2006-958: SUSTAINABLE DEVELOPMENT DESIGN PROJECTS FOR ENGINEERING FRESHMEN

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Sustainable Development Design Project for Engineering Freshmen

Abstract:
This paper outlines the sustainable development design project created by a team of graduate students and professors for 1,200 first semester freshmen engineering students in the fall 2005 semester. Student teams were presented with a five week long design assignment which focused on low tech solutions for a developing community. All teams were given a set of appropriate construction materials. The project required the students to complete a series of assignments which reflected significant stages in the engineering design process, and culminated in the "Sustainable Development Design Fair" where one team from each of the forty-one workshop sections competed for one of three awards decided by a panel of faculty judges. Supplemental educational material was also presented in the lecture and workshop sessions to aid the students through this assignment. Results of the project are discussed and include a focus group interview and online surveys conducted to assess the effectiveness of this new approach of introducing design in the early part of engineering curriculum.

1.0 Introduction

A new department of engineering education (EngE) was created at Virginia Tech in May 2004 to improve engineering pedagogy within the college of engineering and to create collaboration between engineering and education faculty within and outside the university to develop an active research program in engineering education. The EngE department offers the General Engineering (GE) program for engineering freshmen. In September 2004, a NSF funded a department-level reform (DLR) project that was developed by a number of EngE faculty in collaboration with faculty from other engineering departments, particularly the Biological Systems Engineering (BSE), and the School of Education. The goal of this DLR project is to reform the GE program within EngE and the bioprocess engineering option within the BSE using a theme based spiral curriculum approach. The twentieth century psychologist, Jerome Bruner, proposed the concept of the spiral curriculum. Bruner advocates that a curriculum as it develops should revisit the basic ideas repeatedly, building upon them until the student has grasped the full formal apparatus that goes with them [1]. In the proposed reformulation, a theme of sustainability has been selected to provide a contextual framework.

The GE program in the EngE department mainly includes two freshman level introductory engineering courses. The first one is called "Engineering Exploration ENGE1024" and is taken by approximately 1,200 engineering freshmen in fall semester each year. A number of changes have been introduced in this course in recent years with the objective of introducing early design experiences. Until fall 2005, this was accomplished by assigning 2 -3 design projects, during the semester, typically involving some "analysis" but mainly a "build" component. Students were typically given a detailed problem statement with well-defined goal. For the "build" assignment, student teams (4-5 students per team) were given a set of materials in the form of a "MacGyver Box." These boxes contained a variety of common materials and tools such as plastic tubing, wooden paint stirrers, string, wire, hobby motors, batteries, clothes pins, plastic wheels, a hammer, and a screw driver. While students enjoyed their MacGyver experiences, it was felt that as part of their freshman year experiences engineering freshmen should be exposed to design experiences that also address the social relevance of engineering. It was also acknowledged that

students may benefit through engagement early in the assignment, particularly during the problem definition phase. The "sustainability" theme that is part of the ongoing DLR project was the perfect fit for this purpose. Therefore, with an objective to introduce the notion of sustainability to engineering freshman, a sustainable development design project (SDDP) was introduced in ENGE 1024 for the first time in fall 2005. The following sections present the details.

2.0 New Format of Teaching Engineering Exploration (EngE1024) Course

In spring 2005, the authors took the lead in piloting a new teaching format for EngE1024 involving one 50-minute lesson, taught by the 2nd and 3rd authors, in a 120-seat classroom followed by one 110-minute workshop, taught by graduate teaching assistants (GTAs) coordinated by the first author, in a 30-seat classroom each week. Prior to spring 2005, this 2-credit course was taught with two 50-minte lessons per week; graduate students weren't involved in this teaching effort. About 210 students were enrolled in this spring EngE1024 course. The principal reasons for initiating this major change were to: i) allow additional time for students to become engaged in more hands-on activities during the workshop period, ii) create teaching opportunities for graduate students, iii) give students the opportunity to present and to become aware of contemporary engineering issues, and iv) collect/analyze data for conducting engineering education research. This new format was well received by the students [2] and in fall 2005 the new format was implemented for the entire freshman engineering class of about 1200 students. These students were assigned to 8 large (~150-170 students each) lecture sections and 41 workshop sections. Altogether 7 faculty members, 14 GTAs and 7 undergraduate students participated in the fall implementation. The 2nd and 3rd authors were the overall coordinators and the lead author coordinated the activities of GTAs. Please see a companion paper [3] for details of the fall implementation. Briefly, the fall 2005 implementation included 15 weekly lessons by EngE faculty followed by 14 weekly workshops by graduate students. All GTAs participated in a number of teaching related training activities. The faculty introduced the notion of sustainability in the week 5 lecture by, first, asking three world facts questions as below, adapted from the work of an MIT researcher Amy Smith [4], with the intent of knowing students' prior awareness of sustainability related issues. Students recorded their responses using a clicker device.

