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Using Innovative Topics to Attract Future Engineers: Liquefaction and Sustainability Modules for Engineering Camp

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ABSTRACT

Efforts to attract quality and diverse students into civil engineering have given rise to engineering camps aimed at secondary school students. Innovative topics such as soil liquefaction and sustainability are typically studied in depth within civil engineering graduate programs. However, worldwide attention to these topics has been generated throughout society through recent natural events such as the earthquake in New Zealand and storm surge effects in New York and New Orleans, along with the on-going issue of global warming. These phenomena have been connected in a way to begin educating secondary school students, while simultaneously encouraging an interest in engineering. This connection was accomplished through the development and implementation of two teaching modules, targeting 13 to 16 year old students. The soil liquefaction module is aimed at familiarizing students with the term as well as fundamental engineering concepts related to the topic. Experiments were conducted both on a small-scale shake table available at select universities and a widely available teaching device for fluidized beds. Students took various measurements and made calculations of soil density before and after liquefaction. For the sustainability module, the students were introduced to key concepts related to environmental, social, and economic sustainability. Two activities were implemented with regards to ecological footprint and green building. Students calculated their ecological footprint based on a survey of lifestyle-related questions and compared their impacts to average values in developing countries. In addition, they completed a case study assessment of exemplary green buildings and developed a concept map depicting the project's applicability to the triple bottom line goals. To simplify the task of implementing the modules, detailed procedures for the experiments and activities, along with worksheets for the students have been developed for interested instructors. The modules have been tested at Bucknell University during the summers of 2011 and 2012, and survey assessment results from student evaluation confirm that the modules are effective in meeting the defined objectives of each topic. The overall goal of the assessment was to establish student learning in the modules.

INTRODUCTION

Recent natural events and global issues have led to a rise in innovative topics in the civil engineering curriculum. Events such as the earthquake in New Zealand, storm surge effects in New York and New Orleans, along with the on-going issue of global warming have initiated the development of topics such as soil liquefaction and sustainability. As new concepts develop, specifically within undergraduate and graduate curricula, the opportunity exists to expose secondary school students to these areas as a way to attract and engage high quality, diverse students in civil engineering. While traditional civil engineering topics, such as bridges, have been used in the past with secondary school students, adapting the current and ever-developing topics to specific hands-on, real world, problem-based lessons specifically for secondary school students, ultimately can increase awareness of and interest in the field of civil engineering.

Currently, Bucknell University offers a week-long summer engineering camp targeting secondary school students. The camp participants are exposed to engineering through a series of lessons and hands-on exercises taught by a wide range of engineering faculty. New topics such

as liquefaction and sustainability have recently been integrated into the camp through lesson modules. This paper describes the development, implementation, and evaluation of the engineering camp lessons to teach innovative topics to secondary students.

Objectives

The primary goal of this research is to develop, implement, and evaluate lesson modules focused on two innovative topics in civil engineering, liquefaction and sustainability, in order to expose and attract secondary school students to the field. Developing the lesson modules includes a thorough investigation of the topic, identification of relevant real world problems, and application of pedagogical techniques such as problem-based learning. The modules have been implemented twice through the Bucknell Engineering Summer Camp in 2011 and 2012.

Based on the assumption that effective engineering modules using innovative topics are beneficial in attracting young people to engineering, the modules were developed and assessed based on specific learning objectives. These learning objectives, described later in detail, serve as the basis for organizing and teaching of the modules. By the end of the module, students should have knowledge of basic principles, perform experiment/activities demonstrating their knowledge, and understand the context for implementation to real world problems.

Methodology

To engage secondary school students through innovative concepts in civil engineering, the following five-step methodology was followed:

1. Complete a literature review on innovative topics in liquefaction and sustainability.
2. Develop modules focused on liquefaction and sustainability for secondary school students including hands on activities and real world problems.
3. Apply modules at the Bucknell Engineering Camp (Summer 2011 and 2012):
    a. Implement modules twice per topic per year.
    b. Evaluate the achievement of lesson goals and objectives through student evaluations (indirect assessment).
4. Determine lessons learned from module application and evaluation results.
5. Identify further research and opportunities for future application.

The following paper describes this process and highlights the key findings of the module implementation.

