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Introducing Sustainable Design Principles in Freshman Civil Engineering Design

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Abstract

As issues dealing with sustainability are becoming more commonplace in industry, it is important for undergraduate students to become aware of how sustainability principles relate to their intended engineering major. By introducing sustainable design principles early in their academic career, students can apply these principles throughout the remainder of their higher-level courses. In a freshman introduction to design course, a more structured strategy to teaching sustainable design was implemented to incorporate sustainability principles early in the civil engineering curriculum. The purpose at this stage in student learning was to increase students' awareness of sustainable design through the introduction to sustainability concepts, such as the triple bottom line, life-cycle assessment, and carbon footprint, through discussion of concrete as a construction material and case studies of building construction. Pre- and post-surveys were conducted at the beginning and end of the quarter, respectively, to assess student learning. Results confirmed an increase in student awareness and understanding of sustainable design concepts that were incorporated on a weekly basis throughout the course and how they can be related to civil engineering projects.

Introduction

In the Fundamental Canons of the American Society of Civil Engineers (ASCE) Code of Ethics, it states that engineers "shall strive to comply with the principles of sustainable development in the performance of their professional duties."[1] Additionally, in the statement *Dialogue on the Engineer's Role in Sustainable Development – Johannesburg and Beyond* (NAE 2002)[2], a number of American engineering societies (including the American Society of Civil Engineers, the American Institute of Chemical Engineers, the American Society of Mechanical Engineers, the National Society of Professional Engineers, and the National Academy of Engineering) formally stated the need for engineers to "deliver solutions that are technically viable, commercially feasible, and environmentally and socially sustainable." As civil engineers design practical solutions to include economic feasibility and environmental impacts of a project, there is a need to develop more engineers who are aware of and equipped with the ability to design solutions that include sustainability principles, enhancing their services to society and the environment[3].

Although the need exists, as educators in civil engineering, it is not always easy to find room in the rigid curriculum to integrate sustainable design principles as a fundamental component in technical civil engineering courses. While still providing the necessary technical knowledge to design solutions, it is also important to balance this, in an effective way, with a broader approach to problem solving that includes ideas of sustainable development across the curriculum[4]. Following curricular goals during the freshman year, as presented by Vanasupa and Splitt (2004)[5], this paper focuses on providing an awareness of sustainability issues and sustainable design principles in an introduction to design course for first-year civil engineering students.

Course Structure

The Introduction to Design course is a required course for most of the freshmen engineering students at Rose-Hulman Institute of Technology (RHIT). Each engineering department that offers this course defines the makeup and activities to meet its curriculum. The department of civil engineering offers two sections of the Introduction to Design course to its civil engineering students in the spring quarter. This is a project-based course, in which students work in teams on a project in the community. An objective of this client-driven course is the design of a real project. Example projects include trail design, drainage problems, and site design and layout. Solicitation of projects from potential clients starts the first week of January, and it takes the form of email to the RHIT community and an advertisement in the local newspaper. Individuals submitting projects for consideration must also include a client contact who is willing to work with the students. Projects are vetted for inclusion in the course based on appropriate level of work involved. Typically, a total of 10 or 11 different projects are required for the class. Usually there are 40 to 50 first-year students majoring in civil engineering. The projects are assigned to teams consisting of four or five students by the first week of the spring quarter. The teams have an initial meeting with their client and faculty mentor to define the scope of the project. Thereafter, each team is required to have weekly meetings with their client and faculty mentor. Each team has a civil engineering faculty mentor to help provide technical project guidance. The course meets once a week for 150 minutes for 10 weeks. The class meets each week for a lecture period to review each step in the development of their final report for their project. The weekly lectures are planned and conducted to introduce and facilitate the completion of weekly assignments that are sections of their report (i.e. project description, project approach, design requirements, evaluation of alternatives, and cost estimates). Students also have weekly reading assignments on which they are quizzed during the class meeting. During the fifth week of the quarter, each student team gives a progress report presentation in the presence of their clients, fellow students, and faculty members. The progress report and the weekly assignments are indicative of the important communication skills that the students develop during the course – a key focus of the class. Finally, at the end of the quarter, each team produces a written report for their client. Each client is asked to evaluate the student team on the basis of its report and the interactions the client had with its team throughout the quarter. Additionally, the course includes a one day trip to a major construction site in a large metropolitan area. The main objective of the field trip is to give first-year civil engineering majors a preview and an appreciation of the work done by a professional civil engineer and to increase their interests and excitement of the various sub-disciplines in civil engineering.