Question 1: What percent of the world's population lives on less than $1 per day?

A. 5%
B. 20%
C. 50%
D. 75%
E. 90%

Question 2: How many people in the world do not have access to safe drinking water?

A. 1 million
B. 20 million
C. 500 million
D. 1 billion
E. 3 billion
F. 5 billion

Question 3: What is the approximate cost to light a household for a year in a developing country (using kerosene)?

A. US $10
B. US $50
C. US $100
D. US $200
E. US $500

Table 1 gives the percentage of students for the given possible answers recorded in the lecture sections (~ 320 students) of the 2nd and 3rd authors. It can be seen in Table 1 that only about 20% students guessed the world fact quiz questions right.

Table 1: Clicker response – Percentage of students

Options	Question 1 (Q1)	Q1-Correct answer	Question 2 (Q2)	Q2- Correct answer	Question 3 (Q3)	Q3-Correct answer
A	5%		3%		10%	
B	21%	XXX	5%		21%	
C	30%		37%		19%	XXX
D	37%		37%	XXX	31%	
E	8%		14%		18%	
F			3%			

The widely accepted definitions of sustainability discussed during the lesson were:

Sustainable development meets the needs of the present without compromising the ability of future generations to meet human needs and aspirations [World Commission on Environment and Development (WCED) – 1987].

Development that will meet the long term needs of future generations of all nations without causing modifications to the Earth's ecosystems. [International Federation of Consulting Engineers (FIDIC) – 1990 quoted from Sustainable Engineering Practice – An Introduction, Published by the American Society of Civil Engineers, 2004].

In addition, a recommendation, as below, made at a recent National Academy of Engineering (NAE) conference was also discussed:

Creating a sustainable world that provides a safe, secure, healthy life for all peoples is a priority for the US engineering community [Source: Dialogue on the Engineers Role in Sustainable Development – Johannesburg and Beyond (held at the National Academy of Engineering, Washington, DC, June 24, 2002)].

Finally, the sustainability related recommendation, as below, in the latest ABET criteria was discussed:

The engineering curriculum must prepare students for engineering practice culminating in major design experience based on knowledge and skills acquired in earlier coursework and incorporating engineering standards and realistic

constraints that include most of the following considerations: economic, environmental, sustainability, manufacturability, ethical, health and safety, social, and political [Source: ABET (2003). ABET Criteria for Accrediting Engineering Programs Effective for Evaluations During 2003-2004 Accreditation Cycle].

Following this, a 5-week long Sustainable Development Design Project (SDDP) was briefly introduced to the students.

3.0 The Sustainable Development Design Project

Instructional material and guidance for the SDDP was provided jointly in both the lecture and workshop sessions by the GTAs and instructors, who visited the workshop sections corresponding to their lecture session for at least 15 minutes to observe and guide the GTAs. Following the introductory lecture lesson, the GTAs further emphasized the definition of sustainable development during the week 5 workshop and presented three examples of sustainable development design; namely, the sari cloth water filter, the pot-in-pot cooling system, and an experimental coal made from bagasse [5]. Sari cloth water filters have shown promise in removing plankton from contaminated drinking water known to cause cholera according to research in the United States [6]. Tens of thousands of people a year die from cholera, affecting most profoundly those communities who do not have access to safe drinking water or sanitation [6]. The pot-in pot cooling system was developed by a Nigerian teacher Mohammed Bah Abba in response to food spoilage in a rural community of subsistence farmers [7]. The cooling system provided safe storage for locally grown vegetables. His innovation has an additional economic potential for local communities who manufacture and distribute the pots. Charcoal made from bagasse, a waste product of sugarcane processing that has the density of wood charcoal yet burns more cleanly. This is especially beneficial in areas of Haiti which have been heavily deforested and where communities rely primarily on charcoal for cooking [5].

