity to apply this new information to their own project. As part of this initial stage, teams identified their potential customers, conducted an analysis of customer needs, and performed a study of past work. The instructor provided a list of acceptable materials for the construction of the system prototype.

Figure 2. Water supply at Umuluwe, Nigeria.

Next, teams determined the design specifications for their project, performed competitive benchmarking and generated alternative system concepts. In order to evaluate the best system concept, the team used a decision analysis matrix. From these steps, each team emerged with a clear system design concept to pursue. At this point, each team performed a cost analysis, prepared a project plan. Each team prepared a 20-minute oral presentation of their project plan and submitted a written report (Milestone 2).

The next step was to develop a scale model or prototype to evaluate the system concept. Teams conducted design reviews to evaluate the safety, environmental impacts, reliability, life cycle issues, maintainability, durability, manufacturability and cost of their design. The following weeks were spent refining the details of the design, building and subsequently testing and debugging the prototype. As the semester came to a close, design teams conducted the final evaluations and demonstrations of their system design concept prototypes. Among issues to consider, they reflected upon the design process and discussed how it impacts people in general as well as any specific questions regarding their design. As Milestone 3, teams made final project presentations and submitted design documentation in the form of a written report.

For those students who enjoyed this course experience, they could choose to continue their involvement in similar projects by joining the Rensselaer chapter of *Engineers for a Sustainable World*.

Evaluation Methods

In addition to the required work assignments discussed in the previous sections, students were asked to fill out a couple of surveys in the course of this class. In order to monitor student progress in acquiring a proficiency and knowledge in several areas, a short survey was administered on the first day of classes. The main purpose of this tool was to establish a base level of knowledge about the Engineering Design process, individual Engineering disciplines as well as basic understanding of Sustainable Development.

Sample questions from this survey follow:

What do you think Civil Engineers do?
What do you think Environmental Engineers do?
What do you think Mechanical Engineers do?
What do you think are the main responsibilities of the Design Engineer?
Who do you think the design engineer should be responsible to?
What would you think is a “design failure”?
Name three important steps in Product Design.
What is Sustainable Development?
What are the important tenets of Sustainable Development?

An exit survey will also be administered at the end of the semester to assess whether or not students increased their knowledge on these various topics. These evaluations will be conducted with the assistance of the ABET coordinator in our program. At the time of the preparation of this manuscript, however, only results from the initial survey were available for analysis.

Results from the initial survey revealed that 38% of the students in this class did not have any knowledge about Sustainable Development and Sustainable Engineering. Similarly, 43% of students couldn't name any steps in the process of product design and 76% couldn't name any components/tenets of Sustainable Engineering.

Members of the faculty, graduate and undergraduate students outside class have been invited to attend the individual and team project presentations, to give feedback and participate in the evaluation of these projects.

Course Outcomes

The specific educational outcomes expected from this new format include the following:

- Students will learn to work in teams. This outcome will be assessed via self-reports, peer reports, instructor observation and outside judging.
- Students will learn to identify key sustainability issues and incorporate those into their design. The sustainable nature of their design will be assessed by peer, instructor and outside observers.
- Students will learn about the need for interdisciplinary design work. This outcome will be assessed by peer, instructor and outside observers.
- Effectiveness of this format in motivating students to engage in issues of Sustainable Development can be evaluated with further tracking of student participation in *Engineers for a Sustainable World* and/or similar groups.

Summary

This paper has described a revised course, Introduction to Engineering Design, as it is taught to Environmental Engineering majors at Rensselaer Polytechnic Institute. This year, however, it has been opened to Civil and Mechanical Engineering majors as well. The main focus of this course has been to serve as a formal introduction to the topic of product or process design with the usual discussions on the topics of problem definition, understanding customer and context, finding and developing mathematical models of process, constraints on cost and materials and ease of use, reliability and failure, prototyping, testing and refining. However, this new format underscored the need to consider issues of sustainability by suggesting projects that address the basic need for clean water in all communities, and those in developing countries in particular. As part of this course, we attempted to inculcate our students with principles of sustainable design and how they are critical for the welfare of our planet. As part of the assessment program, faculty, graduate students and undergraduate students outside this course were invited to evaluate and give feedback on the individual and team presentations.

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