BACKGROUND

Civil engineering has traditionally been viewed as the discipline involved with structures, roads, and bridges. Increasingly, the general public and hopefully secondary school students are hearing more about infrastructure needs in the U.S. As many know, the field of civil engineering is broad and could potentially attract students interested a wide range of topics beyond roads and bridges. Thus, current topics such as soil liquefaction during earthquakes and sustainable design offer a broader view of civil engineering. In addition, since these topics appear in the news, they are by definition contemporary. The contemporary nature of liquefaction during earthquakes and sustainability will also serve to attract secondary school students interested in studying a currently relevant topic.

Liquefaction

Liquefaction describes the phenomenon wherein saturated, loose, cohesionless soil (sands) loses the friction-dependent strength and acts like a fluid when subjected to static or dynamic loading. In such scenarios, structures on the surface can partially or fully sink beneath the surface and buried structures could potentially become buoyant and rise to the ground surface. Liquefaction occurs when saturated cohesionless soil particles lose inter-granular friction due to increased pore water pressure. This can happen during an earthquake when loose sand is cyclically loaded and pore water pressures build up. The soil particles then effectively are suspended in water, losing virtually all strength, and the soil mixture acts like "quick sand". Liquefaction occurs in loose sands and thus is influenced by the void ratio of the soil (the ratio between the volume of voids and the volume of solids). Dense soils (soils at void ratios less than their critical void ratio), are too dense for liquefaction to occur. Hence, liquefaction occurs most often in loose sandy soils beneath the water table.

Liquefaction was first identified as an engineering problem in the 1930's by Arthur Casagrande.[1] He identified liquefaction caused by static load on the soil in the Fort Peck Dam failure of 1936 (Fig. 1a). Before the 1964 earthquakes in Niigata, Japan and Anchorage, Alaska, liquefaction was not considered a significant component of earthquake damage. The June 16th 1964 earthquake hit 55 km from Niigata, a city built upon about 100 m thick sand deposits from the Shinano River. Liquefaction caused major bearing capacity failures at an apartment complex as shown in Fig. 1b.

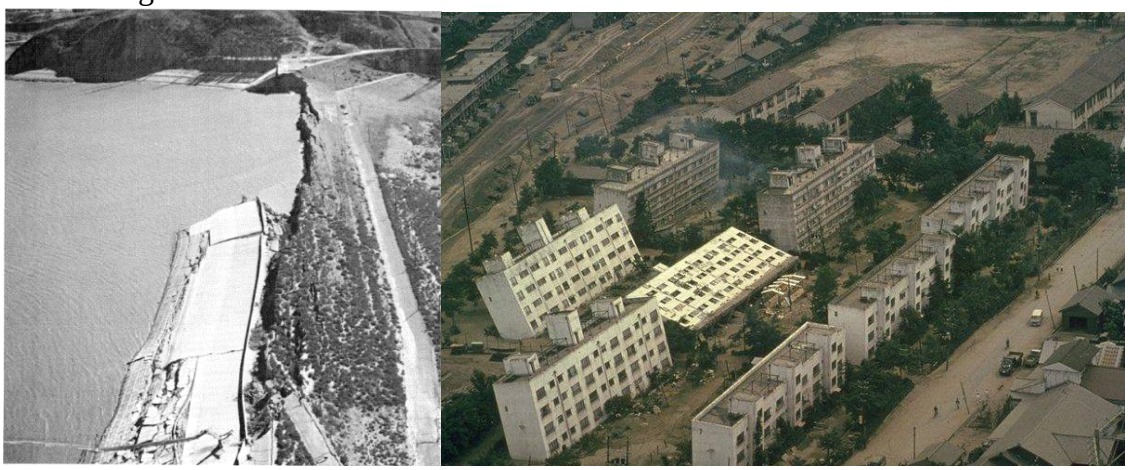

Figure 1a. Failure of Fort Peck Dam (from Casagrande, 1965) and Figure 1b. Apartment houses after the 1964 Niigata earthquake

Sustainability

Interest in sustainability continues to rise as local, national, and global events strive to bring insight to the human impact on the natural environment.[2] Storm surge events along the East and Gulf Coasts of the U.S., rising sea levels, depletion of natural resources, and the increasing global population are indicators that are raising awareness that a sustainability movement, particularly with regards to reducing the anthropogenic influence, is needed. Since sustainability is defined as "meeting the needs of the present without compromising future generations to meet

their own needs" secondary school students are the generation that will have to innovate, plan, and develop in ways that reduce negative impacts on the environment, society and economy.[3]

