AC 2011-314: ENGINEERING SUSTAINABLE CIVIL ENGINEERS

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Engineering Sustainable Civil Engineers

Abstract

Engineering Sustainable Engineers (ESE) was designed to infuse curricula in the Departments of Civil (CE), Industrial and Mechanical Engineering at the University of Texas at Arlington with sustainability. The overarching aim is to improve student knowledge of and competency in addressing sustainability issues in engineering design and problem solving. Three key program elements are (1) sustainability learning modules, (2) multidisciplinary senior design project and (3) quality sustainable engineering internship. This paper describes the implementation and preliminary assessment of the Civil Engineering (CE) components of the project. The targeted courses are required for all CE students and span from freshman through senior year. The courses are common to many civil engineering curricula nationwide. The program components address, to varying degrees, all facets of sustainability – economic, social and environmental impacts (triple bottom line); however this paper addresses primarily the environmental aspects.

Sustainability course modules were implemented in Spring 2010 with pre-tests and post-tests administered for each. Additionally, students completed a self-assessment of their learning in each course. With one exception, self-assessment results indicated that a majority of students (> 50%) were "strongly confident" or "confident" of their ability to address each of the learning objectives in each module. Pre-test and post-test data are being compared to the students' self assessments. The modules have been revised to further improve this outcome and were implemented and evaluated again in Fall 2010. The final modules will be faculty-ready "grab-and-go" curricular units that include objectives, lecture and reading materials, active learning activities, homework problems and assessment tools.

In Spring 2010, civil and industrial engineering seniors collaborated on a project to design a portable biodiesel production refinery for the campus. The refinery will use waste vegetable oil from campus dining facilities as feedstock to be transformed into biodiesel for use by the university's shuttle busses and generators. While the students pointed out challenges faced in completing the project (e.g. coordinating schedules among multiple groups with different deadlines), they were generally positive in their overall responses regarding the experience. All of the CE students involved agreed that participation in the project made them more likely to consider sustainable design options as practicing engineers, and all indicated that they would recommend the experience for other students.

Surveys were administered to several companies in Spring 2010 to determine their interest in hosting an intern, their commitment to sustainability and to evaluate the quality of internship experience for prospective interns. Four companies hosted quality sustainability internships during Summer 2010, three of which were held by CE students. The internship experiences were evaluated by faculty, company representatives and students through student presentations and surveys. With the exception of one response for one objective, all students indicated that the internship experience improved their knowledge of and competency in addressing sustainability issues in engineering design. While company responses were mixed regarding the quantity and

quality of internship candidates, survey results indicate 100% satisfaction with the internship program; and all company representatives are interested in participating in the future.

Project evaluation is on-going. Assessment results are being used to modify content and implementation strategies as needed.

