AC 2012-3285: "GREEN PROJECTS TO PAVEMENTS": A PROJECT-BASED LEARNING APPROACH TO INTRODUCING SUSTAINABILITY TO CIVIL ENGINEERING STUDENTS

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"Green Projects to Pavements"
A Project-Based Learning Approach to Introducing Sustainability to Civil Engineering Students

Abstract

Today's education system generally adheres to a deductive style where instructors present the fundamentals that lead to application. In addition, the majority of engineering students are visual, sensing, and active learners, whereas traditional delivery of course material in engineering academia is auditory, passive, and sequential. The objective of this study was to evaluate the problem-based learning approach in introducing sustainability and concrete mixture design in an effort to increase student learning. The goal of any instructor is to engage students and find more effective methods of teaching course topics. This study addresses these objectives and provides faculty teaching similar courses at other institutions the necessary information needed to implement this program. Sustainability is a major topic that is being addressed by cities, states, and national governments around the world. This Green Projects-to-Pavements program introduces the topic of sustainability while enhancing materials learning through a project-based learning approach. This program was implemented in a junior level civil engineering course, Introduction to Structural Materials, at the University of Colorado Denver. Students were provided a project goal (design, test, and place a sustainable concrete pavement) and given access to resources that aided in their design of a sustainable concrete mixture. The instructor acted as a facilitator and advisor to the students instead of using a deductive approach, such as lecturing on the topic. Students were active in performing their own research rather than being passive listeners in course lectures. In addition, the students mixed and tested concrete themselves, which provided for a more "hands on" role in the learning process.

The performance of each student was assessed over a semester of observations via (1) weekly project group meetings, (2) oral presentations by each group, (3) a technical report, (4) end of semester feedback by the students, and (5) final exam questions. The results of this study indicate that this program was beneficial for introducing students to sustainability in regards to civil engineering materials. Student feedback was very positive regarding this project and scores on project related questions on the final exam demonstrated that students developed a clear understanding of how materials could be used to achieve a sustainable concrete mixture.

Introduction

Beginning at birth, most individuals learn in an inductive manner (i.e. learning from discovery or observation). Conversely, most teaching is delivered in a deductive style in which instructors present the fundamentals that lead to application. In addition, the majority of engineering students are visual, sensing, and active learners, whereas traditional delivery in engineering academia is auditory, passive, and sequential (Fedler, 1988). This incompatibility in learning styles and delivery methods may result in some students' lack of interest in the subject matter, decreased performance in other course work, and potentially a drop in student retention. Students will be introduced to the topic of sustainability through the selection of concrete materials and will select materials based on their life-cycle impact and influence on concrete performance.

The primary objective of this study was to evaluate student performance by means of problem-based learning. This was achieved by introducing sustainability concepts using concrete mixture design in an effort to increase student learning. The goal of any instructor is to engage students and find more effective methods of presenting course topics. This study addresses these objectives and will provide faculty teaching similar courses at other institutions the necessary information needed to implement this program. Sustainability is a major topic that is being addressed by cities, states, and national governments across the global. It is important for students to be introduced to sustainability as they will be the individuals forced to consider issues such as virgin materials depletion, greenhouse gas emissions, and the heat island effect. Such concerns are of critical importance to the future design and construction of civil engineering infrastructure.

This Green Projects-to-Pavements program introduced the topic of sustainability while enhancing materials learning through a project-based learning approach. This student design project was included as a supplement in the junior level civil engineering course, Introduction to Structural Materials. The students were presented a project goal of designing, batching, and testing an economical and sustainable concrete pavement mixture. The students were given access to resources that aided in their sustainable concrete mixture design. The instructor and teaching assistant acted as a facilitator and advisor to the students (in contrast to using a deductive approach and lecturing on the topic).

This program introduces a learning style that is more compatible for the typical engineering student that is inductive, active and sensory (visual and kinesthetic styles). Each learning style in terms of their relationship to the proposed study is discussed in the following:

- Inductive Learning:
  - Students will be provided a problem in which they must, on their own, develop a solution. The students must perform their own research and learning of the subject rather than a lecture style presentation by the instructor (traditional auditory and sequential teaching style). In addition, students will experiment through trial and error with mixture designs and testing to determine what "works" and "doesn't work."
- Active Learning:
  - Students will be active in performing their own research rather than being passive listeners in course lectures. In addition, the students will be mixing and testing concrete themselves, which provides for a more "hands on" role in the learning process.
- Sensory Learning:
  - Students will experience both visual and kinesthetic learning through seeing the concrete mixed and tested as well as physically placing the concrete during the application phase of the study.