Sustainability is more than simply "protecting the environment". Civil engineers of today, and especially the future, will have to design and build in a way that addresses all three pillars of sustainability (economy, environment, and social) as shown in Figure 2.[4]

Figure 2. Three Pillars of Sustainability

This model is referred to as the triple bottom line of sustainability and suggests an equal balance of all three components by reducing environmental, economic, and social impacts. Therefore, engaging future engineers in this effort and attracting them to the field of civil engineering is vital as they will be the next designers, contractors, and tradesmen.

The connection between sustainability and civil engineering can be made through teaching sustainability concepts such as ecological footprint, green building, and sustainable performance measures. Ecological footprint is a metric that is developed to quantify human "pressure" on the planet with regards to resources, emissions, land consumption, etc. in comparison to the current carrying capacity of the Earth.[5] This metric begins to measure the problem in order to then support potential solutions, such as green building rating systems. Green building rating systems such as LEED (Leadership in Energy and Environmental Design) have been a popular measure for sustainable design through applying credits and receiving points for sustainable projects.[6] As engineers continue to implement more innovative techniques, the education and awareness of sustainable design will continue.

Pedagogical Techniques

Much has been written regarding pedagogical techniques and the benefits of active learning are generally well recognized and accepted. While precise definitions may vary, active learning is a process by which students are engaged in the learning process by doing meaningful learning

activities.[7] A review and analysis of the literature reveals considerable support for the core elements of active learning.[8] Active learning improves the recall of information with accompanying benefits of student engagement, such as clarifying student misconceptions and improving conception understanding. It is also clear from Prince's analysis of the literature that collaboration enhances student retention, student attitudes, and academic achievement. With this in mind, the Liquefaction and Sustainability Modules were developed to incorporate both active and collaborative learning processes as well as traditional instructional methods.

LIQUEFACTION MODULE

Module Development

Researchers at Bucknell University are part of a team with researchers from Stanford University and Arizona State University investigating the post-liquefaction shear strength and structure of sands. It is hypothesized that the liquefaction and resedimentation process results in a soil structure that is amenable to reliquefaction under subsequent earthquake events. In seeking funding from the National Science Foundation, it was proposed to develop learning modules for two demographic groups. The work for the first group, secondary students, is included with this paper. The second group, upper level undergraduates and graduate students, will be the subject of a future publication. While the module is centered upon a small-scale shake table and liquefaction, several other components of the module were developed and employed to illustrate the principles as described below.

Objectives and Experiments

The following module learning objectives were identified for the liquefaction module.

- Students will be exposed to and learn new concepts and principles of geotechnical engineering including:
    - Void ratio
    - Effective stress
    - Pore pressure
    - Liquefaction

The following lesson objectives describe the specific student activities that comprise the liquefaction module and the module objectives for each of the activities.

1. Students will perform an interactive liquefaction experiment that demonstrates primary and secondary effects of liquefaction such as:
    - Void ratio changes and related ground subsidence
    - Surface flooding from pore water being ejected to the surface as the soil densifies during shaking
    - Foundation failure due to soil strength loss as they observe a model structure supported on the sand surface before, during, and after cyclic shaking and liquefaction
    - Role of mini penetrometer testing (modeled after Standard Penetrometer Test) to evaluate changes in soil properties as a result of liquefaction and resedimentation

2. Students will perform fluidized soil bed experiment that demonstrates:

    - Concept of void ratio
    - Role of air as a fluid (compared with water as a fluid in shake table experiment)

3. Students will run the gauntlet where some participants serve as individual soil particles while others pass through the student soil particles simulating penetrometer passing through the sand in the mini penetrometer testing:

    - Concept of void ratio
    - Concept of soil particle displacement during cone penetration testing
    - Concept of an increase in soil strength following the liquefaction

