122nd ASEE Annual Conference & Exposition
June 14 - 17, 2015
Seattle, WA
Seattle Making Value for Society
Paper ID #13027

Making Students Cognizant of Sustainability through a Multidisciplinary Term Project in Low Level Courses

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Abstract

Current engineering students need to be equipped with a wider knowledge base in terms of environmental, economic, and social attributes of engineered systems, work, and materials. Sustainability is a perspective that can be introduced in early classes and not only as a technical topic in upper level classes. Lower level sustainability courses can be related to the knowledge gained in the required math, science, humanities, and social sciences through "mind mapping."

This paper presents a comprehensive term project entitled "Greening the Engineering Building" that was utilized to simulate sophomore civil engineering students' interest in green buildings through the development of a sustainable alternative to the current engineering building on campus. Students were asked to use passive design strategies to optimize the layout of the building, its location and window sizes, utilize green technologies in the form of geothermal heat pumps as well as solar panels for electricity generation for heating and cooling, and improve the building envelope performance through the selection of proper insulating materials. This project was assigned in CIVL 201: Introduction to Green Buildings. The course focuses on the mix of traditional engineering topics with emerging concepts of green technology in architecture and engineering. Students from various concentrations within the civil engineering department—environmental, structural, geotechnical, water resource, and construction management—were asked to work together in diverse groups of four on the aforementioned project.

Prior to the completion of, and at the completion of the project, students were asked a series of questions gauging their interest in sustainability, green buildings, green energy, and materials. Outcomes assessed the increase in interest in sustainability as well as the increase in student learning and understanding of sustainability related topics. Although the students found the project somewhat complex at the sophomore level, they indicated that it broadened their understanding of sustainability issues in civil engineering problems and informed them on how civil engineers are working in a multidisciplinary environment.

Introduction

The American Society of Civil Engineers (ASCE) released the second edition of the Civil Engineering Body of Knowledge for the 21st Century: Preparing the Civil Engineer of the Future (BOK2) in 2008.[1] BOK2 documents the need to proactively prepare civil engineers for a profession driven to change by sustainability requirements, among other factors, and identifies 24 outcomes which are necessary to fulfill the Body of Knowledge. The outcomes are wide-ranging and encompass some topics that were traditionally not part of civil engineering, but potentially related to civil engineering. ASCE describes "horizontal thinking" in the BOK2 in the context of a broad understanding of these related topics, resulting in engineers who are better prepared to work on interdisciplinary teams to "solve the complex problems of the future." The concept of horizontal thinking can then be directly related to understanding the broad scope of sustainability, which includes environmental, economic, and social needs of the current and future society.

ABET, Inc. requires that engineering programs assess student performance in courses and demonstrate that specific program outcomes are being met.[2] The current ABET requirements directly address sustainability through: Criterion 3(h) – "the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context"; and Criterion 3(c) – "an ability to design a system, components, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability." The inclusion of sustainability in the ABET Program Outcomes ensures that the students will be prepared to consider sustainability in engineering projects when they complete a bachelor's degree from an accredited institution. The question that then arises is how to best educate these students in sustainability.

As the faculty begin to incorporate concepts and principles of sustainability into the civil engineering curriculum, it is important to focus on teaching methods that encourage critical thinking and creativity in the students. Students not only need an understanding of sustainability to make significant engineering decisions, they also need the critical thinking skills to supply effective solutions to complex technical problems.[3] In this context, an active learning environment around sustainability issues in the civil engineering industry is useful for students to develop practical skills.[4]

Active learning techniques can vary from low-risk to high-risk with respect to teacher preparation, use of classroom time, student interaction, and resulting student learning. High-risk activities may offer large payoffs in student learning. Many high-risk active learning techniques have been documented in recent literature, including field trips,[5] peer teaching,[6] class discussions on open-ended questions,[7-8] hands-on manufacturing, laboratory testing,[9-10] project-based learning,[11] and cross grading and debate.[12] The flipped classroom technique is also a new and effective method of teaching[13] where traditional lectures are converted to readings assigned to students outside of class and the class time is used for homework assignments and other activities. This technique was used successfully to teach sustainability in the past.[14]

Low-risk active learning techniques have been introduced to engage students even in a lecture-based delivery, such as lecture worksheets,[6] reading quizzes,[7] and muddiest point exercises.[6, 9] Low-risk activities can be enhanced by converting lecture worksheets to active learning sheets of questions[15] followed by think-pair-share exercises between students and instant quizzes. Low-risk activities can also be used in conjunction with new technologies such as smartphones or clickers in the classroom to assess the reading/instant quizzes and muddiest point exercises. These technologies are more effective and engaging by providing instant feedback and focus the discussion.