The performance of the students using this teaching style were assessed using weekly project group meetings, oral presentations by each group, a technical report, end of semester feedback by the students, and final exam questions.

Background

Problem based learning is not new to civil engineering education (Mills and Treagust, 2003; Reeves and Laffey, 1999; Jonassen and Strobel, 2006; Hadgraft, 1993). In 1993, Hadgraft examined the use of problem-based learning in civil engineering education. Hadgraft saw students being taught with problem-based learning as having not only the technical skills, but the communication, teamwork, leadership, innovation and initiative. Jonassen and Strobel (2006) commented how practicing engineers are employed and rewarded for solving problems and wonder why we do not teach students in the same fashion. One such way of exposing students to problem solving and problem solving skills was through problem-based learning. Problem-based learning programs use integrated and interdisciplinary problems that involve a high degree of collaboration. Hasna (2008) discussed how using problem-based learning in engineering design courses allowed students to be more independent learners. Hasna further explains that problem-based learning helps with students learning the "soft skills needed to enter the engineering workplace."

Few studies have examined the incorporation of problem-based or project-based learning when introducing sustainability as the course topic (Steinemann, 2003; Chau, 2007). Chau (2007) examined the integration of sustainability into the civil engineering program in Hong Kong. He utilized a team based design project with a problem-based learning approach to introduce sustainability concepts into the program. Chau used the problem-based learning design project as a way for students to experience "real-life" problem solving, project management, interpersonal skills, teamwork, and the ability to integrate education and leadership skills. An example of a design project that was used was the design of a footbridge. Students were required to consider the use of recycled materials as construction materials for the project, examine the ecological impact of their design, ensure that their design would blend in with the surrounding environment, provide a feasible engineering solution to minimize waste during construction, and examine daylighting and energy consumption concepts. The results of this integration (through student and employer questionnaires) suggested that multidisciplinary skills were developed by the students in the program. Another finding from the employer surveys suggested that students from the problem based learning program were found to be more innovative when compared to students at other universities.

Steinemann (2003) developed a course that linked pedagogy and practice. The course used problem based learning with emphasis on students identifying and solving sustainability problems on a university campus. The primary objective of the course was to explore the principles and practice of sustainable development. Project topics ranged from energy efficiency, water conservation, and stormwater management to sustainable landscaping, recycling and composting and transportation. The study found that the problem based learning style was a very effective method of learning about sustainability. One student commented: "as a sustainability curriculum is established, faculty should encourage creative thought and the analysis of local conditions." Another student commented that "the most valuable learning tool in this process for me was that I could apply techniques learned in school to a concrete project." Steinemann found that the problem based learning provided a motivating environment for learning and problem solving. In addition, problem-based learning allowed the students to be more innovative in their class projects.

The authors are not aware of any studies that have incorporated this learning style when discussing sustainability and structural materials learning.

Problem-Based Course Project Description

The Green Projects-to-Pavements course project was introduced in a junior level civil engineering course, Introduction to Structural Materials, at the University of Colorado Denver in the fall 2011. The objective of this course is to acquire the basic understanding of the production, properties, and behavior of common structural materials. In addition, it is the goal of the course to provide opportunities for students to develop solutions to problems by working individually and with others in presenting these solutions in a clear and professional manner. This course focuses on materials used in the construction of of our nation's infrastructure. Emphasis is placed on concrete, steel, and wood. Sustainability through materials selection and usage is covered. Lastly, the course aims to prepare students to demonstrate effective communication skills through the writing of laboratory reports and in-class presentations.

The Green Projects-to-Pavements project was a proposed study funded in-part by the University of Colorado – Presidential Teaching and Learning Collaborative Program. The individuals that contributed to this study included the faculty and teaching assistant that developed and administered the study, a peer-group of collaborators acting as an advisory panel, and the students of the class. The problem-based design project was a semester long project beginning with students being given a project objective, followed by students performing their own literature research, material selection, obtaining materials, experimentation, testing, and presentation. In regards to the course topic: Design and Batching of Concrete Mixtures, the traditional teaching style was to conduct a PowerPoint lecture, work through an example problem, and assign projects. Assessment of the students' learning was performed through homework and exams.

