AC 2010-395: ENGINEERING DESIGN FOR SUSTAINABILITY: A COURSE FOR MAJORS AND NON-MAJORS

Catherine Skokan, Colorado School of Mines

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Abstract

As part of a one-semester international experience for undergraduate students, a lower-division course in engineering design for sustainability was offered. The course participants consisted of majors in engineering, architecture, political science, and economics from numerous universities. This survey course, beyond providing a basic introduction to sustainable development concepts, exposed the students to the challenges of sustainable development from an engineering design perspective. The course objectives were that students would:

1. Be able to define sustainability
2. Identify sustainability issues in the atmosphere, hydrosphere, and lithosphere
3. Apply the engineering design process to sustainable projects
4. Summarize methods to measure sustainability
5. Analyze examples of sustainable and non-sustainable programs.

Participants were also exposed to field experiences to observe issues in sustainability. Assessment of the course objectives illustrates the need for cooperation among engineering and other disciplines, such as economics and politics, in the design process for a sustainable society.

Introduction to the Academic Partners

The Institute for Shipboard Education and its educational partner, the University of Virginia, operate the Semester-at-Sea program. The mission of this program is "to educate individuals for leadership, service, and success in shaping our interdependent world.[1]" The program provides a study-abroad experience in which students and faculty from institutions throughout the world, but primarily from the United States, can compare customs and gain a deeper international perspective. A semester is spent traveling around the world on a ship. Approximately 10 countries are visited during the voyage. While on ship, classes are held and while in port, international observations take place. This ship-board university has approximately 700 students and 35 faculty as well as support staff. The ship has many of the features of a land-based campus: computer center, library, fitness center, medical facilities, as well as classrooms. Classes are offered with credit from the University of Virginia in a wide range of topics such as business and economics, communication, history, environmental science, biology, sociology, literature, the arts, and oceanography. In each course, traditional material is augmented with in-port experiences which illustrate the practical application of that subject This paper will discuss a new class introduced in the Fall 2009 voyage around the world. The course, titled Engineering Design for Sustainability, was offered through the University of Virginia's Department of Science, Technology and Society (STS) which is housed in the School of Engineering and Applied Science. The multidisciplinary STS department "advances understanding of the social and ethical dimensions of science and technology[2]". This paper will describe the development of course and its goals, expand on the course syllabus and choice of texts, discuss the in-port field experiences, and summarize the assessment of both the students and the course.

Course development and details

The home institution of the course faculty member is the Colorado School of Mines (CSM). A Humanitarian Engineering Program[3] has been developed at CSM to educate engineering students to solve the problems of fulfilling basic human needs both locally and abroad. The program offers a minor in Humanitarian Engineering and requires a core of both social science and engineering courses aimed at applying appropriate technology to serve the underserved of the world. In an attempt to bring the Humanitarian Engineering concepts to both engineering and non-engineering students at the Semester-at-Sea program, this course, Engineering Design for Sustainability, was developed.

The three-credit hour course was designed at the lower division level. The objective of this survey course, beyond providing a basic introduction to sustainable development concepts, was to recognize the challenges of sustainable development from an engineering design perspective. The course topics included a definition of sustainability and a look at examples in the world of both sustainable and unsustainable designs. Issues included an investigation of both economic and technological aspects of sustainability. In the course, there was an attempt to measure sustainability and investigate possible appropriate technologies for sustainable development. Students observed projects in the field throughout the semester and studied how sustainable they might be.

Specifically, the course objectives were that students would:

1. Be able to define sustainability
2. Identify sustainability issues in the atmosphere, hydrosphere, and lithosphere
3. Apply the engineering design process to sustainable projects
4. Summarize methods to measure sustainability
5. Analyze examples of sustainable and non-sustainable programs.

The course consisted of 24 sessions of 75 minutes each. The syllabus is listed below.