Liquefaction Module Implementation

The liquefaction module was implemented in four two-hour sessions with summer camp students at Bucknell University. The liquefaction teaching module was therefore implemented a total of eight times each year, as each session of students was divided into two and rotated between the fluidized bed experiment and the liquefaction shake table experiment. This rotation of experiments allowed for a small group size, about 10 students, and provided a very interactive experience for the students. The overall time of the sessions was divided equally among the following activities:

a) PowerPoint presentation
b) Liquefaction shake table experiment
c) Fluidized bed experiment
d) Regroup and data review

a) PowerPoint presentation

The first part of the module implementation included a PowerPoint presentation. During the presentation, objectives, introduction to liquefaction and secondary effects, videos about liquefaction both in Japan and New Zealand, conditions required for liquefaction, schematics for visualizing liquefaction, liquefaction experiment materials, experimental setup, mini penetrometer, and data analysis were presented to the students.

b) Liquefaction shake table experiment

Methods of sand deposition and soil liquefaction were demonstrated during this period. During the deposition process it was necessary to point out to students that the use of a pluviator box to deposit the sand into a mass of water recreates a very loose soil sample by ensuring that the sand particles reach terminal settling velocity prior to being deposited. So that students can easily relate to the experiment, a real world scenario was mentioned, typically as a loosely deposited river delta.

The student instructor also explained the capabilities and limitation of the shake table in addition to why and how the rigid soil box was built. To facilitate students' visualization of liquefaction especially after watching videos of buildings in New Zealand and Japan sinking, a solid metallic block representing a building was placed on the surface of the soil contained in the rigid box and

mounted on the shake table. Students were amazed when the shake table was activated and the model building sank into the sand due to the soil liquefaction. Throughout phases of the experiment, students recorded measurements of sample height that they would later use to compute the differences in densified sand void ratio and mini penetrometer blow count to compare the strengths of the pre and postliquefied soils.

c) Fluidized bed experiment

During this session, soil properties such as porosity and void ratio were discussed both in general and how they relate to liquefaction. Most importantly students were also introduced to the structure of soil which consequently made it easier to explain porosity and void ratio. Prior to the experiment the students were asked to define porosity and void ratio. Fortunately a number of students could relate porosity to the volume of voids with respect to the total volume. The fluidized bed was used to demonstrate porosity and some students were able to correctly predict what would happen if air was blown from the bottom of the cylinder filled with dry sand. Students were also asked to identify the reason for the increase in volume once the sample was aired. This was followed with asking students to identify methods of how to compact the soil. With the help of the instructor, methods such as blowing air in a different direction, creating a vacuum through the bottom of the cylinder, applying stress to the surface of the specimen and shaking the soil specimen were identified. The question and answer sessions during the experiment stimulated discussions and helped students understand the concepts.

After recording the data from the fluidized bed device, the concept of effective stress was discussed. The students were able to understand the effect of water on effective stress. The analogy of a person standing in a pool with different amounts of water was used which proved to be useful in explaining the changes that occur in effective stress of a soil specimen in presence of water. Effort was also taken to ensure students recognized that the effective stress in a dry soil sample is equal to the total stress while the effective stress in a liquefied soil (where there are no intergranular stresses) is zero. Students also gained an understanding of why the soil became denser after liquefaction and why ponded water occurred on the top of the liquefied soil surface.

As a final step students were introduced to Gauntlet experiment that helped them understand the movements of individual sand grains and performance of the Miniature Penetration Test. This included lining up students in a corridor in different arrangements (denser and looser) and asking a student to walk through their fellow students. The student then had to relate the resistance experienced by the student moving through the crowd to how the soil property of density related to liquefaction. The students enjoyed the experiment and were able to understand its purpose.

d) Collaborative work and data review

A liquefaction worksheet was prepared for students to record data during experiments. This helped keep students engaged and inquisitive to understand the purpose of data recording and guided student progress throughout the experiment.

The questions were chronologically organized to avoid confusion. In addition, fundamental equations necessary for void ratio calculation were available on the worksheet. There was no need for an extensive knowledge of phase diagrams to be able to apply the equations and answer the questions. The worksheet was extremely effective and allowed students to successfully

determine a pre- and post-liquefaction void ratio such that a change in void ratio could be used to explain secondary effects of soil liquefaction.

After participating in both hands-on experiments and collecting raw data, students worked individually or collaboratively as they sought help from classmates to complete the computational questions in a group setting.

Evaluation of Liquefaction Module

To better gage students' understanding of the concepts presented during lecture and laboratory sessions, an evaluation survey was developed and implemented as shown below.

