AC 2012-4108: MULTI-DISCIPLINARY SUSTAINABLE SENIOR DESIGN PROJECT: DESIGN OF A CAMPUS BIODIESEL REFINERY

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Multi-Disciplinary Sustainable Senior Design Project: Design of a Campus Biodiesel Refinery

Abstract

Engineering Sustainable Engineers, a program sponsored by National Science Foundation, was designed to improve undergraduate student knowledge of and competency in addressing sustainability issues in engineering design and problem solving. One of the key program elements involved a multi-disciplinary senior design project focusing on sustainability. Students from the three participating University of Texas at Arlington departments (Civil Engineering, Industrial Engineering, and Electrical Engineering) collaborated to design a biodiesel production refinery for the campus.

Students designed a refinery that could use waste vegetable oil from campus food service as feedstock to produce 100 gallons per week of biodiesel for campus shuttle buses and generators. Microreactors that facilitate rapid mixing of input waste oil, potassium hydroxide, and methanol were designed by Dr. Brian Dennis of the Mechanical Engineering Department. Civil engineering students were charged with designing other refinery system components, including feed lines, tanks, pumps, and heaters. Highlights of the student design included:

- A dry wash system for the biodiesel to reduce water use and labor requirements.
- Use of the glycerol byproduct to make high quality soap.
- A distillation system for recovery and re-use of methanol.

Civil Engineering students also assessed the environmental impact of switching buses and generators to biodiesel. Industrial Engineering students designed and optimized the facility layout and designed operating procedures for refinery use. Electrical Engineering students designed required sensors, actuators and controls.

Students participating in the multidisciplinary design project were surveyed regarding the multidisciplinary team experience to determine whether the project increased their knowledge of and competency in addressing sustainability issues in engineering design, as well as whether the experience increased their ability to function successfully on multi-disciplinary teams. The paper will present survey results, as well as lessons that faculty learned related to future multi-disciplinary design projects.

Introduction

Sustainability has been identified as one of the global grand challenges of the 21st century. In order for future generations to enjoy a satisfactory quality of life, the current generation must find ways to meet humanity's needs for energy, shelter, food and water in ways that are environmentally, economically, and socially sustainable.

Sustainable engineering may be defined as engineering for human development that meets the needs of the present without compromising the ability of future generations to meet their own needs.[1] Due to population growth and expanded global development, the next generation of future generations to meet their own needs.[1] Due to population growth and expanded global development, the next generation of engineers must be able to design with fewer resources for a wider variety and greater number of end users.[2] According to National Academy of Engineering (NAE) President Charles M. Vest, macroscale issues of great societal importance, like energy, water, and sustainability, will dominate 21st century engineering.[3] According to the NAE report *The Engineer of 2020*, engineers of the future must gain a holistic understanding of sustainable economic growth and development, in order to solve society's pressing environmental problems.[4]

The University of Texas at Arlington has created the Engineering Sustainable Engineers program with support from the National Science Foundation to educate undergraduate engineering students about sustainable engineering, and specifically to improve their knowledge of and competency in addressing sustainability issues in engineering design and problem solving. The program involves collaboration among faculty in Civil, Industrial, and Mechanical Engineering. Program elements include:

1. Sustainability Learning Modules, incorporated into 17 undergraduate engineering classes,
2. Multidisciplinary Senior Design Project, and
3. Sustainable Engineering Internships.

The program components, taken collectively, are designed to expose engineering students repeatedly to sustainability concepts during their undergraduate education. Components 1 and 3 are discussed elsewhere.[5-9] This paper discusses Component 2, Multidisciplinary Senior Design Project.

According to the National Academy of Engineering report *Educating the Engineer of 2020*, it is important to introduce interdisciplinary learning into the undergraduate curriculum.[10] In the future, interdisciplinarity will be critical to solving complex engineering problems.[4] The multifaceted, multidisciplinary challenges of sustainability can introduce students to approaches to solving the complex, interdependent, global problems that engineers increasingly face.

Research Questions

The research described here aimed to answer the following questions:

1. Does participation in a multi-disciplinary sustainable senior design project increase students'
   - knowledge of sustainability concepts?
   - ability to recognize impacts of engineering projects/designs on sustainability?
   - ability to propose mitigation strategies for reducing negative impacts?
   - ability to evaluate potential engineering solutions based on sustainability?

