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Jennifer Mullin, Virginia Tech

Jinsoo Kim, Korea National University of Education

Dr. Jinsoo Kim is a visiting professor in the Department of Engineering Education at Virginia Tech from July 2006 to July 2007. He is a professor in the Department of Technology Education at Korea National University of Education. He is interested in subject-matter education of Technology, Engineering, and Industry. His permanent e-mail address is jskim@knue.ac.kr

Vinod Lohani, Virginia Tech

Jenny Lo, Virginia Tech

Sustainable Energy Design Projects for Engineering Freshmen

Abstract

In the fall 2006 a sustainable energy design project was piloted in a first semester engineering course "Engineering Exploration" at Virginia Tech. The main objectives were to develop students' knowledge of sustainable energy, provide an introduction to the engineering design process, and to improve students' team and communication skills. The theme of sustainable energy was selected in support of the goal of an ongoing Department-Level Reform (DLR) project from the NSF, and to also initiate curricular activities supporting the newly formed Dean's Taskforce on Energy and Sustainability. This task force seeks to coordinate, promote, and position the university's educational, research, and outreach efforts to achieve sustainable and secure energy systems. Approximately 1,200 students completed the six week long team design project which culminated with a design showcase where 17 semi-finalists competed for 1 of 3 prizes. This paper presents the implementation details of the design project. In addition, results of a mixed-method study with 112 students which include pre- and post-test survey data examining general knowledge of renewable energy, attitudes towards renewable energy, engineering design and feedback from focus groups interviews are discussed.

1. Introduction

The General Engineering program at Virginia Tech is being reformed as a part of a Department-Level Reform (DLR) grant from the NSF. A theme based spiral curriculum approach, proposed by an educational psychologist Jerome Bruner, is adopted with sustainability as the theme for the proposed reformulation [1]. "Engineering Exploration EngE1024," is a 2-credit first semester course, offered by the Department of Engineering Education (EngE), which traditionally incorporates a student design project. Successful completion of EngE 1024 and another introductory engineering design course is mandatory for all engineering students prior to their admittance into 1 of 11 degree granting engineering departments. As a result of the DLR project, EngE 1024 has undergone significant restructuring targeted at enhancing student learning by incorporating contemporary engineering issues and implementing a variety of formative and summative assessment tools [1, 2, 3, 4]. A major restructuring of the EngE1024 course was initiated in spring 2005 when students began attending both a weekly lecture and workshop session. The 50-min lecture was led by EngE faculty in a large classroom with approximately150 to180 students. A weekly 90- min. workshop session followed where the emphasis was on active learning through a variety of hands-on activities led by a graduate teaching assistant. In addition to a variety of collaborative student-centered learning activities created specifically for these workshop sessions, design projects were also developed in order to promote teamwork skills, provide an introduction to the engineering design process, and to highlight a variety of contemporary social and technical topics relevant to a broad range of engineering disciplines. This paper presents implementation details of a six week long sustainable energy design project, developed by the lead author and course coordinators, and piloted in the fall 2006 semester. In

addition, results of a pilot study designed to determine gains in students' knowledge of renewable energy, attitudes towards engineering design, and interest in the topic of renewable energy are discussed.

2. Sustainable Energy Design Project (SEDP)

The "Sustainable Energy Design Project (SEDP)" was piloted in the fall 2006 with approximately 1,200 engineering freshmen enrolled in EngE 1024 course. The student teams were presented with an open-ended assignment which required them to design a "promotional invention" for 1 of 4 renewable energy topics which included wind, hydropower, solar, and biomass. The students were required to complete a set of graded assignments which covered major activities of the engineering design method and included problem definition, information gathering, generating alternatives, modeling, construction, and communication. The design project culminated with a "design showcase" where student teams competed for 1 of 3 prizes. This design assignment was built on previous curricular design, development and implementation efforts by the lead author and course coordinators in the first semester course. The topic of sustainability was introduced in previous semesters through a series of design projects which emphasized sustainable development and an international perspective.

The EngE1024 teaching team included five faculty, 14 graduate workshop instructors (GTAs) and 8 undergraduate graders. Students were assigned to one of 8 large lectures taught by faculty and one of 41 workshops taught by the workshop instructors. The SEDP was briefly introduced in the lecture part of the course during the 5th week of the semester and a detailed project document including project's objectives, timeline, deliverables, etc. was made available to students through the course Blackboard site. The workshop instructors assigned students into teams of 3 to 4 and facilitated and assessed all design assignments.