Introduction

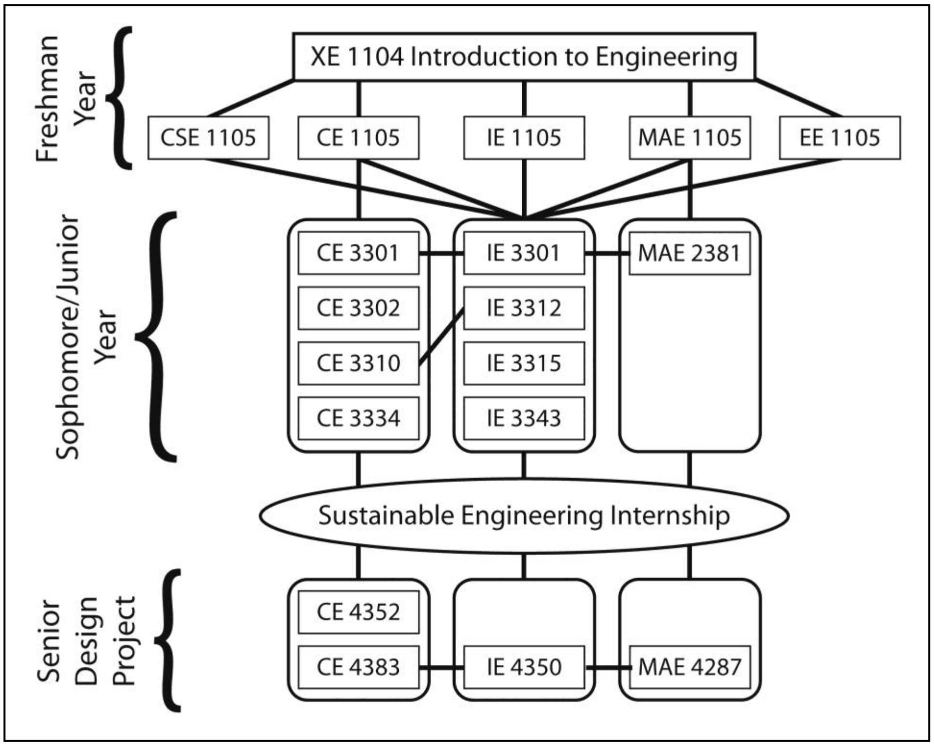
While there are many definitions for sustainability and sustainable engineering, most have two common elements. Those elements have been aptly summarized by the World Commission on Environment and Development, which defines sustainable engineering as engineering for human development that meets the needs 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 engineers must be able to design with fewer resources for a wider variety and greater number of end users.[2]

> "…engineers of the future will be asked to use the earth's resources more efficiently and produce less waste, while at the same time satisfying an ever-increasing demand for goods and services. To prepare for such challenges, engineers will need to understand the impact of their decisions on built and natural systems, and must be adept at working closely with planners, decision makers, and the general public. Sustainable Engineering emphasizes these and related issues."[3]

Sustainable engineering addresses the challenges of sustainability by adapting existing technologies and developing new ones. Engineers have the opportunity to reinvent how we produce and use energy, how we move people and goods, and how we meet basic human needs for food, shelter, water, sanitation, and clean air.[4] 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.[5] The NAE report *The Engineer of 2020* states that engineers of the future must gain a holistic understanding of sustainable economic growth and development in order to solve society's pressing environmental problems.[6]

To address these challenges, faculty from three departments within the College of Engineering at the University of Texas at Arlington (UTA) received funding through the National Science Foundation's Innovations in Engineering Education, Curriculum, and Infrastructure (IEECI) program to support the project Engineering Sustainable Engineers (ESE). ESE was designed to integrate sustainability concepts throughout curricula in the Departments of Civil (CE), Industrial (IE) and Mechanical Engineering (ME) at UTA and to reinforce those concepts at every level of matriculation (Figure 1). The overarching aim is to improve student knowledge of and competency in addressing sustainability issues in engineering design and problem solving. This paper describes the implementation and preliminary assessment of the Civil Engineering (CE) components of the project.

Figure 1. Integrating and Reinforcing Sustainability throughout Engineering Curricula



Program Description

Eight courses in the civil engineering curriculum were chosen for ESE implementation. The targeted courses are required for all CE students and span from freshman through senior year. Additionally, the courses are common to many civil engineering curricula; therefore project results should have broad appeal to civil engineering programs nationwide. The targeted courses are:

- CE 1104 – Introduction to Engineering
- CE 1105 – Introduction to Civil Engineering
- CE 3301 – Stochastic Models
- CE 3302 – Transportation Engineering
- CE 3310 – Construction Value Engineering
- CE 3334 – Principles of Environmental Engineering and Science
- CE 4352 – Professional Practice
- CE 4383 – Senior Project

The expected outcomes of the project are to (1) increase students' knowledge of sustainability concepts, (2) increase students' ability to analyze project components for sustainability, (3) increase students' ability to propose mitigation strategies for reducing negative impacts and (4) provide opportunities for students to apply their knowledge of sustainability to real-world projects and problems.

