2006-1428: TEACHING SUSTAINABLE ENGINEERING TEN YEARS LATER: WHAT'S WORKED & WHAT'S NEXT?

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Abstract

Teaching environmentally related courses in environmental engineering and mechanical engineering technology curricula at two institutions has generated a wealth of experiences. Design for the Environment at the associate level, Design for Society at the senior level, and Sustainable Engineering at the graduate level are similar, complementary courses. Topics in each include green engineering and environmentally-conscious manufacturing. Environmental awareness discussions are included to make clear the perspective of why engineering students need to learn about green design. The writing components in each course are more involved than those in other engineering courses.

Whereas each course has undergone student and faculty assessments, an accounting of the results reveals similarities and differences in student reactions to environmentally considerate material. This paper includes numerical analysis of student assessments and faculty reviews for the purpose of measuring progress towards common objectives. The paper also discusses qualitative data for understanding the direction sustainable engineering education might take. This analysis becomes useful when making changes to existing courses and plans for future ones by identifying what has worked well and what has not.

Sustainable engineering

While the definition of sustainable development traces to the Brundtland Commission in 1989, a working one for sustainable engineering continues to evolve. The Centre for Sustainable Engineering defines the term as "Engineering technologies and services which deliver greater resource productivity or efficiency and fewer emissions of hazardous substances and/or emissions presenting lower hazards."[1] Considering greater productivity and efficiency in resource use is not a new concept to design engineers. However, the increased awareness of hazardous emissions and their effects is.

As the definition of sustainable engineering has evolved, so has the engineering coursework. Two similar courses at different institutions began in 1995 and 1996. The first, Engineering (ENGR) 271, Design for the Environment, became a requirement of an associate-degree program in mechanical engineering technology (MET). According to the catalog description, the course "examines the effects of progress and advances in technology on the global environment. Product design and manufacturing processes are studied for their effects on the environment." In the following year, the second institution added the course Engineering Technology (ET) 420, Design for Society, to its bachelor-level program in mechanical engineering technology. Its description is, "an interdisciplinary study of the engineering design process and the influence of society and culture on design." Although a technical elective initially, the course is required today. In 2001 that same institution added an upper-level course for its senior and graduate students. Environmental Engineering (ENVE) 430, Sustainable Engineering, is a technical elective accepted in a variety of engineering and engineering technology programs. Its description is "a course on engineering which uses ecological principles to minimize waste and maximally use input materials." Since the 1970s, students from the associates program transfer to the second institution to pursue the bachelors degree in MET. That transition continues today, so the three related courses coexist. ENGR 271 is accepted in place of the required ET 420. Although they are not prerequisites, students completing either design course are well prepared to take ENVE 430 as an elective.

Table 1 contains data related to the sections of the courses that were taught during this study period. The numbers of sections and numbers of student, both maximum and minimum give an idea as to the total students who experienced sustainability-related courses. Also included in the table are the course percentages for how grades were distributed across each of the courses.

Course	**ENGR 271**	**ET 420**	**ENVE 430**
Number of sections	6	2	3
Maximum number of students	21	47	22
Minimum number of students	10	22	6
Exam percentage	40%	40%	30%
Homework percentage			15%
Written assignment percentage	20%	20%	
Team project percentage	35%	30%	50%
Class participation percentage	5%	10%	5%

Table 1 - Number of Sections and Students with Course Percentages for the Study Period

ENGR 271 and ET 420 each began as interdisciplinary approaches to engineering design. Since the global environment and its community are themselves diverse, interdisciplinary study of them is the best approach to understanding their interactions. Sustainable engineering assumes that engineers will continue to provide technologies and services to the global community. Doing so with objectives of resource efficiency and emission reduction is what makes engineers' actions sustainable.

Results from student assessments

As different as the two institutions are, their standardized student assessments of teaching are also different. The two-year institution uses the Student Evaluation of Educational Quality (SEEQ), which is a 40-item survey using a 5-point scale that can be machine scored or web-based. SEEQ items are standardized over the institution making it easier for instructors to compare their results versus those of their colleagues.

In the Design for the Environment course, students generally considered having "learned something valuable" at an above-average level when compared to all their college courses. In 2001, the course was delivered on line, which may have caused the rating of value to drop slightly below the college average. In the same assessment, students ranked Design for the Environment consistently higher overall than the average institution course.