2. Does participation in a multi-disciplinary sustainable senior design project increase students' ability to work effectively in multidisciplinary teams?

Methods

Methods for Coordinating with Instructors. Before the Spring 2010 semester started, we contacted the instructors of the senior design project courses in Civil, Industrial, and Electrical Engineering about allowing students to participate in the multi-disciplinary sustainable design project. The IE instructor was a project Co-PI, and was thus committed to the multi-disciplinary project. The CE and EE instructors were initially skeptical about this multi-disciplinary project, which was very different from projects traditionally assigned in those departments, meeting their interpretation of ABET requirements. After a meeting among the project PIs, the biodiesel reactor team representatives, and the senior design course instructors, the CE instructor agreed to recommend 3 students to participate in the project, and the EE instructor chose not to participate.

The project being part of an NSF grant likely provided critical encouragement for the CE instructor to participate. Several of the NSF Co-PIs have recently submitted a proposal to a different agency for a small grant ($15,000) to support another multi-disciplinary sustainable design project. We believe that even a small grant will provide critical impetus to overcome potential faculty resistance. Senior project course instructors are more likely to assent to a request stating, "We need your help in implementing this funded project," as opposed to, "We have a nice idea we would like you to try

Methods for Recruiting Student Teams. Three Civil and three Industrial Engineering students who were enrolled in their department's respective senior design project courses were chosen for the multi-disciplinary sustainable design project by the senior design course instructors. In the case of Industrial Engineering, students wishing to participate submitted an application, and they were chosen based on their interest in sustainability issues, and their potential for producing a high-quality design. In CE, prospective students complete survey forms prior to senior project and the students for this project were handpicked based on their interests and capabilities.

Since the EE design project course instructor had chosen not to participate, the co-PI from EE recruited 3 undergraduate and graduate EE students to voluntarily participate in the project.

Development of Project Work Scope. The group of nine students, three from each department, was tasked with designing a biodiesel refinery for UT Arlington. Waste vegetable oil from campus food service was to be used as feedstock to produce 100 gallons per week of biodiesel for campus shuttle buses and generators. During a previous project, Dr. Brian Dennis, Mechanical Engineering, designed the micro-reactors (shown in Figure 1) that facilitate rapid mixing of input waste oil, potassium hydroxide, and methanol. Students now needed to design all other refinery system components as follows:

- Civil Engineering students were to design feed lines, tanks, pumps, and heaters, and to assess the environmental impact of switching buses and generators to biodiesel.
- Industrial Engineering students were to design and optimize the facility layout and design operating procedures for refinery use.
- Electrical Engineering students were to design required sensors, actuators and controls.

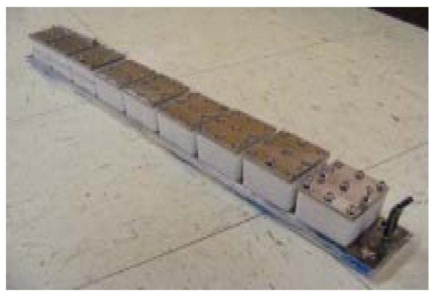

Figure 1. Biodiesel microreactors

At the beginning of the semester, each student group was given an initial work scope with tasks to be completed and design parameters to be specified. Students in each group divided the task list among themselves. Each student then submitted a proposal that included a list of tasks to be performed and project schedule. The initial tasks were modified as necessary due to changes as the design progressed. For example, the initial work scope contained a task "Design a washing, drying, and storage system for biodiesel methyl esters." Wash system parameters to specify included wash water flow rate and water cleaning/reuse system. In the course of conducting research on-line, the design team found a dry wash system, which eliminated the need for water washing altogether. The dry wash system was chosen, and the design parameters specified were modified accordingly.

Team Coordination. At the semester outset, a weekly meeting was set up, involving the entire student group and the faculty advisors (one from CE, one from IE, and one from EE, who were Co-PIs on the NSF project). This meeting was designed to facilitate communication among the 3 engineering disciplines involved.

Each of the three student groups then met on its own as needed during the week. In the case of CE, the faculty member met with the students each week. At this meeting, students reported on their progress during the preceding week. These meetings were useful in making sure that progress was steady; otherwise, students can procrastinate without regular due-dates.