1 = strongly disagree, 2 = somewhat disagree, 3 = Neutral, 4 = somewhat agree, 5 = strongly agree

1. I can describe effects of earthquakes on soil.	1	2	3	4	5
2. I can describe soil liquefaction.	1	2	3	4	5
3. I can name the 3 main criteria for liquefaction to occur.	1	2	3	4	5
4. I can name the 3 components of soil.	1	2	3	4	5
5. I can explain what void ratio is.	1	2	3	4	5
6. I can explain what porosity is.	1	2	3	4	5
7. I can name ways of making the soil more/less dense.	1	2	3	4	5
8. I know how liquefaction affects soils and structures.	1	2	3	4	5

The results of the surveys were compiled from the ninety students who took the survey and the summarized results are shown in table 1 below.

Table 1: Summarized Module Implementation Survey

	Questions								
Survey	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**Average**
Average (2011)	4.2	4.4	3.7	2.9	3.6	3.7	4.1	4.6	3.9
Average (2012)	4.0	4.1	3.7	2.9	3.4	3.6	3.7	4.4	3.7

The overall average score for all questions for both years was 3.8 out of 5.0, indicating, on average, the students felt they had a reasonable understanding of concepts. Considering the level of sophistication of concepts in earthquake engineering and that most students arrived in the module with virtually no understanding of these concepts, these scores are considered most satisfactory. Examining the average scores for each question in Table 1, it can be seen that only question four had an average lower than a score of three. This result suggests that the concept of soil components was difficult to understand and retain. Thus, better and possibly simpler visual aids need to be developed to facilitate teaching this concept. Otherwise, the remainder of the scores seems to suggest a high understanding of the major and crucial concepts covered in the module implementation. The data also indicate a decline in overall scores from 2011 to 2012 and average of slightly less than 0.2. With only two years of data it is not clear whether this decline is indicative of a real difference in modulus effectiveness or simply within the variation that

could be expected from year to year. More data is needed to evaluate this question. In future years pre-module surveys are planned to capture the improvement in understanding from the module.

SUSTAINABILITY MODULE

The following section describes the development and implementation of the Sustainability Module as it was applied to the Bucknell Engineering Summer Camp. The module was developed in 2011 and then implemented twice during the 2011 and 2012 camp programs.

Module Development

The module was developed for the purpose of integrating sustainability concepts and activities into the mindset of secondary level students interested in engineering. With rising issues related to anthropogenic impacts on the environment, pressure will be placed on future engineers to prepare, protect, and renew the natural and built environment.

Process

The module was developed through two main steps: (1) define the scope, lesson objectives, and background content, and (2) develop activities and examples to support the scope.

Step 1 was primarily completed based on recent literature, news articles, and relevance to current events. The scope of the lesson was to teach secondary school students about sustainability through discussion and interactive activities focusing on engineering-related applications through a 90 minute module. The lesson objectives, as described in the next section, are developed as the overarching goals for the module. By the end of the lesson, students should successfully be able to understand and apply the concepts discussed in class. In terms of background content, related concepts such as the triple bottom line, ecological footprint, and green building were included as well as relevant data and statistics to draw on the current state of sustainability-related issues.

Step 2 focused on developing real world, hands-on, problem-based activities that require the students to demonstrate critical thinking and communication skills. Activities such as calculating their ecological footprint as well as drawing concept maps on exemplary green building projects were developed and adapted for implementation within the 90 minute time period as well as for a class size of about 35 students.

Objectives

The lesson objectives serve as the goals for the module. There are four main lesson objectives that by the end of the lesson all students should be able to achieve:

- Define sustainability and related key concepts;
- Understand how engineers can integrate principles of sustainability into design;
- Apply the concept of ecological footprint;
- Evaluate exemplary green building projects based on sustainable design components.

At the beginning of the module, students were shown these four objectives and the instructor discussed how each would be achieved. Then, after the module was complete, the successful

completion of all four objectives was reiterated. To conclude, students were asked to relate the key concepts to their own life as both future engineers as well as members of the public.

Module Implementation

The module was implemented at the 2011 and 2012 Bucknell Engineering Summer Camp in 2 sections, both 90 minutes long with approximately 35 students each. The students were selected based on an application to participate in the camp focusing on engineering-related topics. The sustainability module was one of approximately 12 different engineering modules.