Figure 1 depicts the fundamental differences between traditional and problem-based learning approaches. In the problem based learning approach, students were given a complex problem and began addressing this problem through group discussion and problem solving. Students sought out resources to complete the project. The students were then assessed through weekly meetings, an oral presentation, a technical report, and end of semester student feedback. Assessment was also performed through project related questions on the course final exam.

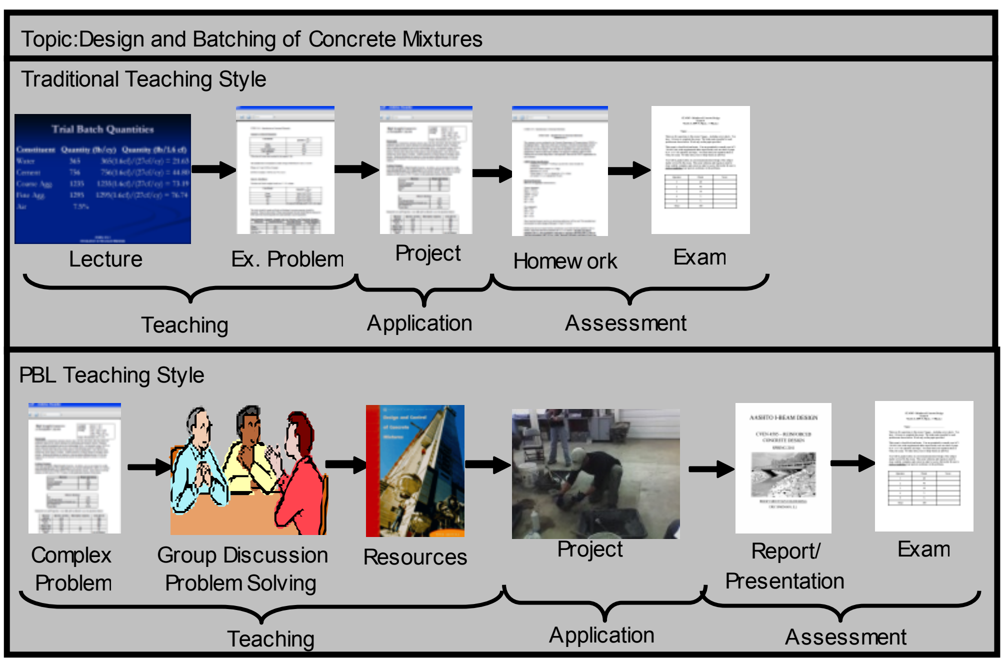

Figure 1. Traditional and Problem Based Learning Approaches

The project was designed to account for 15% of the student's grade for the course. Students worked in groups of 4-5 individuals to complete the project. The instructor met with each group at least once per week throughout the semester to discuss the groups' direction and monitor progress toward project completion. The following is an overview of the project as provided to the students.

Background

Concrete is the most commonly used building material in construction today. In 2009, an estimated 70 billion tons of cement was produced in the United States. Everything related to construction is open for scrutiny in today's eco-conscience society. People today are more in tune and informed about the negative effects humankind leaves behind for future generations. Builders today are under constant pressure to become more "earth friendly" and are constantly looking for more ways to incorporate recycled materials into their products. The potential use of recycled materials in concrete is a growing interest.

The production of portland cement (PC) requires significant amounts of energy as well as significant amounts of carbon dioxide (CO_2). Although recent advancements in cement production have reduced the amount of CO_2 produced to below 3% of the United States total industrial CO_2 emissions, cement production in 2009 produced an estimated 29 million metric tons of CO_2. Carbon dioxide is a greenhouse gas and believed by the majority of researchers to be a one of the main contributors to global warming. Most of the CO_2 produced comes from the high temperature kilns used in PC production plants. When considering all the raw materials used to produce concrete today, PC is the largest contributor to greenhouse gases.

The use of recycled materials to replace cement is common practice and has been for many years. It has been demonstrated that concrete's strength, durability and workability can be increased from the use of certain recycled materials. Supplementary cementitious materials (SCM) have been used to replace cement in concrete for thousands of years.