1. Pre- Content Assessment, Introduction
2. Definition of Sustainability, Brundtland Report
3. Continuation of Brundtland Report
4. Continuation of Brundtland Report
5. Visit from Ship Engineer on workings of the ship's energy and water systems
6. Examples of issues in sustainability in history (Easter Island, Ireland, Iowa)
7. Modern examples of sustainability (UN Water project, Honduras)
8. The Engineering Design Process and Characteristics of Sustainable Engineering Design
9. Atmosphere Structure and Climate Issues
10. Hydrosphere Structure
11. Hydrosphere Issues; water treatment methods – slow sand filters, SOLDIS
12. Lithosphere Near-surface Structure and Issues
13. Mid Term exam
14. Natural resources
15. Energy resources
16. The Role of Technology in Solutions

17. Life Cycle Analysis and Quality Function Deployment – engineering tools
18. Technology and Society: Case Histories of Sustainable Development
19. Measuring Sustainability
20. Is the news good or bad? Class summary
21. Project (apply design process, parts of a proposal, research and brainstorming)
22. Project (choose and defend methodology, economics)
23. Project (appropriate technology and sustainability)
24. Present final designs; post-content assessment

Two primary text books and a United Nations Report provided the basis for the course. In addition, numerous journal articles were assigned for reading and discussion. The two text books were The Skeptical Environmentalist: Measuring the Real State of the World by Bjorn Lomborg[4] (Denmark) and Sustainable Development for Engineers by Karel Mulder[5] (The Netherlands). These two text books were chosen because they both were written by Europeans and gave opposing points of view on many, but not all, issues. Both books quote the same data sets, but often come to different conclusions. The goal in using these two books was for the students to become critical readers and to learn to draw their own conclusions from a variety of sources. In addition to the two primary text books, The United Nations Document, Our Common Future[6], more commonly referred to as the Brundtland Report was read and discussed. This report, dating from 1987, introduces challenges in the arena of sustainability. Students were assigned chapters in the document to report on in class. Their report included a summary of the 1987 information and an update through a literature search of each topic. The Brundtland Report and its update provided the foundation for the rest of the course.

One of the first topics in the class was to define sustainability. The Brundtland Report, as well as both text books use the definition below.

> Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs. It contains within it two key concepts:
>
> - the concept of 'needs', in particular the essential needs of the world's poor, to which overriding priority should be given; and
> - the idea of limitations imposed by the state of technology and social organization on the environment's ability to meet present and future needs.

Figure 1. Definition of Sustainability from the Brundtland Report[6].

The Engineering Design Process as a problem solving technique was introduced. Although the engineering majors were familiar with the process, the non-majors were not. The engineering majors were able to share examples of engineering design and use of design tools. In addition to the traditional steps of the engineering design process, constraints for sustainable design were discussed. These included:

1. Increasing local economic diversity
2. Reducing the use of energy

3. Recycling waste products
4. Using appropriate technology
5. Providing labor intensive solutions
6. Involving local community

Next, the class discussed the state of the world with respect to the atmosphere, hydrosphere, and lithosphere. Both problems in increase of pollution as well as successes in reducing pollution were argued. Observations from port experiences provided real-world examples of each of these topics.

In the second half of the course, the appropriate role of technology was discussed in greater depth. The class also looked at tools for measuring sustainability. These included environmental statistics, economic indicators, and computer analyses such as measurement of an ecological or carbon footprint.

Finally, the students worked on a class project. The engineering design process was applied step-by-step to a solid waste situation. The constraints for sustainable design were emphasized along with the engineering design process.

Class style

In order to facilitate classroom discussions, the classroom seating was arranged in a circle. A class size of 14 students and a faculty member allowed for involvement of all of the participants. Daily readings were assigned for discussion. Because of the different points of view from the texts as well as assigned journal articles, discussions were often lively (even at 8:00 in the morning).Twenty percent of the students' grade was based on classroom participation. After the first few class sessions, the students realized the importance of the readings and of the discussions and were prepared for sharing their thoughts. An emphasis was placed on support of argument with facts and observations.

Field experiences

A unique aspect of the Semester-at-Sea experience is the practical field component comprising 20% of each class. Therefore, the lectures and classroom discussions were integrated with the ship's itinerary. For the Fall 2009 voyage, the ship departed Halifax, Nova Scotia on August 27 with ports of call in: Cadiz, Spain; Casablanca, Morocco; Accra, Ghana; Cape Town, South Africa; Port Louis, Mauritius; Chennai, India; Ho Chi Minh City; Vietnam; Hong Kong; Shanghai, China; Yokohama and Kobe, Japan; and Honolulu and Hilo, Hawaii; before arriving at San Diego, California on December 14. While in port, students were required to keep a journal that recorded visits to locations with sustainability-related problems or projects. Students were also required to participate in at least one service program along the voyage to contribute to the class sustainability project proposal. An observational methodology was developed during class which applied to the journal entries. The journals provided a basis for class discussions and case histories as well as the final design project.