2.1 Course Activities in Support of SEDP

The project was designed to increase the students' awareness of renewable energy, provide an introduction to the engineering design process and improve team skills. Prior to assignment of SEDP, students were assigned an out of class video lecture given by Prof. Ishwar Puri, head of the Dept. of Engineering Science and Mechanics. In his 45 min. video, "Future Energy Scenarios," Prof. Puri discussed the limitations of fossil-fuel energy sources and potential solutions to an impending energy supply shortage which included clean coal technologies. A variety of data from reputed journals, *Nature* and *Science,* were presented in support of this global energy scenario. Following the energy video assignment, students participated in a world map activity. This activity was developed to introduce students to an international perspective on global energy issues and was completed in a workshop session prior to the assignment of the design project. Students worked in small groups and were given a world map, Lego blocks, and data for several countries and were assigned to construct three dimensional models of population, oil supply and oil demand (see Figure 1). They also completed a worksheet which included the calculation and graphing of projected population growth and discussion of

environmental issues and fuel requirements from a global perspective. The data sheets supplied for this activity contained pertinent information retrieved from the "CIA World Factbook" [5]. Another in-class problem-solving exercise was developed to highlight the personal relevance of sustainability and included the estimation of waste in the U.S.A. annually. Additionally, the students were assigned readings from *Holtzapple and Reece* [6] on engineering design. In lecture, the energy and sustainability related materials and activities were reviewed and discussed.

Figure 1: World Map Activity

2.2 SEDP Implementation Details

The sustainable energy design project was part of EngE's participation in the activities of a recently formed Dean's Taskforce on Energy and Sustainability which seeks to coordinate, promote, and position Virginia Tech's educational, research, and outreach efforts to achieve sustainable and secure energy systems [7] in addition to supporting the DLR/NSF project. As mentioned earlier, students in groups of 3-4 were presented with a comprehensive design assignment document during the 5th week of semester. This document was posted on the main Blackboard site and included an introduction to the project, key learning objectives, the design assignment, design specifications, project instructions and deadlines for all project deliverables. In replacement of a standard set of materials, given in previous semesters [8], the students were allowed to spend up to $10 per team for the project. The students were asked to design and construct a "promotional invention" that promoted awareness of a renewable energy source. Each team was assigned one of four renewable energy topics (namely, *hydropower, solar, wind, and biomass)* by their workshop instructor. They were instructed to assume that the audience was the general public, who may have limited knowledge of renewable energy sources. The following parameters were to be considered in the design solution:

-It should be functional, safe, and interesting.

-It must highlight one or more key components of a renewable energy source. For example (but not limited to) the collection of solar power, the conversion of hydropower to mechanical work, the potential for wind power to create electricity, etc.

-It should strive to educate and entertain as well as generate further inquiry and interest in renewable energy sources.

-It should aim to have broad appeal, across gender, age, race, and nationality.

The SEDP included a series of individual and team assignments to be completed during the six week long project. These assignments were developed to guide the students through key stages of engineering design process and to provide sufficient feedback from the instructor, see Table 1.

Table 1: SEDP Individual and Team Assignments

Grade	Assignment	Due date
15%	Individual Research Paper and Proposal	Workshop 7
10%	Team Research and Proposal Paper	Workshop 8
10%	Individual Sketch of Group Design	Workshop 8
5%	Team Prototype	Workshop 10
10%	Team Log	Workshop 11
10%	Team Demo Workshop	Workshop 11
40%	Team Final Report	Workshop 11

Note: Each workshop took place during a corresponding week of the semester. For example: Workshop 7 took place during Week 7 of the semester.

The "Individual Research Paper and Proposal" required the students to individually research their team's assigned renewable energy topic as well as major benefits and trade-offs and to discuss potential solutions to the design assignment. The following week the student teams were required to submit a summary of their team's research and potential solutions to the design assignment, along with an individual sketch of one of these solutions. Teams received feedback from the workshop instructors on these graded assignments, but were allowed to redefine their design solution if necessary. Students were requested to bring a constructed "prototype" of their design to workshop 10 where they received feedback from classmates and instructors. The final report was collected on the 11th week of the semester, following a demonstration of their final design to the class and workshop instructor. Each student was responsible for maintaining a record, or team log, of their team's meetings which was also collected along with the final report. A multi-layered selection process was used by the course and workshop instructors to select the 17 semi-finalists for the design showcase from the approximately 300 total designs, beginning with 1 "best" design from each workshop section. The design showcase was held during on an evening in the 13th week of the semester, and a panel of 5 faculty and graduate student judges, who were not directly involved with the course, were selected for their expertise and experiences with engineering design to select three finalists. The three winning designs, "Best in Show" and two "Honorable Mention" were chosen according to the design criteria stated in the design assignment.