Aside from cement, concrete is composed of several other ingredients, primarily aggregates. Although important in varying degrees to a concrete mixture, aggregates generally are a filler material. In fact, it is the bond between the aggregate and cement that is the weakest link in the concrete matrix. Typically, it is only in high strength concretes where aggregate strength becomes a contributing factor. Quality aggregate sources are becoming more difficult to find. Many aggregate sources used in the past have been depleted and concrete batch plants are forced to use lesser quality aggregates. To acquire aggregates from the earth, considerable energy must be used to quarry and refine the rock before being suitable for use in concrete. Mining operations are always at the forefront of environmental debate, not only from the destructive aspect, but from an aesthetic standpoint. For these reasons, aggregates are of primary interest with regards to potential replacement with recycled materials.

Problem Statement

The task of the student was to design a **Sustainable Concrete Mixture** that could be used for pavements. This design project required students to design a concrete mixture that (1) met the structural requirements (compressive strength) of a Colorado Department of Transportation (CDOT) Class P "pavement" concrete, (2) incorporate sustainable concrete materials into the design of the mixture and quantify through an "abbreviated" life-cycle assessment (LCA), (3) demonstrate the necessary properties for field placement through laboratory experimentation, and (4) provide an economical concrete mixture.

Within this design project, the student groups designed a preliminary sustainable concrete mixture that was batched at the quarter point in the semester. Based on the initial performance of the mixture, each group had an opportunity to redesign or confirm the results of the first batch by mixing a second time two weeks following the initial batching.

Initial Direction

Student groups began researching potential materials to be used in their designs. Students either acquired material properties (i.e. specific gravity, absorption capacity, etc.) or performed the necessary tests to determine the properties. The instructor was available to help guide students in appropriate directions and provide necessary resources to the student groups. Ultimately, it was the student group's decision to select the materials used in the concrete mixture design. The instructor worked with the student groups to acquire the needed materials for the concrete mixtures if the materials were not available in the University of Colorado Denver (UCD) - Concrete Materials Laboratory.

Scoring System

The total score for the project was 100 points. The scoring system was categorized into 4 sections:

Part I - Design of the concrete mixture and meeting the necessary field performance (structural and workability requirements) (30 Points)

- How was the concrete mixture designed?
- Why were specific materials selected?
- What are the material properties of the materials selected?
- Did the mixture meet the structural requirements of a CDOT Class P?
- Did the mixture meet workability requirements (slump = 4±1in)?
- Other?

Part II - Quantifying Sustainability (30 Points)

- How are the materials selected sustainable?
- Provide data to support your decision to use these materials (embodied energy, CO2, transportation, etc….)
- How does your decision to use these materials affect materials resource, consumption, etc…?
- Other?

Part III - Economics (20 Points)

- Provide an estimated cost for your sustainable concrete mixture.
- How would the concrete mixture cost be different had the sustainable concrete materials not be included in the design?
- Is there any additional "potential" cost savings by using the materials you have selected (cost savings that may not be seen initially; however, may be realized long-term)?
- Other?

Part IV - Final Report/Presentation (20 Points)

- Each group will be required to submit a technical report on the developed mixture. In addition, group presentations will be given, presenting the results from your report. The report / presentation will be worth a maximum of 20 points. The report will be due the day of the presentation. Presentations should be approximately 20 minutes in length. Presentations will be given on the last regularly scheduled class day of the semester. The report and presentations must include a summary of Parts I-III above. Additional information to support your design project should be included.
- The report and presentation should include graphs, tables, photos, etc. to help the audience understand your design project.

Instructor Observations

From the start, this project generated a high level of interest by the students in the class. Within the first week of handing out the assignment, students were in the laboratory testing materials they thought they may want to use for their projects. Some student groups became very creative by looking at very different, but still sustainable pavements. One of the six groups in the class approached the instructor about designing and testing concrete mixtures for pervious concrete pavement. The project description was specifically for a concrete that could be used for high-volume highway traffic; however, the group provided a strong case for wanting to develop a sustainable concrete pavement. Other groups became creative by looking at including waste materials in their concrete mixtures. Specifically, one group looked at using waste latex paint citing the large amount of paint that is illegally disposed of, stored, or donated to collection agencies. Other groups used materials waste-stream materials such as recycled concrete aggregate as replacement of the rock and sand, while some groups examined the use of crumb rubber for disposed tires. Figure 2 shows some of the class groups mixing and testing their concrete mixtures in the laboratory.