Three key program components are being implemented to achieve these outcomes:

- Sustainability Learning Modules
- Multidisciplinary Senior Design Project and
- Quality Sustainable Engineering Internship

Each program component addresses specific learning objectives/student outcomes associated with the outcomes described above. The learning objectives (Table 1) reflect increased expectations and levels of complexity as students attain higher academic classifications and matriculation levels. The key components are described in the sections that follow.

Table 1. Engineering sustainable Engineers Learning Objectives

Learning Objective/Student Outcome	Course Level(s)/Experiences
Explain sustainability concepts and terminology	Freshman and Beyond
Identify components of sustainability and impact metrics	Freshman and Beyond
Examine and prioritize project impacts on sustainability	Junior and Senior
Recognize engineering solution impacts on sustainability and impact metrics	Junior, Senior and Internship
Identify mitigation strategies for reducing negative impacts on sustainability	Junior and Senior
Demonstrate and develop oral and written communication skills	Internship
Perform a comprehensive evaluation of candidate engineering solutions that includes sustainability	Senior and Internship

Each module was developed to meet one or more of the outcomes in Table 1. These outcomes, to varying degrees, address not only the technical and environmental aspects of sustainability, but the social and economic aspects as well. The following sections describe the rationale for the program and brief descriptions of each of the learning modules.

Rationale

ESE is designed to expose engineering students repeatedly to sustainability concepts during their undergraduate education. Integrating sustainability modules into existing courses was the chosen approach because it is a more conservative approach than designing entirely new courses or majors. It is tractable, however, as a first step. Allensby argues that inserting appropriate educational modules into existing classes, especially capstone practice courses, is a way to make some progress in teaching sustainable engineering, given the challenges of an already full undergraduate curriculum.[7] Further, integrating sustainability modules into required courses will ensure that all undergraduates are exposed to sustainability concepts; new courses or majors may not reach all engineering students. The approach of integrating modules into existing courses is similar to that chosen by Rowan University to integrate sustainability across the engineering curriculum.[8]

Sustainability Learning Modules

"Grab-and-go" ready modules have been developed to facilitate implementation by other faculty members, thereby increasing the transferability of the course innovations developed as a part of ESE. The modules contain everything a faculty member needs to present a lecture, lead discussions, conduct active learning in-class activities, assign homework exercises, and assess student learning. The focus of the individual modules was decided by project team members in conjunction with faculty who teach the courses. With the exception of the freshman courses, the topics chosen were those that would be relevant for the subject area, and in some cases were extensions of material that was already being taught. Modules include the following components:

- Unit objectives written in behavioral language (things students should be able to do by the end of the unit);
- PowerPoint lecture slides introducing the concept of sustainable engineering, including sustainable engineering case studies;
- Reading materials and visual aids, to include textbooks, scientific articles, patents, web-links, applets and animated simulations;
- Discussion questions and several active learning activities to promote deeper understanding of key concepts and higher order thinking skills (application, analysis, evaluation);
- Homework practice problems/exercises, which include application of sustainable engineering concepts, analysis and evaluation of alternatives based on sustainability metrics, and open-ended problems; and
- Assessment tools (test questions), with the exception of the Senior Project module, since testing is not typically conducted in that course.

Use of the final modules will require minimal preparation time, which will further facilitate their use. Module descriptions are provided in the paragraphs that follow.

"Sustainability: What does it Mean for Engineers?" Module for Introduction to Engineering Module. This module provides an overview of sustainable engineering concepts, including definitions of sustainable development; significance; environmental, economic, and social impacts (triple bottom line); the importance of engineering in sustainable development; sustainability indicators/metrics; examples of sustainable engineering design; and life cycle assessment. These topics were chosen to give students an understanding of fundamental concepts associated with sustainability and draw attention to the need to address the triple bottom line as opposed to the typical emphasis on economic bottom line. It contains a one-class-period PowerPoint lecture, reading materials, discussion questions/active learning activities, homework exercises, and assessment tools. Because Introduction to Engineering is a course that is required of all engineering majors at UTA, and is taught in multidisciplinary sections, the material presented is general in nature.