Given the open-ended nature of the assignment, the student's final designs reflected a diverse range of potential solutions. These designs ranged from playful to practical to conceptual. A few examples included a solar powered drink mixer, a solar powered cell phone charger, a wind powered light tower, a hydro-powered drawbridge, and a

submerged bottom feeding hydropower plant. The modest expense constraint inspired further resourcefulness for many teams who incorporated a variety of recycled materials in their designs including scrap metals, springs from broken staplers, gears from discarded toys, plastic bottles and corrugated cardboard.

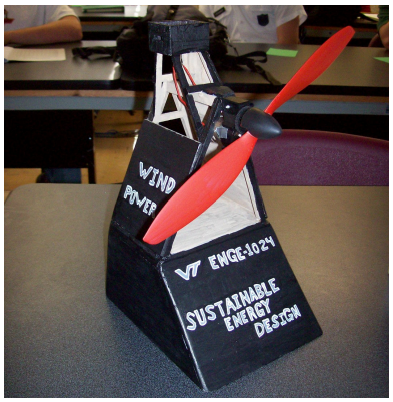

Figure 2: *Student Design of a Wind Powered LED Unit*

Figure 3: *Semi-finalists and Judge at the Design Showcase*

2.3 Pre- and Post-Tests

A twenty item pre- and post-test survey was developed to assess gains in students' knowledge of renewable energy and attitudes on teamwork and engineering design. It contained twelve multiple choice general knowledge questions concerning renewable energy which were selected from several on-line quiz sites [9], for example:

> Which is currently the leading renewable energy source used by electric utilities to generate electric power?
>
> 1) Solar 3) Hydro (water)
> 2) Wind 4) Biomass (wood, waste, alcohol fuels)

It also contained five Likert scale questions regarding the student's interest in renewable energy sources, level of importance of the topic, preference for teamwork and value placed on study of the engineering design process. One open-ended question was included in the pre-test where students were asked to identify skills they expected to improve by the end of the design project. The question was modified in the post-test; students were asked to identify skills they felt had improved due to participation in the design project. Additionally, two multiple choice questions concerning orthographic projections of an isometric drawing were included. Prior to administering to students, the survey was reviewed by ten workshop instructors and three faculty instructors for content validity.

Five workshop sections were selected to participate in the pre- and post-test survey based on meeting times and availability of the investigators who supervised the tests. One hundred and twelve students, identified as Groups 1 through 5 in Tables 2 thru 4, completed the pre- and post-test surveys. Four workshop instructors assisted in administering the tests to their students. Three of the instructors led 1 workshop section

each, Group 1, 2 and 3, and 1 instructor led 2 sections, Group 4 and 5. Four of the workshop sections, Group 1, 2, 3, and 4, all met on a common day and time. One workshop section was unique in that all the students and the workshop instructor were female. The other workshop sections were mixed-gender, although gender data was not collected on the surveys and was not the primary focus of this study.

The pre-test was given at the beginning of the workshop sessions on the 4th week, one week before the assignment of SEDP, and students were allowed up to 10 minutes to complete. The post-test was administered on week 12, one week after the final design was completed and the final reports had been submitted. The students were informed by the authors or their workshop leader, prior to each survey, that their participation was voluntary and anonymous. They were further reassured that their scores on the survey would not affect their grade in the course, nor were the test questions reflective of future exam questions in the course.

2.4 Results of Pre- and Post-test Survey Analysis

SPSS (V 15) was used to perform descriptive statistics to determine the mean scores on both the pre- and post-test results, see Table 2. A paired sample t-test analysis was also run on the pre- and post-test to determine students' gains in the general knowledge of renewable energy, see Table 3. The results indicate significant ($p < 0.05$) gains in 4 groups, Group 1, Group 2, Group 3 and Group 4 between the pre- and post-test. Group 5 did not have significant gains ($p > 0.05$) in general knowledge between the pre- and post-test. Several students in Group 5 did not complete the pre-test due to timing issues (i.e. there was insufficient time during the workshop due to other planned activities).