Figure 2. Student Groups Mixing and Testing Their Concrete Mixtures

Student Research

The instructor found that the students researched their topics on sustainable materials, concrete design and testing, LCA, economics, etc… from a variety of sources. A list of sources that were mentioned to the instructor by the students included:

- Internet
- Online Archived Journals
- American Concrete Institute
- Local Ready-Mixed Concrete Companies
- Peers or Superiors at their place of employment (if engineering offices)
- Graduate Students at the UCD
- Class Textbook

Students performed their own research to learn the concepts needed to conduct this project. In addition, students performed tests on their materials to determine the needed properties of the concrete mixture design. Figure 3 shows a group performing a specific gravity and absorption capacity test on recycled concrete fine aggregate. The instructor and graduate teaching assistant acted as facilitators by ensuring the students maintained progress and advanced in an appropriate direction. In addition, the instructor and teaching assistant assisted with obtaining materials; however, the majority of groups located companies were able to donate materials to their group.

Figure 3. Students Performing Properties Testing on Their Materials

Outside of Class Experimentation

The most surprising aspect of this study by the instructor was the amount of time students spent on this project outside of class time. The instructor and teaching assistant witnessed groups working on their projects early mornings and late nights, before and after classes, and on weekends. The project required the groups to design, batch, and test only two mixtures; however, most of the groups produced three to four mixtures as part of their project. The motivating factor in most cases was *"I wonder if we can add even more sustainable materials to the concrete and still produce a quality concrete mixture."*

Assessment

Assessment was performed though weekly meetings between the instructor and the student groups, oral presentations, technical reports, and student feedback. A summary of each of these assessments are provided below.

Weekly Meetings with Groups

The instructor met with each group weekly throughout the semester to discuss their progress towards completing the project. This provided the instructor an opportunity to measure progress, but more importantly determine the direction the group was going on the project. If the instructor found that the group was moving in a direction that was not appropriate, this could be discussed with the group and a change could be promptly made. In addition, the instructor could get a sense of how well the group was working together. If everyone was involved in the discussion during these meetings, it seemed that everyone was participating and doing "their share" during group events (meetings, design, batching, testing, etc.); however, if others were less vocal, the majority of time it was found that those students had participated very little in the group activities. For these situations, the instructor was able to meet with these students one-on-one and correct the situation without the other group member's involvement.

The dialogue at these meetings was mostly positive and enthusiastic. During the majority of meetings, students were excited to discuss what they had found since the previous week. These meetings were a great setting for the instructor to assess the learning of the students. The students did not know that they were being assessed on their learning and project progress at the time of these meetings. The instructor was able to determine how much research had been performed on the various topics and whether the students fully comprehended what they had read.

Oral Presentations

Often a negative observation of engineers is the lack of communication skills. As part of this project, each group was required to give a presentation not less than 20 minutes in length. While preparing for the presentations, many student groups thought that they could not speak for 20 minutes. However, most all presentations lasted for at least 30 minutes. Each group was required to discuss Parts I-III of the scoring system above. Many of the groups provided additional information than required. At the conclusion of the presentations, questions were asked by the instructor as well as their peers. Because many of the groups produced mixtures with different sustainable materials (i.e. latex paint, crumb rubber, recycled concrete aggregate, etc…) students from other groups were genuinely interested and wanted to learn more. The oral presentations provided an opportunity for the instructor to determine whether the students fully understood the scope of the project (i.e. sustainability through concrete materials) and whether students were able to teach themselves concrete mixture design, life-cycle analysis, and economics. In most cases, the students groups were successful in understanding these areas. The instructor noted that some groups did not completely understand the LCA portion of the project; however, this could be expected since LCA is generally taught in more senior and graduate level courses.

Technical Reports

Each group was required to submit a technical report detailing every aspect of their project. These reports included the original scope of work, literature research, mixture design, batching, and testing, life-cycle assessment, economic comparisons, project findings, and recommendations. Each groups' report was well written and very detailed. When comparing this report to a report submitted by the same groups on another very different and more traditional project in the class, the green projects-to-pavement reports were considerably more detailed in both literature research as well as experimental findings. This is likely due to the amount of research the groups were required to perform on their own as opposed to the other project assigned in the class. In addition, it is hypothesized that students were more interested and invested in the green projects-to-pavements project as opposed to the other project.

Similar to the oral presentations, the instructor was able to assess whether the student groups understood the concepts of the project. The instructor observed the same findings in that students did very well in discussion of past research, mixture design, and economics, but lacked a complete understanding of life-cycle assessment. However, this was not the case with all groups. One group specifically researched the manufacturing locations for all materials included in their design (i.e. cement, water, rock, sand, recycled concrete aggregate, etc…) and was able to determine CO_2 emissions for their mixtures based on emissions from material manufacturing and transport.