Formal Methods of Providing Feedback to Students. CE students submitted a mid-semester report to the senior design project course instructor, which focused on alternatives analysis. The students also gave a mid-semester oral presentation, describing the rationale for the decisions they had made thus far in the project. This mid-semester deadline was useful in ensuring that students made a reasonable amount of progress by mid-semester. IE students submitted regular progress reports to their senior design project course instructor as well. Regular feedback was important given the short timeline available for design completion.

CE and IE students also submitted final project reports, and gave presentations to department faculty and advisory board members from government and industry. Faculty and advisory board members provided verbal and written feedback to student teams.

Methods for Assessing Project Effectiveness. Students participating in the multidisciplinary design project were surveyed to assess whether the project increased students' knowledge of sustainability concepts, ability to recognize impacts of engineering projects/designs on sustainability, and ability to propose mitigation strategies for reducing negative impacts, as well as whether the project increased students' ability to work effectively in multidisciplinary teams.

Results and Discussion

Resulting Design. Fig. 2 shows the process diagram that resulted from the student work. Highlights of the design included:

- A dry wash system for the biodiesel to reduce water use and labor requirements.
- Use of the glycerol byproduct to make high quality soap for use on campus.
- A distillation system for recovery and re-use of methanol.

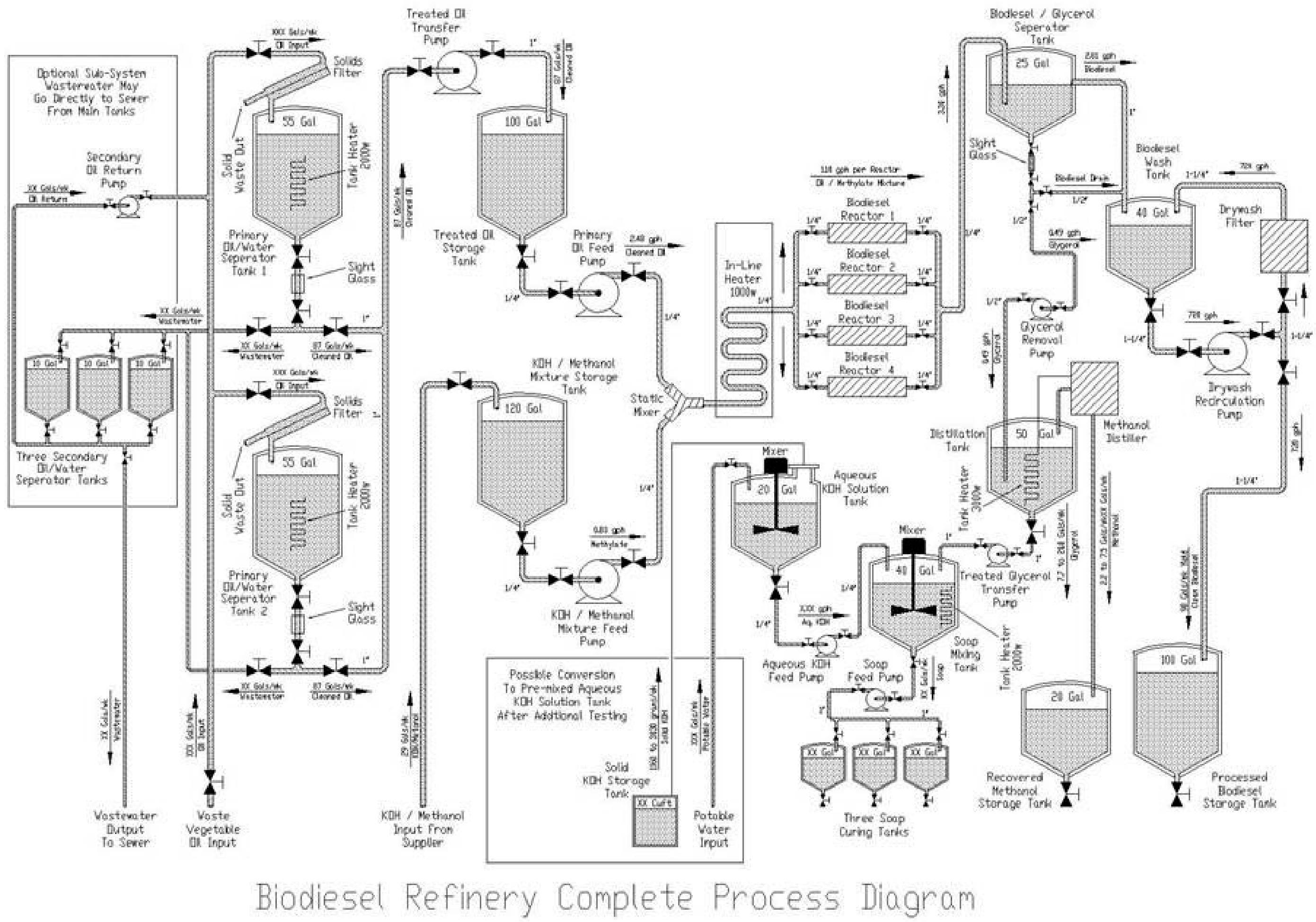

Figure 2. Biodiesel Refinery Complete Process Diagram

The IE students worked closely with CE and EE students to develop a workable layout, basic material handling and operations procedures to be used after the refinery is constructed. These operations procedures included set up times, run times, batch sizes, labor requirements, etc. In addition, the IE students developed project management timelines and lifecycle cost models to ensure minimum cycle time and reasonable return on investment for the construction and implementation of the biodiesel refinery. Views of the refinery layout developed by the IE students are shown in Figure 3.