Following the class discussion, students were assigned into teams of four to five and allowed fifteen minutes to conduct their first team meeting. They were also provided a document detailing all aspects of the project, including assessment, a profile of a fictional community, four design topics (i.e., energy, nutrition, education, agriculture) from which to choose, and all assignment specifications. A broad design requirement was given for each of the topics; education, energy, nutrition, and agriculture. For example, concerning the topic of education, students were instructed to "design a tool or device that will help the villagers improve literacy…they do not have access to books, pens, pencils, chalkboards or other basic teaching aids…you may also consider the needs of adult learners"

3.1 Project's Objective and Materials

One of the key objectives of the SDDP was to provide the students with a challenging and real world problem from which to have an educational hands-on experience with certain fundamental aspects of the engineering design process. These included the development of a problem definition, performing research, understanding a communities needs, working within well defined constraints, identifying design trade-offs, developing testing and performing basic analysis, presentation skills, and the writing of a technical report. Another key objective of the project was to give the freshmen students a team based design assignment in order to experience

first hand the challenges, benefits, and stages of teamwork. Sustainable development design was selected as a topic due to its emergent relevance to future generations of engineers. While the topic of sustainable development design is broad, another project objective was to provide students with material from which they would make connections concerning the impact of technological development on a community. By limiting the building materials, the designers of this project purposely intended it to stress the conceptual development of a design as opposed to an emphasis on construction and material manipulation.

Student teams were given a bag of supplies which included a ziplock plastic bag, a bandana, ten bamboo skewers, 3 ft. of jute twine, 3 ft. of rope, and 4 oz. of terra cotta modeling clay. In addition, they were allowed to use one soda can and one plastic water bottle in their final design, which they were expected to provide. The only supplemental tools allowed were scissors and a knife.

3.2 Project Assessment

In order to assess students' performance, a series of individual and team assignments were specified in the SDDP document (see Table 2). Overall, the SDDP accounted for 17% of the students overall grade in the course.

Table 2: Sustainable Development Design Project Assignments

Assignment	Type	Weight	Due Date
Research Paper	Individual	15%	Workshop 6
Proposal	Team	10%	Workshop 7
Sketch	Individual	10%	Workshop 8
Prototype	Team	5%	Workshop 9
Log Book	Individual	10%	Workshop 10
Demo	Team	10%	Workshop 10
Final Report	Team	40%	Workshop 10

3.3 Guidance from Instructors/ GTAs

Due to the open-ended nature of the assignment, students had a variety of questions concerning the project specifications. In response, a "Design FAQs" page was created on the main Blackboard site that documented these questions and the instructors' responses. Throughout the project, the GTAs provided guidance and feedback to the students concerning their progress and also answering the many questions. Most of design projects were graded by the GTAs using a grading rubric provided by the instructors. Several of the student's questions early in the project indicated their engagement, as documented in "DESIGN FAQs" such as:

> -We know that a fire would be available in the village, but the university rules do not allow me to use fire in the classroom. Is a video allowed as a part of the demonstration?
> -Can we use any additional natural materials such as rocks, leaves, etc. as construction materials?

-What about animals?
-Can math be included under literacy in the education topic?