Design Project Grades

Project grades ranged from a class high of 93% to a low of 88%. Table 1 shows the scores given for each Part I-IV of the project. The two lowest scoring areas were Part II – Quantifying Sustainability and Part IV – Final Report/Presentation.

Table 1. Final Project Grades

	Project Objectives				Project Grade (%)
	Part I	Part II	Part III	Part IV	
Maximum Points Possible	30 pt.	30 pt.	20 pt.	20 pt.	
Group 1	30	25	20	18	93
Group 2	28	25	20	19	92
Group 3	27	18	19	14	88
Group 4	29	28	18	15	90
Group 5	30	27	19	15	91
Group 6	28	30	18	17	93
Average Score (%)	96	85	95	82	91

Groups did not exhibit a complete understanding of LCA, embodied energy, and other factors that are used to quantify sustainability. For future course offerings a greater effort to direct students to more resources in this area will be made to improve the students' understanding in this area. Based on the academic stage of many of the students in the course (i.e. second semester sophomore and first semester junior students), the reports and presentations were very well. The instructor expected that this portion of the project may score lower than others as many of the students had not or very limited experience in presenting to an audience. The majority of reports were well thought out and clearly written; however, improvement could be made in some areas of the technical report as well as the presentation portion. At the conclusion of all the presentations, the instructor provided feedback to the students on ways to improve their presentation for future design projects. The student responses after the oral presentations and submission of their technical report demonstrated a sense of accomplishment.

Student Feedback

The student feedback on this project was very positive. Most students initially felt intimidation with the project due to the involvement of the project and the "unknowns" to the students. For example students prior to this had not: (1) design, batch, or tested concrete mixtures, (2) had limited experience in performing a literature research (3) been introduced to sustainability and LCA, and (4) had limited experience with economics, as it pertains to materials and design. However, students were able to learn the needed concepts to complete the project. This learning was conducted by themselves rather than through course lectures. Some of the comments to the class instructor included:

> *"My initial impression of the green concrete design project was intimidation. It seemed like a very daunting task to start from scratch and create an original batch of concrete that was in some way green and sustainable. Through the process of working on this project I found it was indeed challenging but it was also incredibly interesting and engaging. I found myself and my classmates taking time outside of class to perform experiments on our concrete and further explore the properties and potential benefits of our concrete mixture. I learned about many beneficial uses of pervious concrete such as applications in parking lots and animal stables. This project was incredibly beneficial to my understanding of structural materials and how to appropriately allocate materials based on structural use. This project probably took more of my mental power and capacity than anything else this whole semester, but the final result is something that I am incredibly proud of and I feel like I have learned very much from it."*
>
> – Class Student

> *"When the project was first presented I was very excited about it. The whole sustainability aspect of it was very interesting to me, and I was eager to learn more about it. There were so many different materials one could use in a concrete mix which really caught me by surprised. I thought this project was very productive in learning how to design concrete batches, and also how to account for cost and other things like that. It made me realize all the ins-and-outs of being an engineer, and what all we need to account for in any design. Though the project was a lot of work I feel that it was very beneficial to the class and overall learning in the civil engineering field."*
>
> – Class Student

> *"My initial thoughts on the green project were uncertainty. I had no previous experience with concrete before this class. I did not even know the main components of concrete. I was also unsure of how to quantify sustainability because there are many factors that*

must be considered. My final impression was I had great interest in the project. I learned the importance of sustainability in civil engineering and how to incorporate materials such as fly-ash and RCA into concrete mixture designs. The green project was very beneficial for me and greatly expanded my knowledge in civil engineering."

– Class Student

"My initial impression was a bit of intimidation. I knew that in order to be happy with the report that I was collaborating on, I would need to do a lot of research. My final impression was that my group did a good job, and put together an informative, cohesive presentation. I learned a lot about an interesting topic. I learned that there is a large market for recycled concrete aggregate. I also got a better idea of just how much demolition/renovation goes on with concrete. The presentation gave me practice in researching, developing and presenting my work. It also gave practice in working within a group to assign jobs and to work together. It was definitely a process with the group. It was fun. I'd recommend doing it again."

