Teaching Sustainability in an Interdisciplinary Environment

Qiong Zhang[1] Delcie Durham[2] Alcantar Norma[3]

Abstract – In the past, several sustainability related courses have been offered in the individual departments in the College of Engineering at the University of South Florida. In spring 2011, the instructors of these courses consolidated them into one interdisciplinary course. This paper examined the successes and failures of an integrated team teaching method. It was found that the breadth of topics covered in this interdisciplinary course and the integrated team teaching have high potential to educate students in the field of sustainability. However, some criticisms were raised from student evaluations including large class size, uneven transitions between different topics, lack of communication, unclear expectations, inconsistent homework grading and mixture of graduate and undergraduate students. Such integrated team teaching may be improved by creating a hybrid combination split between large common lectures focusing on the concepts and tools and smaller class lectures and exercises focusing on application within the different disciplines.

Keywords: Sustainability, Interdisciplinary course, Team teaching

INTRODUCTION

There has been an increasing articulation of the need for student training that includes the consideration of sustainability. For example, accreditation assessment criteria established by ABET include "Students must be prepared for engineering practice through the curriculum culminating in a major design experience based on the knowledge and skills acquired in earlier course work and incorporating engineering standards and realistic constraints that include most of the following considerations: economic; environmental; **sustainability**; manufacturability; ethical; health and safety; social; and political. …to understand the impact of engineering solutions in a **global, economic, environmental, and societal context**" [1]. Responding to such needs, sustainability has gained much attention in engineering education in the last decade. This trend has been observed in the rising number of courses relating to sustainability, materials design and green engineering taught at the university level. From 2005 to 2008, Allen et al. [2] conducted a very comprehensive survey of courses taught and research being performed in engineering as they relate to sustainability. It was found that of 270 university faculty respondents to their survey, 80% were teaching courses related to sustainability. Allen et al. [2] categorized the types of courses being taught in sustainable engineering as the following: (I) courses that tend to focus on tools such as Life Cycle Assessment (~ 50%), (II) courses which integrate sustainability concepts into traditional engineering courses in order to broaden the students' skill set and awareness (~ 25%), (III) courses that focus on innovative technologies (~ 15%), and (IV) cross-disciplinary courses taught in conjunction with other departments that address aspect such as economic, political, and social aspects of sustainable engineering (~ 15%). Of these four types of courses, none of Type IV courses were found to be part of formal degree program. It was concluded by Allen et al.

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[1] University of South Florida, Department of Civil & Environmental Engineering Department, 4202 E. Fowler Ave. ENB 118, qiongzhang@usf.edu

[2] University of South Florida, Department of Mechanical Engineering, 4202 E. Fowler Ave. ENB 118, drdurham@usf.edu

[3] University of South Florida, Department of Chemical & Biomedical Engineering, 4202 E. Fowler Ave. ENB 118, norma@usf.edu

[2] that most courses being taught focus primarily on smaller scale that does not incorporate systems that go beyond the firms, products or processes. Allen et al. [2] study clearly points out the need for cross-disciplinary courses because the concept of sustainability encompasses many disciplines beyond engineering, such as economics, political and social science, public health and arts. However, many challenges remain to the successful delivery of an integrated sustainability education within engineering. One of challenges identified is the lack of an established pedagogy for teaching involving multidisciplinary topics. Creating the appropriate interdisciplinary environment is critical for sustainability education to enhance the ability of students to grasp the concepts of sustainability science, materials design and green engineering and to apply the principles they have learned to solve real world problems.

OVERVIEW OF THREE COURSES

At the University of South Florida (USF), several sustainability related courses have been offered in the College of Engineering, such as “Sustaining the Earth: Engineering Application” from Chemical and Biomedical Engineering (CBE), “Green Engineering for Sustainability” from Civil and Environmental Engineering (CEE), and “Sustainable Design & Materials” from Mechanical Engineering (ME). In the past, these courses have been offered in the individual departments.