Table 2: Pre- and Post-test Mean Scores

Group		N	Mean	SD
1	pretest	26	52.58	12.297
	posttest	26	59.81	10.385
2	pretest	25	57.56	10.377
	posttest	25	69.72	9.775
3	pretest	22	59.14	15.075
	posttest	22	69.41	9.525
4	pretest	24	56.13	12.326
	posttest	24	71.38	11.776
5	pretest	15	54.00	13.400
	posttest	15	63.93	13.008

Table 3 : General Knowledge of Renewable Energy, Paired Sample T-test of 5 Groups

Group			Paired differences		t	df	Sig. (2-tailed)
			M	SD			
1	Pair 1	pretest - posttest	-7.231	15.066	-2.447	25	.022
2	Pair 1	pretest - posttest	-12.160	13.996	-4.344	24	.000
3	Pair 1	pretest - posttest	-10.273	17.841	-2.701	21	.013
4	Pair 1	pretest - posttest	-15.250	16.796	-4.448	23	.000
5	Pair 1	pretest - posttest	-9.933	20.005	-1.923	14	.075 N.S

A paired sample t-test was performed on responses to the five Likert scale questions regarding the student's attitudes on renewable energy and engineering design. Results of this analysis did not indicate significant ($p > 0.05$) differences between the pre- and post-test for 3 of the 5 groups. Two groups, Group4 and Group5, did demonstrate significant ($p < 0.05$) gains between the pre- and post test, see Table 4.

Table 4: Attitudes on Renewable Energy and Engineering Design, Paired Sample T-test of 5 Groups

			Paired difference		t	df	Sig. (2-tailed)
			M	SD			
1	Pair 1	Pretest - Posttest	.277	.995	1.420	25	.168 N.S
2	Pair 1	Pretest - Posttest	.064	.765	.418	24	.680 N.S
3	Pair 1	Pretest - Posttest	.045	.868	.246	21	.808 N.S
4	Pair 1	Pretest - Posttest	.275	.618	2.180	23	.040
5	Pair 1	Pretest - Posttest	.893	1.074	3.221	14	.006

Responses to the one open-ended question on the pre- and post-test regarding students' self-reported improvements in design skills were coded and frequencies are given in Table 5. In the pre-test, students were asked to identify skills they "hoped to improve" by the end of the design project. In the post-test, students were asked to identify skills that "were improved" as a result of the design project. Many students responded with 2 or more skills per survey, other left this question blank. A variety of skills were reported by the students and included teamwork, knowledge of renewable energy, design process, building, communication, critical thinking, sketching, innovation, problem solving, creativity, leadership, reporting, and others. The 3 most frequently identified were teamwork, knowledge and design process. Responses to the pre-test question were speculative on the student's part, and reflect skills they anticipated being improved

during the course of the SEDP. Student responses on the post-test reflect students' perceptions of skills they felt improved during the course of the project. Teamwork was mentioned 45 times in the pre-test, and 55 times in the post-test. Knowledge was mentioned 24 times in the pre-test, but only 7 times in the post-test. Design process, critical thinking, innovation, reporting, researching, building and communication were mentioned more often in the post-test than the pre-test.

Table 5 : Total Response to Open-ended Question Regarding Improvement of Skills

	Pre-test	Post-test
Teamwork	45	55
Knowledge	24	7
Design process	21	22
Building	5	8
Communication	5	7
Critical thinking	8	9
Sketching	9	5
Innovation	2	4
Problem solving	5	4
Creativity	6	3
Leadership	4	2
Reporting	4	8
Researching	4	5

2.5 Focus Group Interview Results

As part of the assessment component of the DLR project, focus groups have been conducted in previous semesters to assess effectiveness of various initiatives taken to meet the goal of DLR project. During 14th week of the semester, focus group interviews were conducted by a Ph.D. student in Psychology department who works at the Academic Assessment of Virginia Tech. Two student groups of 8-10 were prompted to discuss their knowledge of renewable energy prior to the design project and to provide recommendations for future projects. Many students expressed an increased interest and appreciation for the topic, while most had limited formal knowledge on sustainability or renewable energy. References were made regarding the global and societal implications of renewable energy sources. Responses included the following:

"I learned how it is real (bio-diesel) and how it works, and society doesn't embrace it as a whole"

"I realized how some countries are embracing it, like Germany, while others are not."

Several students discussed the research aspects of the project, and a few requested clarifications in future projects between the research and design focus of the project.

"Make the next project less research based"

"Make the project more design based, and graded more heavily on design and creativity in the design."