– Class Student

Assessment Through Final Exam Questions

The final exam given in the class consisted of 50 questions covering topics relating to Introduction to Structural Materials, Aggregates, Concrete, Steel, and Timber. Two of the fifty questions on the final exam were written to determine whether the students gained an understanding of the Green Project-to-Pavement design project overall objective (1) how/why can concrete mixtures be sustainable and (2) design a concrete mixture to be sustainable. Question 29 on the exam was used to determine whether students understood how/why the materials that make up concrete could be used to produce a sustainable concrete mixture. The question reads:

Question #29

Not only can pozzolans affect (both positively and negatively) the properties of concrete, pozzolans also have economical and environmental benefits. List below one positive economical and one positive environmental benefit of using pozzolins in concrete.

Figure 4 shows the scores of the students on this question in relation to each student's final exam grade. The most significant observation is that 25 out of the 28 students in the course received a perfect score (4 points) on this question. The 3 remaining students scored a 50% (2 points) on this question. Another observation is that students scored extremely well on this question even though they may have received a low grade on the final exam. For examples the average grade for this question is 95%, where as the average grade for the final exam was 74%. This demonstrates that student gained an understanding of the sustainability concept through this project and learning style. It should be noted that the material students were tested on with the remaining 48 questions was taught using a deductive, PowerPoint lecture style approach.

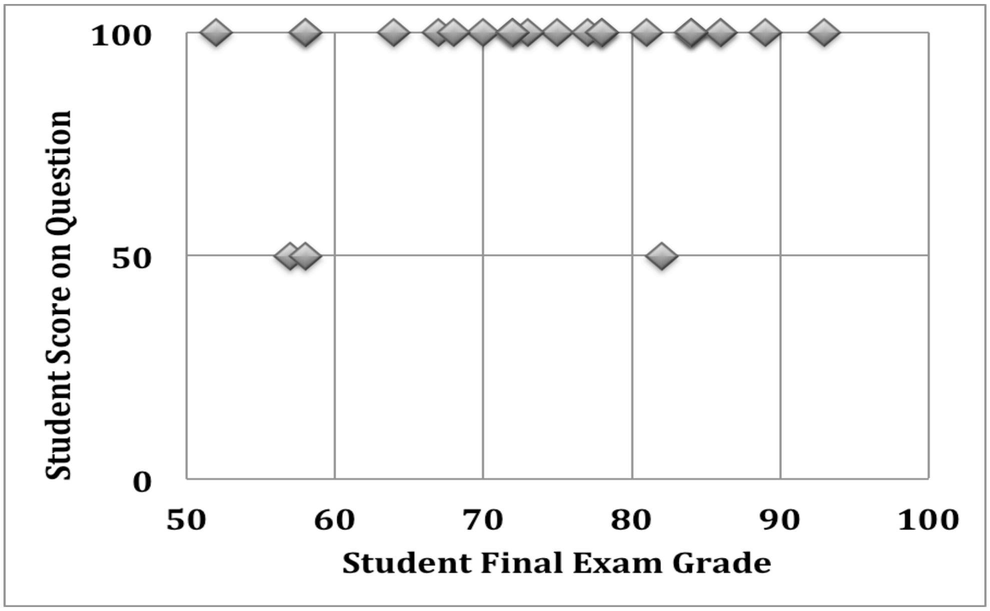

Figure 4. Student Question #29 Score vs. Final Exam Grade

Question 49 was used to determine whether students could design a sustainable concrete mixture based on the knowledge they learned during the course of the project. This question reads:

> Question #49
> *This summer you are working for a concrete company who manufactures concrete pavements. They have asked you to develop a preliminary concrete mixture that is considered to be a sustainable concrete mixture for a Colorado highway. The concrete is expected to reach a compressive strength at 28 days of 4,200psi. In the table below, develop an economical and sustainable concrete mixture design that would be a good starting point for the pavement manufacturer. List your estimated quantities for the materials you are using and justify why you are using that particular material and quantity (why/how does it make it sustainable).*

Figure 5 provides the scores of the students on this question compared to each student's final exam grade. The results of this analysis show a trend of increasing score on the question with increasing final exam grade. Thus, students that scored high on the question generally performed better on the exam. It is hypothesized that this trend is the result of one or two students in each group being the main individuals responsible for the design of the mixture. One method to over come this in future offerings is to require each student in the group produce a preliminary mixture design as part of the project.