Sustaining the Earth: Engineering Application

This course offered to Chemical and Biomedical Engineering majors introduces an approach of global perspective on ecological principles to chemical engineering processing and product development. The goal for the students is to understand how all the world’s life chemical processes are connected and how to implement sustainable solutions within the biosphere. The students also learned how engineering provides the tools to design solutions engaging materials science and environmental ethics. The outcomes for the class are three fold. First, it provides an understanding of sustainability and how it applies to green engineering processing and design. Second, students learn to determine how design decisions and material selection affect environmental impact and costs. Third, students learn and understand how to construct a life cycle assessment (LCA) and how to apply LCA tools to engineering processing and design. Enrollment in the past two years has been between 10 and 18 students. Primarily graduate students, although there is a class section offered to undergraduate sophomores as an elective class.

Green Engineering for Sustainability

The course “Green Engineering for Sustainability” course was initially implemented at the USF in spring 2010. The class enrollment was 42 with 26 undergraduates and 16 graduate students mainly from Civil and Environmental Engineering. The principles of green engineering was introduced and the topics on the application of these principles addressed include innovative thinking, biomimicry; toxicity, risk assessment, and green chemistry; social ecology, governance and economics; supply chain management and lean manufacturing; system and complexity; life cycle assessment/life cycle costing; and appropriate technologies. The course objectives were created according to the Fink taxonomy of significant learning [3]. Students participated in the class through lecture, in-class activities and a course wiki site where students can upload examples of green engineering and sustainable design. Students formed 11 teams and each team innovatively designed a solution to a real sustainability challenge for the USF campus community. The course was received well and scored above average by the student evaluations, especially by graduate students (overall evaluation is 4.15 with 4 as very good and 5 as excellent).

Sustainable Design & Materials

This course is a new offering for Mechanical Engineers at the graduate level and as a tech elective for Senior undergraduate students. The class enrollment was 19, with 8 at the undergraduate level. The concepts of sustainable design, based upon the 12 principles of green engineering [4], are an important component of sustainability education for Mechanical Engineering.

DEVELOPMENT OF THE INTERDISCIPLINARY COURSE

In spring 2011, the instructors of these three courses described above consolidated them into one interdisciplinary course, believing that it would be more effective to expose students to an integrated, interdisciplinary learning environment.

Course syllabus

The three instructors developed the common syllabus for this interdisciplinary course based on previous course structure. The course approaches sustainability from a design perspective. The principles of green engineering: (1) *Innovation* – “we can’t solve problems at the same level of thinking used to create them”, (2) *Inherency* –we can’t solve problems without looking at the nature of system that created them, (3) *Interdisciplinary* –we can’t solve problems without looking at other aspects of the problem, (4) *Integration* –we can’t solve problems without connecting segments at system level, and (5) *International* –we can’t solve problems without considering the context of the problems, are incorporated into diverse topics. The topics are organized following the design process: ideation, metrics, evaluation, and implementation. The curricular plan included a mix of experiential learning, hands-on projects and invited speakers in additional to lectures. The course outline is shown in Table 1.

Table 1. Course Outline of Consolidated Interdisciplinary Course

Week	Topic	Plan
1	Course Overview Introduction to Sustainability and Challenges	Lecture
2	Green Engineering Principles Design Process	Lecture, in-class activity
3	***Ideation (different thinking):*** System thinking Life cycle engineering	Lecture
4	Life cycle engineering Biomimicry	Lecture, in-class activity
5	***Metrics:*** Toxicity and risk assessment Efficiency and effectiveness	Lecture, in-class activity
6	Sustainability indicators Introduction to Design Projects	Lecture, hands-on projects
7	***Evaluation tools:*** Life cycle assessment Economic input-output LCA	Lecture
8	Process LCA Introduction to LCA software	Lecture, experiential learning
9	LCA software experience	Experiential learning
10	Material selection and flow analysis Design Projects Update	Lecture, hands-on projects
11	***Implementation consideration:*** Social and cultural context, Policy issues	Invited speakers
12	Case Studies	Experiential learning
13	Case Studies	Experiential learning
14	Project Presentations	Hands-on projects

Course materials

In the development of the course syllabus, the instructors found that it is difficult to assign a textbook. Although there are three books [5-7] that have relevant information related to the course content, there is no single book to cover all topics planned. That is one of challenges to teach interdisciplinary courses involving multidisciplinary topics. To address this challenge, the tailored course package was compiled by the instructors from various sources including peer reviewed journal articles, chapters from books, reports, articles from public domain based on the content listed in Table 1. The materials covered in the package as listed in Appendix, have been printed with permission acquired by Pro-Copy, Inc. and made available to students.