The module included four main components:

a) Warm up Activity
b) PowerPoint presentation,
c) Ecological footprint activity
d) Green building concept map exercise

a) Warm Up Activity

The module begins with a warm up activity that requires the students to work in teams of about 5-6 students. The instructor passes out a series of objects (wooden spoon, cloth bag, shoe, belt, plastic cup, and a dish towel) so that each group has one object. The students are given five minutes to invent five appropriate uses for the object, other than it is original use. For example, the plastic cup can be used as a flower pot, or the cloth bag can be made into a pillow. Through the process of identifying other uses, the students have to be creative and think outside-of-the-box, which is the foundation for innovative, sustainable, systems-based thinking. The students report their top 3 answers to the class and justify their thoughts.

b) PowerPoint Presentation

The second portion of the module is focused on student-learning through presentation and discussion. A PowerPoint presentation is used to show figures and display definitions related to sustainability. Slides on "Sustainability and Engineering", "What is Sustainability", and "Sustainable Design Goals" are used. The WCED[3] formal definition of sustainability is used as a reference to the recent 1987 Bruntland Report which highlights the fact that sustainability is a fairly new topic when compared to engineering as a discipline. In addition, a series of design component such as cost, safety, equity, emissions, waste, mobility, and public health were listed on a slide and the students discussed whether the goal is to "increase or decrease" the component and provided one example for each in terms of how that could be achieved. For example, for "mobility" the students indicated that the goal is to "increase" mobility and that one way it could be achieved would be through increasing transit service or adding ped/bike facilities in addition to vehicular infrastructure.

c) Ecological Footprint Activity

The module continued with a discussion of the concept of ecological footprint and how its usefulness. A short 90 second videoclip was shown based on a National Geographic[9] documentary on "Human Footprint". The documentary discusses how much humans consume and how that amount continues to grow as demand increases. Based on the clip, the concept of ecological footprint was discussed in detail and then a follow up activity was distributed.

A quantitative exercise requiring students to answer a series of questions regarding their lifestyle and daily activities (such as walking versus driving to school, washing clothes in hot versus cold water, etc.) was used. The questions then allowed the students to add or subtract their value and compare it to the size of football field equivalents. The football field equivalent provides a more visual approach to understanding how their input/output impacts their footprint. The instructor created a table on the board and had students raise their hand when their number was called. By the end of the exercise all students had their footprint (in football field equivalents) on the board and then the instructor calculated the average for the entire class, including their own value.

Following the activity, information on how the United States compares to other countries in terms of ecological footprint and daily consumption was discussed. This leads to the discussion of equity and how developing countries are consuming at a rate much less than Americans. Students raise issues of how to balance consumption rates and through engineering the United States can start to reduce its impact on the environment.

d) Green Building Concept Map Exercise

The last portion of the module is devoted toward applying engineering design principles to address sustainability. Green building is discussed as one "tool" used to integrate sustainable techniques into engineering. The USGBC (United States Green Building Council)[6] and its widely-used Leadership in Energy and Environmental Design (LEED) rating system is discussed on a broad scale in terms of creating a standard for how engineers can begin to reduce environmental, economic and societal impacts. The purpose, as well as the process, for how projects become LEED certified is discussed in detail. Following the discussion, students are divided into six teams and exemplary project packets consisting of a project summary and related news articles from the internet are distributed. The projects selected for the case studies were the Exelon Building, Nationals Park Stadium, Chipotle Restaurant, Vista Dunes Development, Clearview Elementary, and Twin-brook Station. These six projects range in the project type (New Construction, Neighborhood Development, School, Homes, etc.), as well as were identified as profile projects by USGBC.

The students are given 30 minutes to read through the materials and identify the key design components that were used in the project and classify them as either economic, environmental, or societal benefits (or a combination). The students created Venn Diagrams and organized the design components into these three components of the triple bottom line. The students then presented their findings to the class and shared background about why the project is exemplary.

Program Evaluation

In order to evaluate the sustainability lesson, a more qualitative approach was used. In future years, the quantitative method used for the liquefaction module will be implemented as a more rigorous assessment process. Based on 71 students enrolled in the 2012 summer program, 17% selected "Sustainability" as their most favorite out of approximately 20 different engineering-focused modules. In 2011, there were 86 students enrolled and 6% indicated that sustainability was their favorite topic out of a total of approximately 20 other modules. Although the term "favorite" does not directly provide information on student learning, interest in this area is evident. Again, in future years this assessment process will be more directly tied to student learning.