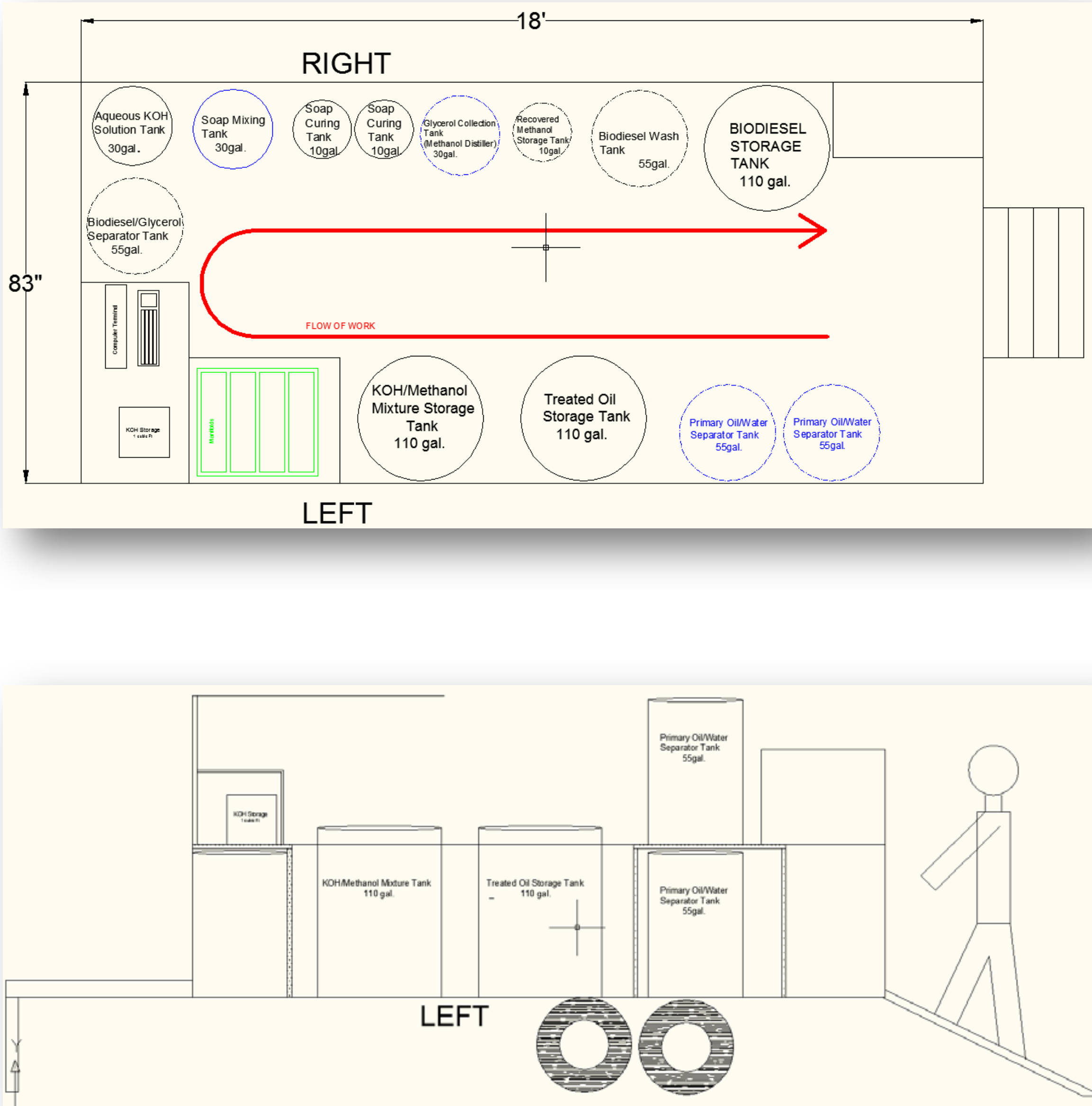

Figure 3. Refinery Layout Developed by IE Students (side view at bottom)

During the spring, the undergraduate students had to assume certain values in their design. During the summer, graduate student ran subsequent lab experiments to obtain actual values (e.g., the University Center waste cooking oil viscosity).

At this point, the refinery has not yet been built at UT Arlington. Safety concerns raised by the Environmental Health and Safety Office need to be addressed, and the design must be finalized and sealed by either a university professor licensed as a professional engineer or an engineering firm contracted by the university.

Project Implementation Successes and Issues. The CE and IE students, who were hand-picked by faculty turned out to be excellent choices because they worked very independently with minimal supervision from faculty. The EE students, who were volunteers, attended project meetings and provided technical advice, but did not produce a final report, as the other two groups did. Understandably, participation from the EE student volunteers was not nearly as even or extensive as that from students actually enrolled in a senior design project course.

Listening to the students try to communicate across disciplinary lines highlighted the project's importance in preparing students to deal effectively with multi-disciplinary projects they may encounter in the workplace. Unfortunately, finding a meeting time which accommodated all student schedules proved difficult. The time chosen meant that IE students had to leave early to attend class.

One coordination issue that arose was the need for one group to have information from another group in order to proceed with their design. For example, the industrial engineering group needed a list of tanks and their dimensions in order to do the facility layout. Early in the semester, the teams identified these critical pieces of information that needed to be transferred among groups, and created a schedule of due dates. In some cases, however, groups fell behind, forcing other groups to wait for information. In future projects, strategies need to be developed in advance that aide the participants in recognizing the importance of meeting critical deliverables for other team members; for example, penalties could be assigned for missing due dates or projects could be staged across multiple semesters.