Instructors

The three instructors were committed to co-teaching the course, not just dividing the course into individually taught modules. From the course outline shown in Table 1, a schedule was developed identifying class content and materials. The instructors then discussed and assigned the responsibility for each lecture based on the nature of the content and the expertise of individual instructor. For example, the instructor who has the expertise in sustainable materials delivered the lectures on material selection and flow analysis. The instructor who has the expertise in chemical process design delivered the lectures on toxicity and risk assessment. The instructor who has the expertise in environmental assessment delivered the lectures on life cycle assessment. For most of lectures, the three instructors were present with one leading the presentation and the other two supporting in-class activities.

Assignments

A total of five assignment sets were developed based on the course content: HW 1 on sustainable design principles; HW 2 on system thinking and life cycle engineering; HW 3 on metrics; HW 4 on life cycle assessment; and HW 5 on materials selection and flow analysis. For each assignment, all instructors contributed to problems. The problems were designed to relate to the real life as shown in the following example.

> Your 11 year old cousin is participating in the Engineering Week bridge competition where a model bridge is designed, built and tested for points. This year, the competition adds a fourth category, giving points for green design so that your cousin can earn up to 25 points for green design, 25 points for regular design analysis, 25 points for aesthetics of the built bridge, and 25 points for the performance (load at failure/kg). You have chapter 9 in Section 4 available to provide advice, and you are allowed to provide up to 4 specific recommendations (but not allowed to help build it of course). What suggestions would you give? Note: allowed materials are wood, aluminum, steel, ceramic tile, all polymers, adhesives, cotton, wool, kenaf.

Projects

A total of nine projects were proposed by the instructors. Each project was designed by a lead instructor with the input from the other two instructors. Student teams were formed by randomly picking students from each discipline for each team to ensure the interdisciplinary composition of the teams. The teams then reviewed the project descriptions and made their top three choices. The instructors then assigned projects taking into account teams' preferences while reserving the right to balance projects between the teams. The teams were provided guidance on project management and team building. The project activities and final presentations were peer reviewed and these evaluations counted toward the final grade.

ASSESSMENT RESULTS AND DISCUSSION

Instructor self evaluation

There is no formal self evaluation by the instructors; however, the informal discussion about the benefits and challenges of integrated team teaching was held frequently among instructors.

All three instructors realized many benefits of such teaching: 1) shared teaching load, 2) peer evaluation, 3) learning opportunities, and 4) support from each other. The lecture preparation time is significantly reduced because of the reduced number of lectures given by each instructor and the familiarity of the lecture materials for each instructor since the lectures were assigned based on their expertise. Since all three instructors were present in the class, it provides an opportunity for developing faculty expertise. Listening to the lectures given by other faculty expands the knowledge base for each instructor, especially in the area of sustainability because multidisciplinary topics are involved. It also provides an opportunity for peer evaluation on teaching. For example, the instructor from CEE had the instructor from ME evaluate her teaching and received helpful feedback to improve her methods of delivery. As described previously, such teaching established a support system for delivering the entire course in and out of classroom.

However, the three instructors also found several challenges: 1) adjusting class materials for a heterogeneous class (disciplines and levels); 2) providing an effective learning environment for the large class size, 3) less individual instructor-student contact time, 4) inconsistent grading across disciplines and 5) unclear responsibility related to project mentoring. The topic of sustainable design drew a large number of students from different disciplines to the course, resulting in reduced individual contact time. The homework assignments were graded by different TAs/instructor in different departments that caused inconsistent grading across disciplines. The project teams consisted of students from all three departments and students tended to go to the instructor they knew best rather than the one most familiar with the project.