LESSONS LEARNED

Implementing these two innovative concepts into engineering modules for secondary school students provided students the opportunity to learn current concepts and expose them to unique sub-disciplines within civil engineering. The rewards were significant; however, the implementation process was not without challenges. Both modules were faced with the limited timeframe as well as pre-determined class sizes. In addition, the pre-existing range of knowledge of each of the students greatly varied, requiring a level of background information to be taught at the beginning. Similarly, the applicants selected are those they have a pre-existing interest in engineering and a desire to learn more about the topic. To that end, the module should be implemented in settings involving a pool of students with diverse interests so as to better gage its effectiveness.

By implementing the modules twice, slight revisions and improvements to the material and activities were made. In general though, the content remained constant from 2011 to 2012. The following module-specific lessons learned are discussed in detail.

Liquefaction Module

Students were actively engaged in the lecture sections, the laboratory experiments, and the data analysis. They seemed to understand concepts and data analysis very well. Overall, less than five out of ninety students could define soil liquefaction before the module. Afterwards, almost all students could describe causes and effects of liquefaction, but like in other teaching settings, students showed different levels of interest. Some answered questions without raising their hands while others sat quietly and watched events unfold. In any case, it is advisable for the instructor to come up with different incentives to encourage equal student participation.

During both lecture and laboratory sessions, visual aids were found to be effective in relaying new concepts to students. YouTube videos were used and students seemed to relate to multimedia form of presentations.

Sustainability Module

Throughout the sustainability module, students were engaged. It was evident that at the beginning of the lecture, many of the students believed “sustainability” was focused solely on environmental efforts such as recycling. However, by the end of the module, students were suggesting a number of sustainability performance measures applicable in civil engineering, pertaining to social and economic aspects of sustainability. Their awareness of the concept as well as application to engineering was evident.

Similar to the liquefaction module, visual aids were extremely useful as they were able to see the figures on the PowerPoint, hold/touch all of the materials used in the first activity, and watch a video on ecological footprint. By the end, the case study activity which required them to draw a concept map similar to one presented as a sample, allowed them to create a visual aid representing the green building project in their case study.

Also, the issue of communication and opportunity for student engagement in discussion was addressed. Student verbal participation varied across the class however, through the three activities (warm up, ecological footprint, and green building case study) every student was able

to actively contribute to the problem-based learning activities. The ecological footprint exercise ensured equal student engagement since it was an individual assignment and students were responsible to calculate their own value. In addition, for many of the low-level discussion questions, the instructor aimed at including students that were not as willing to volunteer. Therefore, by the end of class, almost all students had verbally participated in the discussion.

CONCLUSION

Integrating innovative topics such as liquefaction and sustainability into curricula for secondary students is essential in attracting future civil engineers. Through the successful completion of the research objectives, lesson modules were developed, implemented, and evaluated based on the Bucknell Engineering Summer Camp in 2011 and 2012.

The lesson modules serve as examples for how to apply problem-based learning and real world applications of the innovative topics. Ideally, these modules can be adapted and incorporated for secondary school curricula through a variety of educational outreach opportunities such as camps, guest lectures, workshops, etc. Exposing the future generation to these current day topics can spark interest and motivate students to pursue the field of civil engineering.

Future work includes revising the modules based on feedback both from the students as well as the instructor. Since these topics are vastly changing over time, the material must be updated to reflect changes within the field. For example, in the sustainability module, the topic of measuring green building is constantly changing as new metrics and rating systems are developed. Therefore, the case study exercise has to adapt to reflect the most rigorous and accepted rating systems being used at the current time. Another future opportunity involves expanding the modules to include additional innovative topics within civil engineering. As new global risks arise, the field of civil engineering will adapt and reflect the needs of society. Therefore, new lesson module topics such as “Engineering for Climate Change” or “Eco-engineering” can be developed to further promote the shifting demands of civil engineering. Exposing secondary students to these innovative concepts can stimulate and prepare the next generation of civil engineers. Future work also includes revised assessment of outcomes, particularly for the Sustainability module.

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