This paper presents use of a high-risk active learning technique to teach some of the technical aspects of sustainability and green building design to sophomore students. The course is designed to deliver the materials through some of the low-risk activities such as lecture worksheets and reading quizzes. However, all the materials that students learn during the lecture come together in a comprehensive and complex term project.

Course Overview

CIVL 201: An Introduction to Civil Engineering is a course that students typically take in the fall semester of the sophomore year. The content of this course is flexible and can be modified to introduce different aspects of civil engineering at an introductory level. Traditionally, this course covered a variety of preparatory topics in civil engineering such as linear and angular measurements, computation of areas and volumes, coordinate surveying, blue print reading, construction document interpretation, and preparation at Manhattan College. However, after receiving an NSF grant in 2005, the content of the course was modified as a part of the grant activities and the course was redirected toward green building design. Now the course focuses on a mix of traditional engineering topics with emerging concepts of green technology in building design. The course was renamed *Introduction to Green Buildings*. At present, the topics that are covered in this course include: green site development such as excavation, foundations and basic surveying; building envelop and passive design such as window size, window placement, and overhangs for appropriate solar heat gains in the winter and shading in the summer; modeling in 3D using different drafting software; alternative energy systems such as solar, wind, hydroelectric and geothermal power; and a review of the basic behavior of existing green materials and their connections to the LEED criteria. At the end of the course students apply the knowledge they learned during the semester to an innovative and comprehensive term project dealing with greening the Leo Building at Manhattan College.

Term Project

Project-based learning is a teaching technique where students learn the technical concepts through a project.[11] In PBL the selection and development of the project is the most critical factor. The project should be directly relevant to the materials taught and open ended so that it doesn't have only one correct answer. Students indicate an increase in their level of learning of sustainability based on when the topics are taught through a combination of lectures (deductive approach) and active learning techniques (PBL).[16]

The CIVL 201 term project was defined very carefully to incorporate all the topics covered in lectures to a real-world application. Students are expected to work in a group of up to 4 students on a term project for more than half of the semester. The term project, defined as "Greening the Leo Building," involves a variety of hands-on activities such as computer modeling, site surveying and literature review related to the modules taught.

Each group starts the project by surveying the parking lot of the Leo Building. Later, they look for the location of the Leo Building foot print in Google sketch up and build a computer model of their new Green Leo Building. They should use passive design strategies to optimize the efficiency of the building, considering and redesigning the interior and the exterior of their new building. The interior layout should be altered to best position offices, classrooms, labs, etc. The exterior of the building should be altered to include the new location of properly sized windows and overhangs to maximize solar heat gains in winter and minimize solar heat gains in the summer. Each group must determine the true sun angles at the location of the Leo Building for the window sizing and overhangs. They should determine the energy demand of the building, both the required electrical energy and the required power for heating the building. They then design alternative green energy systems to provide the required energy for the building. A geothermal heating system should be used to provide winter heating and should be installed under the parking lot. A solar panel array should provide the electrical energy for the building and be installed on the roof.

The project statement provides some of the required information to each group such as the percentage of labs, classrooms and offices in each floor. However, to avoid any academic misconduct, some of the required information or assumptions are purposely not given to the students. Through this process students learn how to seek information by asking, refining questions and performing a literature review. The authors intentionally selected the Leo Building for the term project. The Leo Building is the engineering building at Manhattan College, and felt that students would be able to relate to it well at the personal level, and would therefore be more enthusiastic about the term project.

The project is introduced to the students after the first midterm examination and they have the opportunity to work on the project for more than half of the semester. The project is complex, challenging and fairly long. To reduce the length of the project, each group is only responsible for calculating the energy demand and interior design of one floor of the building. At the end of the project each group is required to submit a final report that includes the following: abstract, introduction, literature review, project design, conclusion, references, and appendix (that includes software-based drawings such as the floor plan, parking lot plan, elevation plan for the building facade and location of the windows, solar panels on the roof, etc.).

The project described above was used from the 2011 to the 2013 academic years in both spring and fall semesters. In 2014 the project was simplified slightly because it was too complex for sophomore students. However, the core content of the project related to green building design and civil engineering were kept intact and only the mechanical engineering aspect of the project (alternative green energy system for the building) was eliminated. The project was limited to surveying of the parking lot and passive design, including: (1) exterior design of the building—e.g., redesigning the location, sizes and overhangs of the windows—to minimize interior heating during winters and cooling during summers; and (2) interior design such as locations of the offices, labs and classrooms.

Learning Outcomes

The desired learning outcomes should be considered when a project is developed.[16] The CIVL 201 term project was created very carefully with two types of objectives, educational objectives and personal objectives.

The educational objectives were to involve students in an active learning environment and help them to use the knowledge they learned from lectures in a tangible multidisciplinary project. The personal objectives were to make students more cognizant about sustainability issues related to their personal and professional lives and encourage them to seek more information regarding these issues during their undergraduate education or at the personal level. The outcomes related to the educational and personal objectives are listed in Table 1.