3. Discussion

Pre- and post-test results of the sustainable energy design project highlight the success of the project in increasing the student's general knowledge of renewable energy. While a main objective of the project was to provide an introduction to the engineering design process, the topic of renewable energy was also introduced but not addressed directly through lecture or assigned reading material. Gains in students' knowledge of renewable energy were assumed to be the result of the students' work on the design project, particularly through the team discussions and research assignments. While many student teams displayed a deeper understanding of renewable energy topics in their final reports, there was very little organized classroom discussion on these topics. Improvements to the SEDP would include a more focused approach to the research assignments and instructor led discussions of the students' findings in both workshop and lecture throughout the length of the project. Also, based on input received from students, they will be allowed to spend $20 on design project material since several students felt extremely constrained by the $10 limit set in fall 2006 SEDP. Students identified the design process and teamwork as the most improved skills on the post-test survey. It was observed throughout the workshop sections that many students' continued to work in these same teams on several in-class and out-of-class assignments throughout the design project and beyond. The perceived benefits of teamwork were also mentioned in the focus group interviews and in exit surveys.

The range of the student's design solutions indicated a diverse assortment of interests, knowledge, skills, and abilities to work productively on a design team. Due to the variety and quality of the design solutions, it was challenging for the instructors and judges to select both the workshop semi-finalists and finalists at the design showcase. Many student teams went beyond the expectations of a first semester engineering design project and were quite creative with their designs. For example, one of the winning teams constructed a bio-fuel pulse jet, which had been built from scrap metal and included specially designed reed valves, which they etched using a process they had researched on-line. Another team designed and built a solar-powered LED water lantern, with a specially designed circuit the team had researched and customized to fit several water bottle covers and to also stay lit for 4-6 hours. Instructor feedback, encouragement and support were integral to the students' progress throughout the SEDP. Improvements in instructor training in facilitating and assessing the design projects is planned in future first semester design projects. For many students the combination of research and an open-ended design assignment presented an additional challenge which requires clarification for future design projects.

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Bibliographic Information

JENNIFER MULLIN is currently a Ph.D. Candidate in the Department of Technology Education at Virginia Polytechnic Institute and State University. She has worked as a graduate assistant in the Department of Engineering Education since fall 2004 and has been instrumental in efforts to reform the first semester general engineering course (EngE 1024) which has included a variety of curricular design, development, implementation, assessment and educational research projects.

JINSOO KIM is a visiting professor in the Department of Engineering Education at Virginia Tech from July 2006 to July 2007. He is a professor in the Department of Technology Education at Korea National University of Education. He is interested in subject-matter education of Technology, Engineering, and Industry. His permanent e-mail address is jskim@knue.ac.kr

VINOD K. LOHANI is an associate professor in the Department of Engineering Education at Virginia Polytechnic Institute and State University (Virginia Tech). He received a Ph.D. in civil engineering from Virginia Tech in 1995. His areas of research include engineering education, international collaboration and hydrology & water resources.

References

[1] Lohani, V.K., Sanders, M., Wildman, T., Connor, J., Mallikarjunan, K., Dillaha, T., Muffo, J., Knott, T.W., Lo, J., Loganthan, G.V., Adel, G., Wolfe, M.L., Goff, R., Gregg, M., Chang, M., Agblevor, F., Vaughn, D., Cundiff, J., Fx, E., Griffin, H., and Magliaro, S. "From BEEVT to DLR NSF Supported Engineering Education Projects at Virginia Tech" *Proc. 2005 ASEE Annual Conference, June 12-15, Portland, Oregon.*

[2] Lo, J., Lohani, V.K., and Griffin, O.H. "Full Implementation of a New Format for Freshman Engineering Course," *Proc. 2006 ASEE Annual Conference, June 18-21, Chicago, Illinois.*

[3] Lohani, V.K., Lo, J., Mullin, J., Muffo, J., Backert, R., and Griffin, H. "Transformation of a freshman Year Engineering Course," *Proc. 2005 International Conference on Engineering Education, July 25-29, Gilwice, Poland.*

[4] Robson, V., Muffo, J., and Lohani, V. "The Little Engineer That Could: Background, Attitudinal, and Academic Predictors of Student Success," poster presented at *Association for Institutional Research Annual Forum*, Chicago, IL, May, 2006.

[5] CIA World Factbook, https://www.cia.gov/cia/publications/factbook/index.html.

[6] Holtzapple, M.T., Reece, W.D. (2004) Concepts in Engineering. New York, NY: McGraw-Hill.

[7] Dean's Taskforce on Energy and Sustainability, http://www.research.vt.edu/energy/index.html

[8] Mullin, J., Lohani, V. K., Lo, J., Griffin, O. H. "Sustainable Development Design Project for Engineering Freshmen." *Proc. 2006 ASEE Annual Conference, June 18-21, Chicago, Illinois.*

[9] Survey Questions retrieved and modified from http://news.bbc.co.uk/1/hi/sci/tech/3996689.stm, http://www.eia.doe.gov/kids/energy_fungames/quiz/index.html, and http://www.quiz-tree.com/Energy_main.html