3.4 Student Designs

Following the submission of an individual research paper, where students were instructed to identify and discuss one example of sustainable design outside of the three design examples provided during the introductory workshop, the student teams were required to submit a one page proposal identifying a topic and four potential design solutions. The results of these proposals indicated a large percentage of student teams chose "Nutrition" as their preferred topic, and "water filter" as the most common design solution. The sari-cloth water filer example might have influenced this choice. A variety of approaches to this situation were taken by the GTAs, from accepting all proposals as they were, to requiring the student teams to select new topics and generate new design solutions. Results of final team topics from nineteen of the forty-one workshops show a disproportionately high preference for "Nutrition" and low preference for "Energy." (see Figure 3) Under the topic of "Agriculture" the most common design solution was a 'drip irrigation system," and for the topic of "Education" a common design solution was the "abacus." There were many instances of student creativity (Fig. 4), for example, one student team designed a model of a mouth to teach dental care with a toothbrush made from the twine and a dental floss dispenser from the can and bandana (Fig. 5), another team designed footwear with cleats made from the can, twine and bandana for climbing muddy hills.

Figure 3: Final Design Topics: From Nineteen Workshops

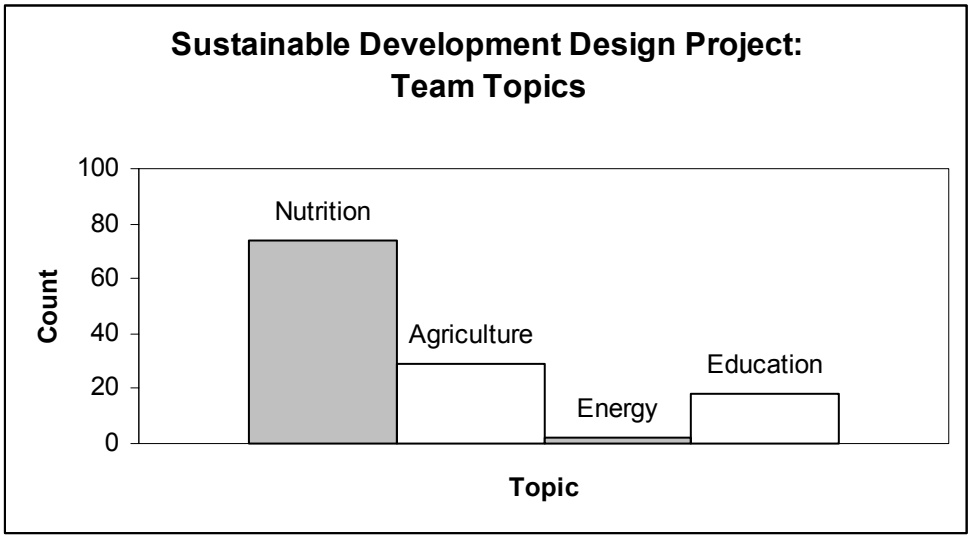

Figure 4: Student Design of Small Burner

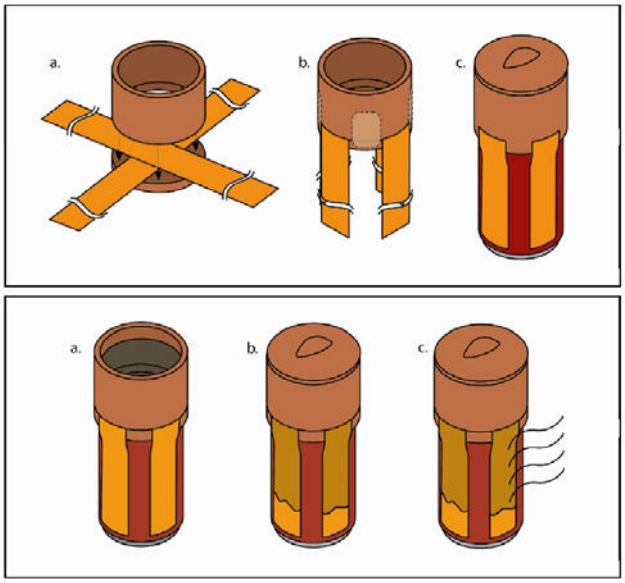

Figure 5: Student Design for the Education of Dental Hygiene

3.5 The Sustainable Development Design Fair

In order to showcase students' designs, a design fair was organized. Forty-one designs, one from each workshop, were selected to compete in the design fair. These designs were chosen through a student voting process following the team demonstrations during the last week of the project. Each team was allowed ten minutes to present their design to the class and to answer questions. Instructors visiting the workshops were privy to such sights as students filtering muddy water before consuming, student built garden boxes with vegetables and irrigation systems, in addition to videos of student designs at work in local fields and small streams. While the GTAs had the deciding vote, all designs showcased at the fair were ultimately chosen through the student

selection process. The students were advised to vote based on the quality of the design, innovation, and adherence to sustainable design principles.