The other institution uses a Student Rating of Teaching Effectiveness (SRTE). Two rating items for ET 420W for the Spring 2004 & 2005 semesters were content related. Students rated "the overall quality of the course" almost identically each year, using a 7-point scale. Students rated "the importance of knowledge learned in the course" slightly lower in one semester and higher in the other.

Students completing the SRTE forms have the option of answering open-ended questions including, "What did you like best about this course," and "What did you like least about this course?" Since the W suffix indicates that the course meets the university writing-intensive requirement, the writing requirements exceed those of many engineering technology courses. Students answering what they liked least were consistent in both semesters in saying there was too much writing required. In terms of course content, some students liked the presentation of facts related to environmental impact. Some students were disappointed in that the course emphasized the motivations for design rather than design criteria itself as in other engineering courses.

ENVE 497A was the pre-approved version of ENVE 430. Results for Fall 2002 and 2003 were available, but the course was cancelled for low enrollment in Fall 2004, and SRTE results for the Fall 2005 offering of ENVE 430 were unavailable as this writing. Two of the 17 SRTE rating items for ENVE 497A were course content related. Although the rating improved by almost one-half a point on the seven-point scale for the item "Rate the overall quality of the course," from 2002 to 2003, the final rating was below expectations. There was a greater increase of more than 1 point for the item, "Rate the importance of the knowledge learned in this course," from 2002 to 2003. The ratings for this second item were higher than the first in both semesters showing that students recognized the importance of the course material even if they did not rate the quality of the course highly.

Results from student and faculty assessments of course learning objectives

Aside from college-wide standardized assessment, program faculty developed a tool to have students and faculty members judge how each class accomplished meeting its course objectives. Both students and faculty respond to a minimum of ten statements pertaining to the written and supporting course objectives. For each class, the instructor averages the students' responses and compares them to his/her own. A program faculty committee reviews all such assessments to see where the student average differs from the faculty member's response by more than 1 point on the 5-point scale. Also, the committee identifies those student averages that are below 3.0. Although the faculty responses might vary with each section of a course, the student responses, when compared from year to year, indicate if an objective is not being met, which results in the committee recommending corrective actions.

Course objective assessments were done in 2004 and 2005 for ET 420W. As part of the assessment, students also respond to open-ended questions including, "What did you enjoy most in this course," and "What did you enjoy least?" In ET 420W, students responded that they liked discussions and projects relating to environmental impact and learning about sustainability with its social and cultural interactions. They disliked writing about some topics and doing the team project.

Responding to the open-ended questions in the ENVE 430 assessment, students liked talking about sustainability and associated topics, such as energy efficiency and resource conservation. Students did not enjoy homework based on some topics, specifically because problems were vague sometimes. Also, one graduate student in the class suggested that more modeling of problem solutions would be helpful. The students split on the benefits of the semester-long life cycle analysis (LCA) project. Two negative issues raised were that they didn't like being paired together for the team project and that the project was a significant work load in a one-semester course.

What has worked?

Both ENGR 271 and ET 420W serve as the introductory sustainability-related courses at their respective institutions. In those courses, students explore the bases for sustainability by discussing issues such as global population, resource consumption, energy use, and hazardous waste. Students become more environmentally aware of the course topics through writing assignments and project work. From the various assessments, students appreciate learning more about sustainability and its connection with engineering design. Some course topics elicit greater responses from students than others. Students, who discover that their home state is the leading importer of municipal solid waste from other states, become more interested in the reasons behind such high environmental impact practices. The instructor can use the solid waste issue as a means to discuss the roles state and local governments play in environmental impact.

Case studies are always helpful in illustrating how governmental agencies, private corporations, and non-profit organizations take strides to reduce environmental impact. The more recognizable the entity is to students, the more evident their example is. Many organizations include environmental awareness as part of their web sites, so it is not difficult to find who is doing what. A lesson in critical thinking can ensue when students research further to find if the web statements are in fact true as judged by unbiased sources. Many recognizable companies and agencies are deeply involved in environmental improvement; their accomplishments serve as examples for young engineers.

ENVE 430 is intended for both senior-level undergraduates and graduate students. From the student assessments of course objectives, the undergraduate students who took the course as a technical elective were less enthused about working on a semester-long project than were their graduate classmates. Most of the graduate students embraced the project as a means to learn life cycle analysis (LCA). The project required a pair of students to select a topic for an LCA. The project teams synthesized the project scope, conducted the inventory analysis, performed an impact analysis, and recommended improvements. A few teams utilized public-domain LCA software for the impact step. Student assessments showed that a few of the teams completed their project tasks successfully in the eyes of their members. All students rated each team's efforts, so the peer reviews provided further evidence of LCA success.