"Sustainability: What does it Mean for Civil Engineers?" Module for Introduction to Civil Engineering Module. The CE 1105 module was designed to reinforce the concepts presented in the Introduction to Engineering course while introducing an application of the concepts by presenting a case study of sustainable design relevant to civil engineering. An in-class assignment requires students to identify the life cycle stages of civil engineering design/project examples. This is extended to a homework assignment in which students must not only identify the life cycle stages, but also use the Sustainable Design Checklist developed for the Senior Project course (described below) to compare two design alternatives, which were simplified for freshman students, on the basis of sustainable engineering practices. This module requires two class periods – one for the lecture and in-class activities, and another to review the homework assignment.

"Data Issues in Sustainability Studies" Module for Stochastic Models for Civil Engineering. This module was developed by both CE and IE faculty for use in each department's probability/stochastic models course. Designing for sustainability requires information on the impacts of the relevant activities, which translates to the need for data that enables measureable outcomes. Given the variety of outcomes that may be employed to quantify "sustainability," the module asks teams to discuss the relevance of different data sets using a practical example. Students use the information to evaluate the impacts of alternatives using statistical analyses. Identifying appropriate data for the analyses is one of the students' requirements, as is determining how data can and should be collected.

"Is Transportation Sustainable?" Module for Transportation Engineering. This course provides an introduction to transportation engineering where the students learn about planning, design and operation of transportation facilities. The module for this course focuses on examining sustainability impacts associated with transportation planning and facility design. It uses a case study discussion to allow students to practice recognizing sustainable impact issues. The students continue to develop and practice these skills later in the semester by completing homework assignments addressing core concepts in the course.

"Life Cycle Sustainability Economics" Module for Construction and Value Engineering. This course introduces principles of construction engineering and basic engineering economics techniques, such as simple and compound interest calculations, equivalence, present worth, uniform annual cost, rate of return, depreciation, and equipment replacement. Evaluation of engineering alternatives for sustainability requires more than just evaluation of traditional financial information; it needs to include data that enables measureable outcomes. For this module, students are required to recognize that conflicting objectives exist. They must then be able to evaluate and make decisions using multiple criteria for success including net present value, return on investment and costs during the entire project life cycle from "cradle to cradle" so to speak.[9] The proposed module will introduce environmental economics concepts of externalities, valuation of benefits accruing from natural resources/ecosystem services, cost-benefit analysis, and emissions trading systems. This module was jointly developed with IE 3312, Engineering Economic Analysis.

"Waste as a Resource" Module for Principles of Environmental Engineering. This course introduces students to environmental engineering, with emphasis on problem solving related to materials balance, water treatment, wastewater treatment and introductory level air quality parameters. Prior to the implementation of ESE, it provided a general introduction to sustainability, which included a discussion of various definitions of sustainability and their key elements, as well as a discussion of how sustainability may be achieved (e.g. minimizing waste production, life cycle analysis of processes, material selection, etc.). The ESE module builds on this introduction and on the current coverage of solid and hazardous waste regulations to include a module on using waste as a resource. It includes topics such as recycling, composting, and recovering energy from waste. The material is presented in the context of waste management alternatives, evaluating impacts based not only on environmental protection, but rather holding paramount public safety, health and welfare while employing principles of sustainable development to the extent possible, as prescribed by the first Fundamental Canon of the American Society of Civil Engineers' (ASCE's) Code of Ethics.[10]

"Incorporating Sustainability into Alternative Analysis" Module for Professional Practice. This course introduces students to key aspects of their senior design project and fills gaps in the curriculum to prepare the students to become practicing engineers. The module for this course focuses on sustainability in existing projects and evaluating the potential impacts that engineering solutions may have on sustainability.