The design fair was held on Nov. 03, 2005, one week after the final reports had been collected. It was held on campus, and the students grades were not affected by their inclusion to the fair student. A team of nine judges including department faculty, engineering faculty, graduate students, and the director of the Green Engineering program at VT chose the winning designs which included one "Best in Show" and two "Honorable Mentions." Figures 6,7 show judging process at the fair. Prizes, gift certificates to the university book store and local restaurants, were given to the winning teams. An article appeared in the college newspaper identifying the winning teams following the fair.

Figure 6: Judges Evaluating a Student Design

Figure 7: Students presenting to Judges at the Fair

3.6 Student Feedback

Students were asked to provide feedback concerning what they thought was the most valuable aspect of the project and what they would recommend changing. Among the most valuable aspects communicated by the students was teamwork, exposure to the design process, learning about sustainable design, designing within constraints, the hands-on experience, and exposure to a real world topic. Overwhelmingly, the students felt the most recommended change would be the materials of which they would have liked more variety, and more detailed assignment specifications. Towards the end of semester, students completed an "exit survey." Some sample responses from an exit survey question, as quoted below, follow:

> Question: What, if anything, did you learn in ENGE 1024 that you didn't expect at the beginning of the semester?
>
> Sample responses:
> -I learned a lot concerning ethics and sustainable design which I did not expect to be the primary focus of EngE 1024.
> -I learned more about engineering as a field than I expected to. I didn't expect to learn what each department does, or about ethics and sustainable design. I think that these things were beneficial.
> -I learned that teamwork is a major key in succeeding.
> -we learned about sustainable development which I knew was important but did not expect it to show up.
> -I learned about Sustainability which is something I knew nothing about beforehand.
> -I'm not sure. Going into the class, I really didn't know what engineering really was and what it would be like or if I would even like it, so I didn't have any real expectations. But after taking the course, I feel more confident about what engineering is and I also know that I am very interested in it and I like it a lot.
> -I did not realize that we would be working in teams as much as we did. I think that this was a good experience because I had very little team experience in the past.
> -Programming, Sustainability, and that engineering not only consists of modern technology but engineering can also be applied to the most simplest things such as making something out of clay, a soda can, and bamboo sticks.
> -I didn't expect to spend half a semester designing something from rope, cloth, and bottles.
> -I learned how an engineering design project is run.
> -I learned how important the engineering process is. The whole thing about teamwork and all the beginning steps to a successful design and construction of a prototype were all interesting and I did not expect to see them.

4.0 Summary :

A SDDP was successfully implemented in the freshman year "Engineering Exploration" course at Virginia Tech. In response to student feedback and faculty recommendations, the project will be redesigned and piloted with a group of 180 students in the spring semester of 2006. While many students thought it was beneficial to have the project centered on the needs of a developing

community, many others did not recognize the relevance of these communities to sustainable design or to their own lives. Improvements to the introduction of the sustainability topic are seriously under consideration at the time of this writing. In lieu of the world fact quiz, a hands-on activity is being designed which examines a projected growth in world population and the resulting energy and water resource requirements. The predominance of water filter solutions fueled much speculation and reflection on the part of the project designers. Ultimately, it was felt that presenting the students with examples of design solutions early in the project predisposed a large percentage to consider only these solutions. It is being planned to present these examples to the students later in the project. Construction materials deserved serious re-consideration, as too many students felt the constraints limited creativity and design options. In response to the need for more meaningful material selection the addition of materials which are currently recycled on campus are under consideration. To further ensure a more diverse set of design solutions, the student teams will be directed to a variety of topics during the team assignment phase. Furthermore, the project will be expanded beyond the five weeks to seven weeks to allow for the addition of these proposed activities.

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