Table 1: Project Outcomes Adopted from the ASCE Body of Knowledge

Educational Outcomes	Personal Outcomes
Application	**Knowledge**
Create a new "green" building utilizing alternative energy systems	***Recognize*** the importance of sustainability issues in their personal life

Two different levels of achievement specified in the Civil Engineering Body of Knowledge of "application" and "knowledge" were considered. Also, the outcomes at these levels were defined to meet the ABET criteria of "The broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context." The educational objectives were aimed at reaching the higher level of achievement in the BOK, while the personal objectives were intended to target the lowest level of the achievement in the BOK.

Student Assessment and Project Evaluation

The educational outcomes of the project were evaluated based on two different perspectives: student performance and student ratings. Student performance was evaluated based on the grade they received in their project. Table 2 shows the grading rubric for the term project.

Table 2: Evaluation Rubric for Introduction to Civil Engineering Course

Outcome	***Create*** a new "green" building utilizing alternative energy systems
Exemplary (3)	Does significant research gathering background information. Can develop a sustainable, energy efficient alternative to the engineering building.
Satisfactory (2)	Gathers background information. Can explain aspects of passive design and alternative energy sources.
Unsatisfactory (1)	Does not do adequate literature search. Can identify but not analyze or explain components of green building design.

The personal outcomes were evaluated based on student ratings in a survey deployed at the end of course. A sample of the survey questions is presented in Table 3. The survey employed a standard set of questions through which students rated their personal interest in sustainability before and after the term project and taking the course. A ratings scale from 0 to 4 was used, where 0 represents "Strongly disagree" and 4 represents "Strongly agree".

Table 3: Sample of the Survey Questions for Personal Outcomes

	Strongly agree	Agree	Neutral	Disagree	Strongly disagree	Not Sure
Recycling	4	3	2	1	0	NA
Minimizing waste sent to the landfill	4	3	2	1	0	NA
Choosing food based on its environmental impact	4	3	2	1	0	NA
Conserving water	4	3	2	1	0	NA
Conserving energy	4	3	2	1	0	NA

Results and Discussion

Three different instructors offer the CIVL 201 course at Manhattan College every semester. Data on 120 students was collected from three sections in Fall 2013 and three sections in Fall 2014 taught by two different instructors. All sections had the same term project, the same syllabus, and very similar lecture content.

Educational outcomes

Figure 1 shows the grade distribution in Fall 2013 and 2014 for the term project.

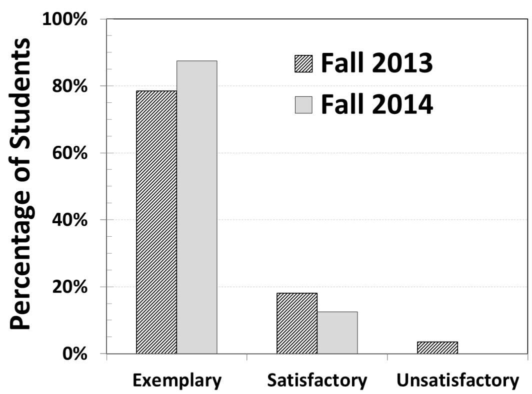

Figure 1: Student performance on project

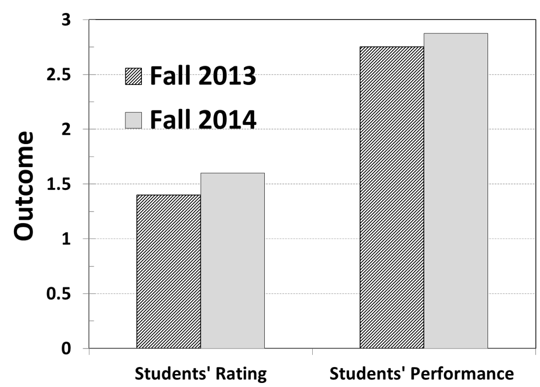

Figure 2: Average student ratings and grades

Figure 1 shows that students performed well despite the complexity of the project. Students performed slightly better in Fall 2014 compared to Fall 2013 after the project was simplified slightly. Figure 2 shows the project outcome from the students' and instructors' points of view. The average rating of student performance in the project by instructors was 2.75 and 2.87 on a 3 point scale in Fall 2013 and Fall 3014, respectively. However, student ratings were considerably lower. Average ratings by students were 1.4 in Fall 2013 and 1.6 in Fall 2014 on the same scale. The authors believe that although students felt obligated to work hard on the project, they were not thrilled to do so. Student performance and student ratings increased by the same percentage after the project was simplified. However, the student ratings did not increase considerably in Fall 2014. In general, the student ratings in Fall 2014 after the project was simplified were only 10% higher in all the categories compared to Fall 2013.