Senior Project Module and Checklist. The Senior Project module covers sustainable engineering concepts in more depth. In particular, it emphasizes quantifying sustainability indicators/metrics over the lifespan of the product, project, or process using life cycle assessment. The module consists of four parts:

- Review of sustainable engineering concepts. This component is similar to the "Introduction to Engineering" sustainability module.
- Broadening of design alternatives. Through use of examples, the module encourages students to think more broadly in developing alternative solutions.
- Life cycle assessment. Sustainability indicators to be evaluated through life cycle assessment include materials intensity, energy intensity, water consumption, waste and emissions generation, and if possible, land impact.
- Incorporation of life cycle assessment into alternatives analysis. This requires students in Senior Project at UTA to use information about sustainability indicators as criteria in their decision-making matrix, which is typically used to compare alternatives. A senior project decision-making matrix typically includes economic and technical criteria and other non-technical issues, such as constructability and maintainability. To ensure that solutions are sustainable, the matrix also needs to include environmental criteria like those mentioned above.

The ESE project team developed a Sustainable Design Checklist that includes sustainability indicators/metrics of economic, environmental and social impacts. These impacts must be considered in comprehensive spatial (local and regional) and temporal (short- and long-term) contexts. Senior project students use the checklist to evaluate alternatives on the basis of sustainability for each life cycle stage, then for the project as a whole. They are encouraged to continue to use the Sustainable Design Checklist as practicing engineers.

Multidisciplinary Senior Design Project

During Spring 2010, CE and IE students collaborated on a multidisciplinary senior design project focusing on sustainability. The Mechanical Engineering Department joined this project after this component had been implemented; however the design was developed partially under the guidance of an ME faculty member. The team was charged with the task of developing a portable biodiesel production refinery for our campus. One of the requirements was for the refinery to use waste/used vegetable grease from campus dining halls as feedstock to be transformed into biodiesel fuel for use by campus shuttle busses and generators (instead of standard diesel fuel).

The multidisciplinary Senior Project design team worked with UTA's current biodiesel team (chemists and a mechanical engineer) to design the portable biodiesel refinery scoped for the needs of our campus. CE students assessed the environmental impact of switching campus buses and generators to biodiesel fuel and designed a protective structure to house the refinery. IE students designed and optimized the facility layout within the protective structure and designed the operating procedures for refinery use.

Quality Sustainable Engineering Internship

The project team developed a survey that is being used to identify companies likely to provide quality sustainable engineering internships. In order to be considered, companies demonstrate that they incorporate sustainability issues into their design processes. For example, the existence of a comprehensive waste reduction and recycling program at a company would be commendable, but would not necessarily help an intern learn more about sustainable engineering design. Company commitment to sustainable engineering and to hiring and engaging interns in the process was evaluated using the Sustainable Internship Company Survey that was developed as a part of this project. The survey contains questions designed to gauge the quality of internship the companies are likely to provide with regards to sustainability. Sample questions include:

- Does your current internship program expose students to the development of solutions that mitigate potential negative on sustainability?
- Give an example of consideration of sustainability in product design at your firm.
- Why do you think your firm would be a good choice to sponsor a sustainable engineering internship?

The survey was posted on the internet via Survey Monkey software. The project team worked with the College of Engineering Internship Coordinator to identify companies in the Dallas/Fort Worth area that were survey prospects. Those companies were contacted via email with an invitation to complete the survey, with follow-up phone calls as needed. One of the goals of the internship component is to initiate long-term partnerships that will enable the internships to continue.

After the companies were selected, interested students submitted applications describing their interests in sustainability and how they believed they would benefit from the internship.

Each student was required to have a faculty mentor to monitor the internship activities. Students were required to write two reports demonstrating their ability to recognize and prioritize sustainability impacts associated with proposed engineering solutions. At the end of the internships, each student was also required to present one of his/her reports at a seminar with an audience of faculty, other students and practitioners.