Sixteen hours of in-port experiences were required for each student. The sixteen hours had to include at least one service-related activity. Students chose working on Habitat for Humanity homes in Ghana and South Africa, visiting orphanages in Morocco and Vietnam, and helping to clean and paint a

school in India for example. Other activities and observations included attendance at a talk on Sustainability and the Mining Industry in Ghana, visits to a variety of electrical power generation facilities (solar and wind in Spain, hydroelectric in Ghana, nuclear in South Africa, biomass in Mauritius, geothermal in Hawaii), a ride on the mag-lev train in Shanghai, and trips to manufacturing plants in Vietnam and South Africa..

Much of the class session after a port was spent discussing issues of design and sustainability at that location. For example, the students who visited the wind and solar facilities in Spain found the wind program to be sustainable, but the solar program to be unsustainable. They cited the definition of sustainability, cost issues, and land concerns. The wind farm allowed farming to continue and the students discussed the sustainability of dual usage of land. The solar facility was considerably larger than the wind facility, but produced 1/10 of the power and destroyed the farm land. This led to discussions on the technological development of each of these alternative energy resources, the additional research needed, and the appropriateness of these technologies for various locations around the world.

The field experiences also formed the basis for the final engineering design project for the class. After traveling around the world and observing problems, the students chose to address the issue of solid waste in Ghana. The countryside that they observed was often polluted with trash. The class divided into sub-teams to attack this issue and aimed the design for a school that some had visited while in Accra. They chose a school because of the size of the facility and the educational mission. One team worked on design of a waste separation setup with three bins. In their report, they documented the steps of the engineering design process as they reached their solution. Another team worked on a composting system which would allow the school to grow a small garden of vegetables. One more team developed a paper-making project that the school children could undertake. The final group created an educational unit on solid waste pollution and disposal. Because of the nature of the semester, the students were not able to implement their designs in Ghana. However, future voyages will travel there and will have these designs available to them for construction. Continuity from semester to semester will add to the sustainability of this class.

Assessment

Assessments of both the students and of the course were undertaken. Both formative and summative assessments of the students occurred. The formative assessment tools included evaluation of student participation during classroom discussions, field experience memos, and homework assignments. Summative tools included a pre-post content assessment, a mid-term exam, and a final engineering design project. The content assessment, in essay and short answer format, asked for a definition of sustainability, the steps in the engineering design process, and measures that should be taken for sustainable design. Although the number of participants is too low to provide statistically significant results, some generalizations can be made. The average on the pre- content assessment was 62% while on the post the average was 95%. All students showed growth with the exception of one student who scored 100% on both. Grades were based equally upon class participation, homework assignments, mid-term exam, field experiences, and final project.

Assessment of the course goals occurred through analyses of class discussions, exams, homework assignments, field experience memos, and final project. The students were able to successfully define sustainability (goal 1) on the first exam. They were able to identify sustainability issues (goal 2) as was evidenced through class discussions and field experience memos. The students were successfully able to apply the engineering design method (goal 3) to their final project. Through class discussions, students were able to summarize methods for measuring sustainability. Finally, the students were able to give examples of sustainable and

non-sustainable projects (goal 5) through class discussions and field experience memos. Both the students and the faculty member were satisfied that all of the class goals had been successfully met.

At the end of the semester, the students were asked to evaluate the course. The overall evaluation of the course was quite positive. However, one student commented that he wished that there had been more engineering content in the course. This student chose to identify himself and was a senior in engineering and was the student who scored 100% on both the pre- and post- content assessment. Because this was a lower division course for both majors and non-majors, it was not designed to challenge someone at this level. However, this particular student was a huge asset to the class and contributed greatly to the discussions. The non-majors were especially positive in the evaluation of the class and pointed out that they better understand technical constraints and design issues especially for underserved communities.

Summary and Conclusion

A survey course entitled Engineering Design for Sustainability was designed for lover division engineering majors and non-majors. The course was offered as part of a semester-long international experience and integrated classroom and field experiences. Students were successful in applying the engineering design technique with constraints for sustainability to a real world project – a solid waste problem in Ghana. Future semesters will have to opportunity to implement the project as well as to design their own project.

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