The end of semester surveys showed that on average 75% of the students found the term project interesting because it tied all the material they learned in lectures together in a real life project and students felt that they could use the knowledge they learned in a real world application. They were just unhappy about the length of the project. However, 52.7% of the students did not care that the project was specifically related to the Leo Building, which was a surprising result for the authors. The authors had selected the Leo Building purposely since it was familiar to students, and they expected that students would be more excited about greening a building that was known to them.

Personal outcomes

The project was more successful with respect to achieving personal outcomes. Figure 3 shows student interest in learning more about environmental issues and sustainability based on what they were exposed to in this course at: 1) the personal level or 2) by taking additional courses related to sustainability.

Figure 3 shows that students were slightly more interest to learn about sustainability issues on their own than on taking additional courses related to sustainability. 78% of the students showed high interest in learning more about environmental issues and indicated they will make a personal effort to be knowledgeable about them. However, only 66% of the students showed an interest in taking more courses with sustainability in their content. The result was very similar in Fall 2013 and Fall 2014, indicating that this interest was independent of the degree of difficulty of the project. 60% of the student did not have any prior knowledge about LEED certification before taking this class.

Figure 4 shows the degree of importance that students placed on different issues related to sustainability.

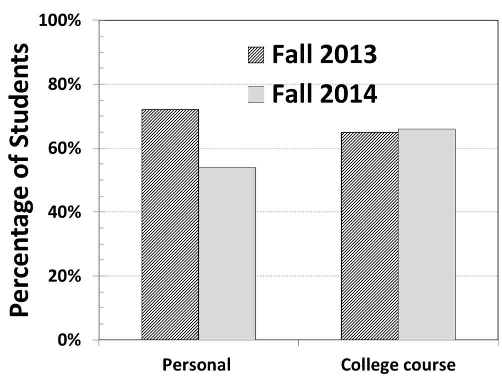

Figure 3: Student interest in learning more about sustainability

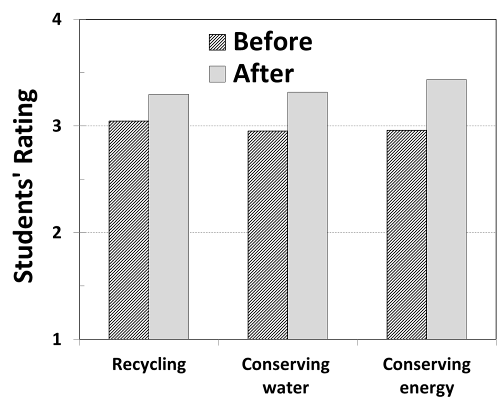

Figure 4: Student awareness of sustainability issues

On average there was an increase of 9% or more in student awareness regarding recycling, conserving water and conserving energy after taking the course. The highest increase, 13%, was in energy conservation, most likely because the term project focused mainly on the design of alternative energy systems for the Leo Building. Almost 30% of the engineering students did not think energy and water conversation was an important issue before taking the course. The project increased student awareness regarding these environmental issues and the percentage of students who were not concerned about any sustainability issues reduced to almost 9% after taking this course.

Conclusions

The paper describes a term project focused on sustainability that was defined for sophomore students in their first introduction to civil engineering course. The term project was defined with two types of objectives: educational objectives and personal objectives. The educational objectives focused on the application of content students learned from lectures on a real world project at a more advanced level. The personal objectives focused on making students more cognizant about environmental issues, especially around civil engineering problems.

The project was evaluated based on two main criteria: student performance and student ratings. The educational objectives were evaluated using grades in the term project and student ratings in surveys administered at the beginning and end of the course. The personal objectives were evaluated using student ratings only. Data was collected from 120 students in 6 different course sections taught in Fall 2013 and Fall 2014.

The results show that although students performed well in the project, they were not happy about the complexity of the project. 95% of the students performed at the satisfactory level and above and on average students rated the term project 2.8 out of 4.

The project was more successful at the personal level. More than 78% of the students showed an interest in learning more about sustainability based on what they learned in the course. As a result of taking the course, the percentage of students who were not concerned about any sustainability issues reduced from more than 30% to less than 9%.

Although the authors do not have comparative data, they believe that introducing sustainability in lower level courses was successful. Sustainability is a concept that should be incorporated into the civil engineering curriculum and the authors believe that it is more suitable to do this in lower level courses. However, the more technical aspects of sustainability should be added to each related topic as a module. Also, although the data showed there was no significant difference in student ratings and performance when the project was changed from a complex to a simplified one, the authors believe less complex projects are more suitable at the sophomore level.

Acknowledgment

The authors are grateful to Dr. Qian Wang for distributing the end of course surveys to his students and sharing the grade distribution from his sections with the authors. The authors are also grateful to Dr. Anirban De for his input.

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