Project Implementation and Assessment

Sustainability Learning Modules

Most of the modules for the CE courses were first implemented in Spring 2010 (Table 2). Unit objectives were developed for all modules; PowerPoint lecture slides and assessment tools were developed for the modules that were implemented in Spring 2010. During Fall 2010, previously-developed modules were revised to make them more complete. Revisions included the addition of reading materials, discussion questions, active learning activities and homework problems.

Assessments consist of pre- and post-tests and surveys in which the students are asked to complete a self-assessment of their learning in each course. Table 3 is a summary of the results of the surveys for the "Waste as a Resource Module." Similar surveys were developed for each module to evaluate its specific learning objectives. (Due to space constraints, other tables are not provided here).

Table 2. Implementation of Sustainable Engineering Modules in the CE Curriculum

		Implementation		
Module	**Course**	**Spring 2010**	**Fall 2010**	**Spring 2011**
"Sustainability – What does It Mean for Engineers?"	CE 1104/1105		X	X
"Data Issues in Sustainability Studies"	CE 3301	X	X	X
"Is Transportation Sustainable?"	CE 3302	X	X	X
"Life Cycle Sustainability Economics"	CE 3310	X	X	X
"Waste as a Resource"	CE 3334	X	X	X
"Incorporating Sustainability into Alternative Analysis"	CE 4352	X	X	X
"Considering Sustainability of Design Project Alternatives"	CE 4383		X	X

Table 3. Spring 2010 Student Self-assessment Survey Results for "Waste as a Resource" Module

	Question	Strongly Not Confident	Not Confident	Confident	Strongly Confident
1	I can define sustainability and clearly explain it to someone else.	0	1	11	11
		0.0%	4.3%	47.8%	47.8%
2	I can list four (4) general strategies that help to foster sustainable development.	0	8	9	6
		0.0%	34.8%	39.1%	26.1%
3	I can clearly explain the concept of "triple bottom line."	2	1	10	10
		8.7%	4.3%	43.5%	43.5%
4	Given several waste management alternatives such as resource recovery, recycling, and treatment, I can prioritize them based on a solid waste management hierarchical system.	0	5	10	8
		0.0%	21.7%	43.5%	34.8%
5	I can differentiate among recycling, waste minimization and recovery.	1	3	8	11
		4.3%	13.0%	34.8%	47.8%
6	I can differentiate among recycling, waste minimization and recovery.	1	6	6	10
		4.3%	26.1%	26.1%	43.5%
7	I can list commonly recycled materials and discuss issues related to each.	0	2	12	9
		0.0%	8.7%	52.2%	39.1%
8	I can clearly explain the terms higher heating value and lower heating value.	4	6	9	4
		17.4%	26.1%	39.1%	17.4%
9	I can prioritize materials' usefulness as fuels based on net heating values.	4	6	7	6
		17.4%	26.1%	30.4%	26.1%
TOTAL		**12**	**38**	**82**	**75**
		5.8%	**18.4%**	**39.6%**	**36.2%**

Across all modules, with one exception, self-assessment results indicated that a majority of students (> 50%) were “strongly confident” or “confident” of their ability to address each of the learning objectives in each module. Each module’s contents were revised prior to Fall 2010 implementation in order to address perceived learning deficiencies identified by the students. The results of the Fall 2010 surveys are not yet available; however, future analyses will include comparisons between successive module implementations.

Pre- and post-test results have not yet been analyzed (at the time of this writing). They will be used to evaluate the impact of the modules on student learning each semester, and to assess differences in learning for successive module implementations. The pre- and post-test results will also be compared to student surveys to determine how accurately students perceive their knowledge of and ability to apply sustainability concepts.

Multidisciplinary Senior Design Project

During Spring 2010, seniors from CE and IE students collaborated to design a biodiesel refinery for UTA. Waste vegetable oil from campus food service will be used 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 an ME faculty member during a previous project.

Students were charged with designing all other refinery system components, including feed lines, tanks, Pumps and heaters. Figure 3 shows the process diagram that resulted from their 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 a high quality soap; and
- a distillation system for recovery and re-use of methanol.