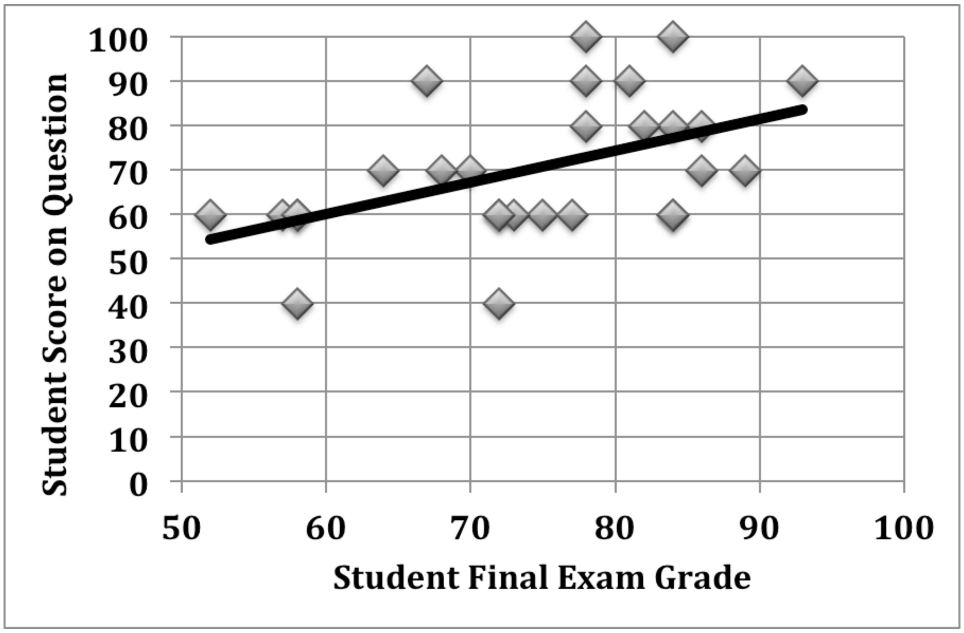

Figure 5. Student Question #49 Score vs. Final Exam Grade

Future Project Changes

The student feedback regarding the Green Projects-to-Pavements design project was overwhelmingly positive. Students often commented on how they felt that they were part of a design team performing a "real world" design. The fall 2011 semester was the first time this project and the type of student learning approach had been used by the instructor and in this particular course. Future course offerings will incorporate a deeper connection with the concrete industry (both design firms and ready-mixed concrete producers), more time to allow for a field placement of the student project mixtures, and a student reflection session.

The authors plan to pursue greater industry collaboration in future offerings of the course. The industry collaboration will be even more important in reviewing the technical report and oral presentations as well as the potential for a field placement. The value in having industry involved in reviewing the technical reports and oral presentations is the feedback they can provide. Individuals involved in the concrete industry can suggest modifications to the students in addition to commenting whether their design is "practical" would have the potential for being used in the field.

Additional time will be given to allow the students an opportunity to place their mixture in the field. Actual placement of the concrete provides students with a sense of accomplishment about their design in addition to seeing the non-technical issues that must be addressed (ordering and working with a local ready-mixed concrete supplier, working with a contractor, issues they may arise during placement of the concrete, etc.). This is a change that several students viewed as having a very high interest in for future projects.

Lastly, the authors feel that a reflection session with each of the groups at the conclusion of the project would prove valuable to the growth and evolution of the project as well as to the students themselves. These sessions could be used as opportunities for students to voice any concerns, weaknesses, strengths, or modifications regarding the project. In addition, students will find themselves having to review all that they accomplished (from starting at ground zero to meeting or exceeding project expectations).

Conclusions

Using a problem-based learning approach to introduce sustainability and concrete mixture design was found to be an effective method of teaching. Benefits that were observed by the instructor were enthusiasm and engagement of the students with the project and a true sense of accomplishment and teamwork at the completion of the project. In addition, the instructor found that since students performed their own research to learn the concepts needed for the project, students often went beyond what would have normally be covered in a traditional lecture style presentation. This was primarily found to be the case as many students commented on "wanting to learn more about the materials" and "wanting to use more and different sustainable materials." Even though the problem based learning style was used for only a class design project, students seemed to be more interested in the class because of the project. Comparing the technical reports submitted for the green projects-to-pavements design project to that of another project introduced and taught more traditionally, the green projects-to-pavements reports were more detailed and well written than the other reports.

Based on feedback, students had great experiences with this project and ultimately taught themselves how to design economical and sustainable concrete mixtures. It is expected that this successful experience will result in additional problem-based learning assignments being introduced to the class and potentially a move towards this type of teaching delivery for the entire course.

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