Incorporation of Sustainable Principles into the Course

Based on our department's discussions with our Board of Advisors, we incorporated sustainable design principles as part of the weekly lectures in the Introduction to Design class. Using *The Sustainable Concrete Guide: Strategies and Examples*[6] as a text for the course, students were given weekly reading assignments from the book. To ensure that students read the text, weekly quizzes were given to assess student understanding of the basic concepts, and the main ideas from the reading were reinforced and discussed in class that week. The lectures were designed to introduce the concepts of sustainable design to the students and, more importantly, to illustrate how each student team should incorporate these concepts into their design. Our main goal at this

level was to emphasize the three critical components of sustainable development: economic, environmental, and social impacts. To facilitate further discussion of these new topics outside of the classroom, a discussion question was posed each week that related to the reading. Students then participated in an online blog discussion and were graded on whether or not they joined in the discussion. The blog site was chosen as a medium for the discussion, as opposed to a verbal in-class discussion, to encourage those freshman students, who may still be intimidated to speak up in class, to feel comfortable participating.

In addition to the weekly readings and discussions on sustainable design principles, students worked on an in-class exercise using the EcoAudit tool from the CES EduPack™ software. CES EduPack includes an extensive database of materials property and processing information. The EcoAudit tool brings in a life-cycle assessment approach to material selection of a product by calculating energy used and carbon dioxide (CO_2) emitted during different stages of the product's life cycle (i.e. material acquisition, manufacture, transport, use, and disposal). For the exercise in the civil engineering introduction to design course, the students were given the problem of choosing a construction material for the design of a bridge girder on a pedestrian bridge. The choice of construction material was based on sustainable design principles to a civil engineering project. Students worked in teams, with each team evaluating a different material: oak timber, steel, or concrete. Students calculated the volume of the material needed based on deflection and moment of inertia computations to maintain a given maximum deflection value as specified in the design requirements. Students then had to choose specifics regarding the manufacture and end-of-life options for their material. Using EcoAudit as an interactive tool, the students could run various simulations to review output based on their selections of manufacture process, end-of-life options, or recycled content in material. They used the EcoAudit tool to evaluate the energy used and CO_2 emitted from the use of their material for bridge construction. When each team finished the evaluation of their material, the class reconvened to discuss the resulting total energy used and CO_2 emitted from each team's bridge material and discussed which material had the lowest environmental impact. This also led into discussions of locally-sourced materials and transportation impacts on economic and social aspects of the bridge construction.

The Sustainable Concrete Guide: Strategies and Examples[6]

To introduce sustainable design principles throughout this course, weekly reading assignments and lectures were based on the text *The Sustainable Concrete Guide: Strategies & Examples*[6]. Although the text is solely based on the application of these principles to concrete structures, the sustainability concepts presented provide a foundation that can be applied to other construction material. The various sections of the text used are outlined as Introduction, Part 1: Concrete Basics for Sustainability, Part II: Considerations for Best Use of Concrete for Sustainable Structures, and Part III: Beyond Sustainable Rating Systems: Project Profiles. The first part of the book includes an introduction to sustainability concepts, including the triple bottom line, life cycle assessment, carbon footprint, and common rating systems. Part two of the book includes considerations for using concrete to construct sustainable structures. This includes topics of carbon footprint in cement production, thermal transmission and thermal mass and storage of concrete as a building material, longevity and service life, pervious concrete and pavers for stormwater management, human factors of the living and working environment in a building,

and economic impact. The final part of the book profiles various examples of buildings and other structures that incorporate sustainable concrete features and sustainable design principles.

Pre- and Post-Course Survey Results

Students in both sections of the civil engineering introduction to design course took a pre- and post-course survey. Thirty-five students participated in the study.

The first part of the survey measured students' perceptions of their ability and knowledge of sustainable design principles related to civil engineering. Students rated how well they agreed with the statements on a 1-5 scale (1 = strongly disagree; 5 = strongly agree). A paired t-test analysis revealed statistically significant differences between the pre- and post-course ratings by students on all 5 criteria. Student ratings of their abilities increased across the course.

Table 1: Mean Rating of Ability Items (N = 35)

Question	Pre	Post
I am able to accurately define what is meant by sustainable design. *	2.66	4.26
I am able to estimate life-cycle effects of processes and products. *	2.49	3.83
I am able to minimize waste, CO_2 emissions, and energy use through sustainable design practices. *	2.49	4.14
I am able to apply sustainable design practices to civil engineering projects. *	2.69	4.37
I am able to describe the triple bottom line. *	1.60	3.74

Scale: 1 = Strongly Disagree, 2 = Disagree, 3 = Neither Disagree nor Agree, 4 = Agree, 5 = Strongly Agree

*Statistically significant difference ($p < 0.01$)

The next part of the survey included multiple choice questions of basic knowledge items relating to sustainable design principles in civil engineering. The related samples McNemar test revealed 2 statistically significant differences between pre- and post-course scores of students on knowledge items. Significantly more students provided the correct answer after completing the course course than prior to the course on 2 items. There was no significant difference pre- to post-course in the percentage of students answering the carbon footprint item correctly.