The CE and IE students each produced a report summarizing their work.

During the spring, the undergraduate students had to assume certain values in their design. A graduate student ran lab experiments in Summer 2010 to obtain actual values. For example, the microreactors were known to use a 3:1 ratio of vegetable oil to methanol to produce biodiesel. The ratio for waste cooking oil to methanol was reported in the literature to be 6:1 for conventional processes producing biodiesel. The graduate student did lab testing with the microreactors to determine the optimum waste cooking oil to methanol ratio for oil from UTA’s University Center.

Students participating in the multidisciplinary design project were surveyed regarding the multidisciplinary team experience in order to improve such project experiences in the future. Results are summarized in Table 4.

Table 4. Student Survey Results for the Biodiesel Refinery 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	2	1	0
		25%	50%	25%	0%
2	The biodiesel design project increased my ability to recognize impacts of engineering projects/designs on sustainability.	3	1	0	0
		75%	25%	0	0
3	The biodiesel design project increased my ability to identify ways to mitigate potential negative impacts on sustainability.	2	0	2	0
		50%	0	50%	0
4	The biodiesel design project increased my ability to evaluate potential engineering solutions based on sustainability.	0	4	0	0
		0	100%	0	0
5	The biodiesel design project increased my ability to work effectively in multidisciplinary teams.	0	2	1	1
		0	50%	25%	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	4	0	0
		0%	100%	0%	0%
7	I would recommend future students to participate in **sustainable** engineering senior design projects.	0	4	0	0
		0%	100%	0%	0%
8	I would recommend future students to participate in **multidisciplinary** engineering senior design projects.	2	0	2	0
		50%	0%	50%	0%
TOTAL		**8**	**17**	**6**	**1**
		25.0%	**53.1%**	**18.8%**	**3.1%**

To give further insight into the effectiveness of the multidisciplinary design project, students were asked to describe the best aspects of the project as well as the areas that need improvement in an open-ended question format. Student responses are summarized below (these are direct quotes from the survey).

- What was the best aspect of the biodiesel refinery senior 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, students were positive about the sustainability aspects of the project. They agreed, from a small to a great extent, that the sustainable engineering design project increased their ability to explain sustainability concepts, recognize impacts of engineering designs on sustainability, mitigate potential negative impacts, and evaluate potential engineering solutions based on sustainability. 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. Students seemed less positive about the multi-disciplinary aspect of the design project. Part of that was 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.

Quality Sustainable Engineering Internship

The Quality Sustainable Engineering Internship was sent to over 250 companies that hire engineers in the Dallas-Fort Worth area. Responses were used to identify four companies with exemplary sustainable design and operation practices. Two companies are consulting firms; two are manufacturing companies. Following review of student applications, four students were placed in internships with the companies during Summer 2010.

At the middle of the internship and at the end, each student submitted a report describing their work on a project, explaining impacts of projects/designs on sustainability, and recommending methods of mitigating those impacts. At the end of the summer, a seminar was held at which each student presented one of his/her reports. Students, company representatives, and faculty mentors attended the seminar, and used a rubric to assess the student presentations.

The student presentations generally received good evaluations. One strategy for improving future student presentations will be to provide students with the rubric ahead of time to give them ideas about what makes for good presentation content and communication effectiveness. In doing so, we will incorporate feedback from faculty and practitioners who assessed the Summer 2010 interns' presentations.

Each student completed a survey at the end of his/her internship to assess the quality of the experience by responding to both multiple choice and open-ended questions. Students were asked to describe the best aspects of the internship as well as the areas that need improvement in an open-ended question format. Student responses are summarized below (these are direct quotes from the survey).