Another issue that arose was vendors appeared reluctant to give price quotes to students, who were not actually going to be purchasing the parts/materials. We are still in search of a good solution to this problem. Having faculty call for pricing information is one potential solution, but faculty time is typically already stretched thin. Alternatively, multiple design alternatives could be developed with the pricing information being included when selecting between the alternatives at the point of final implementation.

Design Project Assessment. Participating student survey results are provided in Table 1.

Table 1. Student Surveys – Biodiesel Refinery Design Project

	Question	**To a great extent**	**To a moderate extent**	**To a small extent**	**Not at all**
1	The biodiesel design project increased my ability to explain sustainability concepts and terminology.	1 25%	2 50%	1 25%	0 0%
2	The biodiesel design project increased my ability to recognize impacts of engineering projects/designs on sustainability.	3 75%	1 25%	0 0	0 0
3	The biodiesel design project increased my ability to identify ways to mitigate potential negative impacts on sustainability.	2 50%	0 0	2 50%	0 0
4	The biodiesel design project increased my ability to evaluate potential engineering solutions based on sustainability.	0 0	4 100%	0 0	0 0
5	The biodiesel design project increased my ability to work effectively in multidisciplinary teams.	0 0	2 50%	1 25%	1 25%
	Question	**Strongly Agree**	**Agree**	**Disagree**	**Strongly Disagree**
6	Participation in the biodiesel refinery project will make me more likely to consider sustainable design options in my future career.	0 0%	4 100%	0 0%	0 0%
7	I would recommend future students to participate in **sustainable** engineering senior design projects.	0 0%	4 100%	0 0%	0 0%
8	I would recommend future students to participate in **multidisciplinary** engineering senior design projects.	2 50%	0 0%	2 50%	0 0%
TOTAL		**8** **25.0%**	**17** **53.1%**	**6** **18.8%**	**1** **3.1%**

Student responses to short-answer survey questions are listed below.