Student evaluation

Student assessment of instruction was conducted at the end of the semester. Based on student comments, the topics covered in this interdisciplinary course and the approach of team teaching for course delivery have high potential to educate students in the field of sustainability as shown in the following verbatim comments.

- "Conceptually this course has a lot of potential to raise awareness and facilitate the growth of holistically-minded design….Overall, this course has a lot of potential to change the way we future engineers will design."
- "Very interesting topics."
- "The final project was the best ever, it could make a real difference if implemented."

However, students raised many criticisms centering on the size of the class, integration and connection of different topics, logistics of the class, unclear expectations, homework grading and mixture of graduate and undergraduate students as discussed below.

Size of the class. The large size of class seems not work well because discussions are an important part for many topics related to sustainability.

- "I think the course should be for a smaller number of students so the classes and lectures can include more discussions."
- "I think the course may have been more effective if the class size was smaller. I appreciate the interdisciplinary idea, but a lot of the topics were/are meant to be discussed and has through examples, but this was essential impossible with so many people."

Integration and connection of different topics. Although the overall structure of the course was collectively designed by the three instructors, each lecture was prepared by the instructor who is responsible. The connection between lectures was not addressed well.

- "The course wasn't bad, but the inclusion of other classes into one class made the topics seem disjointed and disconnected to course idea."
- "The 3 professors need to work together to develop a more integrate course that does not feel disjointed."

Logistics of the class. Since three instructors and three departments were involved, many details on coordination and communication were not paid enough attention. In addition, there were some issues in terms of software application. The software (SimaPro) for the life cycle assessment was installed late due to the delay of the purchasing approval that resulted in insufficient testing of software from multi-users.

- "This class was team taught with two other instructors – communication between professors seemed incomplete…different professors would tell the class different things – due dates for assignment etc."
- "The class was run a little disorganized. The LCA tutorial requires at least two class sessions and they should have taken place in a lab where SimaPro was already installed."

Unclear expectations. Many homework problems are open ended questions that were designed to provoke thinking, similar as design projects. Student would expect the rubric for homework to clear up the expectations for homework and project.

- "The expectations of assignments are not explained by the instructors. The information given is very simple and the expectations are really high."
- "Questions were not clearly written."

Homework grading. Since different TAs/instructors graded homework from different departments, the grading is not consistent across departments.

- "Different TAs or instructors graded the different sections, and it was surely reflected on the method (or criticism) in the grading."
- "Grading is not consistent between classes and it should be because it is the same course just in different departments."

Mixture of graduate and undergraduate students. There is a mixture of undergraduate and graduates in the class. The same homework assignments and exams were given while sections for undergraduates and graduates were specified. The project teams have both undergraduate and graduates. This type of mixture received some criticisms.

- "The fact that there are undergraduates and graduates taking the same course has really made it difficult for undergraduates."
- "Mixing undergraduates with graduate students didn't work well, since undergrads do not perform at the same level and do not produce the same quality of work."

Potential improvements

The three instructors met together at the beginning of fall 2011 to discuss how to make improvements in course delivery based on faculty self evaluation and student evaluation. Since one of the major complaints concerned class size, and several of the other criticisms were related to it, an improvement could be made by changing the structure of the course to include fewer common lectures and to create separate undergraduate and graduate project teams.. The common lectures will focus on basic concepts and tools, such as green engineering principles and life cycle assessment. Those lectures will be limited to 6 to 7 times through the semester. The remaining lectures will be delivered by the individual instructors with a focus on application of principles in the relevant disciplines. This will also address the integration and connection of topics and part of logistics issues. Each discipline will prepare different homework sets, but will continue to develop some homework questions that transcend the discipline. The instructors will continue to have different expectations for graduate and undergraduate students, and this will be reflected in the homework sets. The rubric will be posted with homework assignment so students will be clear what is expected. For group projects, interdisciplinary undergraduate teams and graduate teams will be formed and the level of complexity and difficulty of the projects assigned will be appropriate for their student status.