Table 2: Percent of Knowledge Items Correct (N = 35)

Question	Pre	Post
A common rating system for sustainable design in building construction is [leadership in energy and environmental design]. *	25%	85%
The three aspects of the triple bottom line in sustainable design describe impacts on [environment, society, economy]. *	17.5%	87.5%
Carbon footprint refers to CO_2 emissions due to the [all of the above].	80%	82.5%

*Statistically significant difference ($p < 0.01$)

Another section was included on the post-course survey only. Students were asked to rate their agreement with 5 items regarding the course and the EcoAudit tool. Again, students rated how well they agreed with the statements on a 1-5 scale (1 = strongly disagree; 5 = strongly agree). The mean rating for each item can be seen in Table 3 below. Overall, students agreed the course increased their awareness of sustainable engineering practices and how those practices relate to civil engineering.

Table 3: Mean Rating of Post-course Only Items (N=35)

Question	Mean Rating
The lessons in this course provided me with an awareness of sustainable engineering practices.	4.40
The class session helped me realize how sustainability relates to civil engineering disciplines.	4.29
The EcoAudit exercise increased my understanding of sustainable design.	3.40
Specifically, I recognize how the EcoAudit tool is beneficial in material selection.	3.94
I was able to interpret the input and output data of the EcoAudit tool to draw conclusions about material selection and environmental impacts.	3.86

Scale: 1 = Strongly Disagree, 2 = Disagree, 3 = Neither Disagree nor Agree, 4 = Agree, 5 = Strongly Agree

The same qualitative questions were posed to the students in the pre- and post-surveys to explore their responses for any changes in substantive explanations of the topics at hand. A sampling of responses is displayed in Table 4.

Table 4: Sampling of Responses to Qualitative Questions

Question	Pre-Survey Response	Post-Survey Response
Define sustainability/sustainable design.	Designs that are 'earth-friendly'	Design that is not only economically, socially, and economically beneficial for today's generation, but for generations to come
Define sustainability/sustainable design.	The ability to last	The act of making structures, buildings, more environmentally friendly to reduce resources used and minimize harm to the environment.
Define sustainability/sustainable design.	Sustainable designs are built with the environment, people, and money in mind. These are created to last a long time.	Sustainability is the use of materials that will uphold and provide benefits now and in the future. Structures are designed with sustainable aspects so that they can provide a better triple bottom line for the future
Describe how sustainable design relates to careers in civil engineering. How are sustainable design practices used in civil engineering projects?	In civil engineering many different structures can be built with a sustainable design, like bridges, buildings and roadways. They keep down the impact on the environment at the lowest cost possible.	Civil engineering uses sustainable designs because we use the triple bottom line. We want to boost the economy by using local materials and getting the most for our money. We want to provide a sufficient areas for people to live. Also we want to maintain the environment so that the future generations have a clean planet to live on.
Describe how sustainable design relates to careers in civil engineering. How are sustainable design practices used in civil engineering projects?	I can't.	Designing a building that will meet the triple bottom line today and will continue to meet it throughout the years to come.

Describe how sustainable design relates to careers in civil engineering. How are sustainable design practices used in civil engineering projects?	Sustainable designs are made in buildings to reduce heating and cooling costs by using less energy, which in turn helps the environment. Engineering new ways to build infrastructure can help reduce the impact on the environment. There are many ways to use sustainable design in civil engineering.	Sustainable design is used in pretty much all types of civil engineering, such as building design, road design, and even designing parking lots. Uses of fly ash in concrete, permeable pavement, and green roofs are all examples of sustainable design elements.

Conclusions

According to the pre- and post-course survey results, the students exhibited an increased knowledge of sustainable design principles due to the information acquired through the civil engineering introduction to design course. This was the first year of incorporating sustainable design principles in the freshman-year course, so there is still much room for improvement to integrate these ideas as fundamental to the course and not supplemental material. Depending on the projects attained each year, the instructors can include sustainability topics in line with the selected projects, with the intention that students can apply their sustainability knowledge from the course to their project. By continuing to perform pre- and post-course surveys, the instructors can continue to assess the effectiveness of integrating sustainable design principles into the course thus setting a foundation for students to build on as they continue their academic and professional careers.

Bibliography

1. American Society of Civil Engineers (ASCE). 2012. http://www.asce.org/Leadership-and-Management/Ethics/Code-of-Ethics/ (accessed August 2012).
2. National Academy of Engineering (NAE). 2002. Dialogue on the Engineer's Role in Sustainable Development—Johannesburg and Beyond. June 24, 2002. U.S. National Academies; statement endorsed by AAES, AIChE, ASME, NAE, and NSPE.
3. Chau, K.W. 2007. Incorporation of sustainability concepts into a civil engineering curriculum. *Journal of Professional Issues in Engineering Education and Practice* 133(3):188-191.
4. Fenner, R.A., C.M. Ainger, H.J. Cruickshank, and P.M. Guthrie. 2005. Embedding sustainable development at Cambridge University Engineering Department. *International Journal of Sustainability in Higher Education* 6(3): 229-241.
5. Vanasupa, L. and F.G. Splitt. 2004. Curricula for a Sustainable Future: A proposal for integrating environmental concepts into our curricula. In *Proceedings of 2004 Materials Research Society Spring Meeting*.
6. Schokker, A.J. 2010. *The Sustainable Concrete Guide: Strategies and Examples.* U.S. Green Concrete Council.