- What was the best aspect of the sustainable engineering internship?
    - *Being able to work in teams with experienced engineers.*
    - *Being able to identify areas of improvement and take the initiative to start process improvement.*
    - *Being able to understand what sustainability is, and how it impacts consumer products.*
    - *Exposure to "real world" applications of coursework.*
    - *Working with the engineers of other disciplines; saw how all the engineers work as a team.*
    - *I got to work on a project that will help reduce water and energy. This will help me a lot in the future when I get to design my own projects. This internship also helped me gain experience in the engineering field.*

- What aspect of the sustainable engineering internship needs the most improvement, if it were to be offered again?
    - *General outline/guideline for reports.*
    - *Rubric for presentation.*
    - *More information on the program prior to application.*
    - *Communication between other students who are also working as sustainable engineering interns.*
    - *Have students take an environmental class (prior to participating in the internship) because I found that class very useful while I was working.*

Survey responses show that the students feel that the internships increased their ability to explain sustainability concepts, recognize impacts of engineering projects on sustainability, and identify mitigation strategies for reducing negative impacts on sustainability. The internships also increased their ability to work effectively in multidisciplinary teams. Particularly encouraging are the responses that students will be more likely to consider sustainable design options in their future career, with three students strongly agreeing and one student agreeing. All four students strongly agreed that they would recommend the sustainable internships to other students.

Company representatives completed a separate survey with both multiple choice and open-ended questions as well. Company representatives' responses to open-ended survey questions are listed below.

- What was the best aspect of the sustainable engineering internship?
    - *Opportunity to expose future engineers to a world class sustainability approach and strategy.*
    - *Win-win situation, additional person resource semi-qualified for the company/company has the opportunity to instruct and in turn gain fresh ideas forcing us to look at processes differently.*
    - *Help provide valuable experience and exposure to the student; was a symbiotic relationship for the student and company.*

- What aspect of the sustainable engineering internship needs the most improvement, if it were to be offered again?
    - *Involve company rep in student selection process.*
    - *Increase time frame or length of internship.*
    - *Look for long-term opportunities for 1-2 year sustainability internships.*
    - *Was done well and appreciated the opportunity to participate. We learned some valuable lessons – would like to participate again so we have an opportunity to grow with the program.*
    - *The student should devote more time to the program and should not be enrolled in summer classes.*

The company survey responses offer helpful ideas for improvement of future internship programs. One company was not satisfied with the student's performance; this student was taking classes in addition to pursuing the internship, which meant less than full-time work on the internship. In the future, we will specify during the application process that the internship is a full-time commitment. We will make additional modifications as warranted by the evaluation results.

Summary

The College of Engineering at the University of Texas at Arlington has made a concerted effort to prepare its students to practice sustainable engineering principles by integrating both basic and advanced concepts throughout courses from the freshman to senior years in three departments. The assessments that have been conducted thus far indicate that the project as a whole is useful, and that it will meet the expected outcomes in both the short and long range. Comprehensive assessments of the attainment of student outcomes have not yet been evaluated (at the time of this writing).

The final learning modules will be faculty-ready "grab-and-go" curricular units that include objectives, lecture and reading materials, active learning activities, homework problems and assessment tools, and should be readily adoptable by civil engineering faculty at multiple institutions. While the students who participated in the multidisciplinary senior design project pointed out challenges faced in completing the project (e.g. coordinating schedules among multiple groups with different deadlines), they were generally positive in their overall responses regarding the experience. All of the CE students involved agreed that participation in the project made them more likely to consider sustainable design options as practicing engineers, and all indicated that they would recommend the experience for other students. Beyond that, the students learned "real life" lessons about teamwork and problem solving. The internship experiences were evaluated by faculty, company representatives and students through student presentations and surveys. With the exception of one response for one objective, all students indicated that the internship experience improved their knowledge of and competency in addressing sustainability issues in engineering design. While company responses were mixed regarding the quantity and quality of internship candidates, survey results indicate 100% satisfaction with the internship program; and all company representatives are interested in participating in the future.

As the project continues, we expect to see improved capabilities of students in Senior Project Courses to include sustainability as a major component in the analyses of design alternatives due to the reinforcement of concepts and principles throughout their matriculation.

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