A couple of simple visuals have proven useful and appreciated as measured by student evaluations. A lesson in global population is enhanced by a graphic of density. Assign the students a global citizenship based on population distribution. Approximately 20% of the class would represent China. Another 15% represent India. Simply using the 11 most populous nations, each with a population above 100 million, involves 60% of the class as that same percentage of global population. To illustrate density, divide the classroom into global area, with chairs and/or desks as land area and the remaining space as surface water. Students understand the concept when comparing the sight of 1 student sitting on 4 chairs in Russia with 5 students trying to sit on 2 chairs in China. The other visual is a tried-and-true children's video called "The Lorax." The Dr. Suess story deals directly with environmental degradation resulting from resource exploitation. consumption, overpopulation, and wastefulness. Some students recognize the video from previous viewings, while others relate quickly to the moral of a simply stated story.

What comes next?

Field trips to facilities that embrace sustainable concepts will become part of future course offerings. From assessments, many students have strong interests in green building design concepts. Local green buildings and architects, who practice such design, are worthy subjects for field trips. Community recycling programs and material recovery operations can also show how waste products can be returned to the manufacturing stream. More traditional environmental engineering subjects, such as wastewater treatment facilities and landfills, if they are following state-of-the-art techniques, can also be beneficial as field trips.

Currently, students taking ET 420Y, renamed from ET 420W to indicate an intercultural as well as writing-intensive course, have the option to take a trip to London during the university's spring break. The trip is offered campus wide with two other course sections, one in finance and the other in criminal justice, traveling at the same time. The focus of the ET 420Y portion of the trip is sustainability as applied by Great Britain and the European Union. The visit includes a walking tour of London architecture with an emphasis on green buildings, a tour of a vehicle manufacturing facility to illustrate manufacturing applications of green design, and a tour of a zero-fossil-fuel-emissions community. Only a small number of students, two in 2005 and 4 in 2006, make the effort to join the trip, but the others still benefit via photographs and descriptions delivered by those who did travel. Based on evaluations, the next step should be to continue the spring break trip, which costs students $1350 excluding air fare.. However, the college should offer a trip to a country whose treatment of sustainability is more different from the United States' than Great Britain's. Tying this visit to a service-learning project is the next logical step. Various examples of such projects are evident, and today's college students seem interested in service learning as supplements to their programs of study.[2]

Most importantly, sustainable engineering must become part of all engineering curricula. One common application is to include sustainability as a constraint in senior project courses. Inclusion of sustainability works this way as long as students have previous instruction in the concepts. An increasingly common approach to introduce all engineering students to sustainability is to include the topic in the first-year seminar courses. Those students can explore sustainability via discussion and conceptual project work. The idea of starting sustainable engineering at the first year is excellent as long as there are opportunities to go into further depth later in the curricula.[3] There is room in engineering curricula for further depth, and that room must be exploited. Engineering material and process classes should include sustainable concepts as part of the traditional course content.[4] Other design courses can include sustainable concepts in the design process. Designing for the environment is as important a consideration as designing for quality, reliability, manufacture, etc.[5] Energy efficiency and resource minimization are already design criteria, so further application of sustainable concepts should be an elaboration and not an innovation.

Conclusion

Sustainable engineering with its components that include design for the environment, green design, pollution prevention, and waste minimization, has evolved into a viable part of the engineering and engineering technology curricula. Treatment of global issues, including environmental ones, is by necessity multi-disciplinary. Students in all engineering disciplines along with peers from around campus benefit from sustainability discussions and applications.

Some institutions have developed semester-long courses that teach students sustainable engineering and related topics. While the commitment needed for that approach is not unanimous, engineering and engineering technology programs serve their students well by incorporating sustainable principles and practices into a variety of programmatic courses. Introductory seminars, other design courses, and material/process courses are those that already have such topics. Opportunities exist in other courses, such as power engineering and construction management, to include them.

Sustainability, as applied to energy efficiency, resource conservation, and waste minimization, is an accepted way of life that is a necessity to support a continually-growing global society. Engineers, in service of society, must demonstrate an understanding of sustainable principles. Engineering students need to develop that understanding throughout their coursework. Over the last ten years, programs and courses have included more sustainable concepts, but they must remain dynamic as global needs identify newer sustainable approaches to design. Some students' assessments of learning sustainability may not be entirely positive, but with more companies and agencies emphasizing these concepts, the need for their inclusion in the curricula becomes more evident.

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