What was the best aspect of the sustainable senior design project?

- The best aspect of the project was knowing that it was an actual real world situation that has the possibility of being implemented based on our research. Some projects are simply book problems that seem to have little practical use. This project gave motivation to research.
- It was interesting to see it (somehow) come together and see the work of the other engineering students and what they came up with. Also I was able to learn a lot about biodiesel and sustainability, and the details of running a refinery.
- Learning how to think on my feet. I knew very little about the biodiesel-making process, and what I know was on a layman level. I had to research while working toward the overall goal of the project, which presented quite a challenge. I am definitely a harder worker and more confident in my abilities after enduring such a project. I am pleased with the project's intent to work as a team.
- The end ☺. Seriously, the opportunity to participate in a unique and interesting project.

What aspect of the biodiesel refinery senior design project needs the most improvement, if it were to be offered again?

- There were many times when we felt a bit "lost" with no one person to turn to for a clear understanding of what we were to do.
- For me it would be better communication and more engaging and commitment from the group as a whole. It felt like each group was just trying to fill their own agenda and do "their" part of the project.
- Also being more flexible making sure that everybody can attend the meetings (even though it's hard to accommodate 12 people's schedule); that way, everybody can participate and be able to give their "2 cents."
- A finalized work scope in the beginning. That the IE group have a schedule that would better suit our (CE's) deadlines. Coordinating with IE's was a challenge, because their work hinged upon our work, which didn't get finished until late in the semester.
- Much more research data on the micro-reactors should be available. We had to make too many assumptions due to a lack of available data.

As indicated by the survey results, participation in a multi-disciplinary sustainable senior design project was effective in increasing students'

- knowledge of sustainability concepts,
- ability to recognize impacts of engineering projects/designs on sustainability,
- ability to propose mitigation strategies for reducing negative impacts,
- ability to evaluate potential engineering solutions based on sustainability.

Students reported that participation in the project increased their abilities in the 4 areas listed above from a small to a great extent. Students also agreed that the design project would make them more likely to consider sustainable design options in their future career, although they did not strongly agree, which was somewhat disappointing.

Based on student surveys, participation in this multi-disciplinary sustainable senior design project was only somewhat effective in increasing students' ability to work effectively in multidisciplinary teams. Three students did report that the project increased their ability to work in multi-disciplinary teams from a small to a moderate extent; however, one student reported that the project did not increase his/her ability at all. The lackluster survey responses in this area were likely due to the fact that the IE students had a class 30 min. after the start of the scheduled weekly meeting time, which made it difficult for them to attend the weekly meeting. In future projects, we will work harder to find a weekly meeting time that accommodates everyone, or at least representatives from each discipline.

Conclusions

- Participation in a multi-disciplinary sustainable senior design project was effective in increasing students' knowledge of sustainability concepts, ability to recognize impacts of engineering projects/designs on sustainability, ability to propose mitigation strategies for reducing negative impacts, and ability to evaluate potential engineering solutions based on sustainability, as measured by survey results.

- Participation in this multi-disciplinary sustainable senior design project was only somewhat effective in increasing students' ability to work effectively in multidisciplinary teams. Finding an inter-group meeting time to accommodate students from all departments is critical in achieving the goal of enhancing student ability to work effectively on multi-disciplinary teams.

- Buy-in from senior design project course instructors is critical. In our case, due to a decision by the EE instructor not to be involved, participation from the EE student volunteers was not nearly as extensive as that from students actually enrolled in a senior design project course.

- Some resistance from senior project course instructors to changing the traditional way of doing things may be expected. Having funding to support the project may help counter this resistance; information about the value of preparing students for the many multi-disciplinary projects they will likely encounter in the real world may also be helpful. Regardless, fostering a cooperative and collaborative relationship with the course instructor appears to have a positive impact on their involvement. As the instructors' involvement moves to earlier stages of the project's development, all participants have greater flexibility to meet their respective goals.

- Weekly inter- (between disciplines/departments) and intra-group (within discipline/department) meetings were useful in keeping students progressing.

- A schedule of due dates for critical pieces of information to be transferred among departmental groups was helpful; strategies for ensuring that these deadlines were/could be achieved must be established (e.g. penalties for missing due dates and/or more effective staging of project tasks).

- Two semesters would be needed for students to actually implement their design.

Acknowledgments

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