CONCLUSIONS

This paper presented the development, delivery and assessment of an interdisciplinary course and examined the successes and failures of an integrated team teaching method for sustainability education. It was found that the breadth of topics covered in this interdisciplinary course and the integrated team teaching have high potential to educate students in the field of sustainability. However, some criticisms were raised from student evaluations including large class size, uneven transitions between different topics, lack of communication, unclear expectations, inconsistent homework grading and mixture of graduate and undergraduate students. Such integrated team teaching may be improved by creating a hybrid combination split between large common lectures focusing on the concepts and tools and smaller class lectures and exercises focusing on application within the different disciplines.

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Qiong Zhang

Dr. Qiong Zhang is an Assistant Professor of Civil & Environmental Engineering at University of South Florida.

Delcie Durham

Dr. Delcie Durham is a Professor of Mechanical Engineering at University of South Florida.

Alcantar Norma

Dr. Alcantar Norma is an Associate Professor of Chemical & Biomedical Engineering at University of South Florida.

Appendix. Materials Covered in the Course Package

Author/Editor	Title	Source
Kates, R.W., et al.	What is sustainable development? Goals, Indicators, Values, and Practice	*Environment: Science and Policy for Sustainable Development*, 47(3): 8-21, 2005
Mihelcic, J.M. & Zimmerman, J.B.	Engineering and sustainable development	*Environmental Engineering: Fundamental, Sustainability, Design*, John Wiley & Sons. pp. 1-25, 2010
Anastas, P.T. & Zimmerman, J.B.	Design through the 12 principles of green engineering	*Environmental Science & Technology*, 37(5): 95A-101A, 2003
Mipenz, C.B., et al.	Sustainability and engineering in New Zealand	IPENZ Engineers New Zealand
Graedel, T.E. & Allenby, B.R.	Technological product development	*Industrial Ecology and Sustainable Engineering*, Prentice Hall. pp. 115-125, 2010
Hjorth, P. and Bagheri, A.	Navigating towards sustainable development: A system dynamics approach	*Futures*, 38: 74-92, 2006
Clarke, A. & Gershenson	Life-cycle design	*Environmentally Conscious Mechanical Design*, John Wiley & Sons. pp. 67-115, 2007
Vallero, D. & Brasier, C.	Models from nature	*Sustainable Design: The Science of Sustainability of Green Engineering*, John Wiley & Sons. pp. 24-26, 2008.
Miller, G.T. & Spoolman, S.	Industrial ecosystems: copying nature	*Environmental Science: Problems, Concepts & Solutions, 12th edition*, Cengage Learning. pp. 275-276, 2008
Sridhar, I.	Materials selection for green design	*Environmentally Conscious Mechanical Design*, John Wiley & Sons. pp. 319-347, 2007
Bartelmus, P. & Douglas, G.	Indicators of sustainable development	*Encyclopedia of Earth*
De Kruijf, H.A.M. & Van Vuuren, D.P.	Following sustainable development in relation to the north-south dialogue	*Ecotoxicology and Environmental Safety*, 40: 4-14, 1998
EPA	Chapter 2. Goal definition and scoping Chapter 3. Life cycle inventory Chapter 4. Life cycle impact assessment Chapter 5. Life cycle interpretation	*Life Cycle Assessment: Principles and Practice*, EPA/600/R-06/060, 2006
Hendrickson, C., et al.	Economic input-output models for environmental life-cycle assessment	*Environmental Science & Technology*, 32(7): 184A-191A, 1998
Graedel, T.E. & Allenby, B.R.	Material flow analysis	*Industrial Ecology and Sustainable Engineering*, Prentice Hall. pp. 240-253, 2010
Cao, J., et al.	Metal cycle	*Encyclopedia of Earth*
Graedel, T.E. & Allenby, B.R.	Sustainable engineering in government & society	*Industrial Ecology and Sustainable Engineering*, Prentice Hall. pp. 365-376, 2010