AC 2011-2428: EXCHANGE - EXPERIENTIAL EARTHQUAKE ENGINEERING EDUCATION FOR HIGH SCHOOL STUDENTS THROUGH THE CALIFORNIA STATE SUMMER SCHOOL FOR MATHEMATICS AND SCIENCE

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Exchange - Structural Engineering and Geophysics Education for High School Students through Experiential and Problem-Based Learning

1. Introduction

The California State Summer School for Mathematics and Science (COSMOS) is a four-week, educational summer program for gifted and talented high school students. Science and engineering topics are presented via a variety of "clusters" located at four of the University of California campuses. The "Earthquakes in Action" cluster at the University of California, San Diego (UCSD) has successfully employed experiential education methods in order to present structural engineering and geophysics topics. Lecture material on seismology and earthquake engineering has been integrated with activities, field trips, and group projects in order to enhance the students' understanding of the material. The goals of the cluster are to present these topics at a high level, meet national math and science program standards for high school students, and to encourage the students to pursue math- and science-based majors at public, in-state universities. The implementation of hands-on components to learning has shown to be effective in both helping to convey the advanced topics presented, while also achieving the greater goals of the program with regard to higher education. This paper discusses the structure of the "Earthquakes in Action" cluster within the contexts of experiential and problem-based learning theories, and will document the curriculum used such that its successes may be improved and replicated.

2. Overview of High School Summer Program

COSMOS is a residential math and science summer camp that provides an opportunity for motivated high school students to work alongside university researchers and faculty to explore topics that extend beyond the typical high school curriculum. The program encompasses four university campuses, each offering a variety of clusters in science and engineering that concentrate on hands-on activities in laboratory settings highlighting current university research[1]. The objective of the "Earthquakes in Action" cluster described herein is to present basic concepts in the fields of geophysics and structural engineering. It employs hands-on and interactive activities, experimental investigations, relevant site visits, and research-based group projects, all of which are integrated with lectures. Often the laboratory or hands-on exercises involve the introduction to and use of computer programs such as Microsoft Excel for data analysis, SolidWorks or Google SketchUp for structural modeling, and Google Earth for geophysics activities.

The format of the program consists of regular classes focused on presenting cluster material, seminars related to science communication which are taught by high school teacher fellows assigned to each cluster, scheduled opportunities for students from all clusters to integrate and learn about the research being conducted by their peers, laboratory time where cluster assistants are available to help students with their course material and projects, relevant field trips, time in the evenings for homework or outside research, and many social activities.

The educational goals of the cluster are to introduce students to the impact of seismic activity on our physical surroundings, to foster creative problem-solving techniques with an emphasis on working in teams, and to encourage students to pursue math- and science-intensive college majors at in-state institutions. This paper presents a sample of some of the innovative instructional methods based on experiential learning and problem-based learning theory that have been implemented in the course.

2.1. Program Topics and Outcomes

The structural engineering portion of the course provides a basic understanding of how a structure will react to earthquakes through fundamental principles of physics and mathematics and how structures can be protected from major damage and collapse. Topics covered include an introduction to earthquakes and seismic damage, structural design principles and design optimization, quantifying motion of a structure (acceleration, velocity and displacement), Newton's laws of motion, prediction of structural response, how various construction materials (wood, reinforced concrete, steel, and masonry) behave in an earthquake, structural response to earthquake ground motions, seismic retrofit, mitigation of structural response by energy dissipating devices, and soil-structure interaction and liquefaction.

The geophysics portion of the cluster allows the students to explore the basics of plate tectonics on our active planet with a detailed investigation of earthquakes from around the world and throughout history. Students use real-time data as well as computer earthquake models to help understand local seismic hazards and test their own theories of stress build-up on fault systems. Students also utilize available earthquake seismogram data to analyze important properties of the Earth's interior and are also given the opportunity to go into the field to make a geologic map and to interact with physical earth materials. Topics include an introduction to geology and geophysics, global plates and quakes, Earth investigations and projects, seismic waves and fault rupture, geologic maps and representations, fault zones and deformation, measurement of earthquakes, prediction and forecasting, and new directions in seismology.

In the science communication portion of the course, students are taught to communicate effectively in both oral and written form. The course concludes with student presentations of their research. The course trains students to work in teams, to apply the scientific method, and to use presentation tools such as PowerPoint, Excel, poster boards, and appropriate presentation of data through graphing, etc. Furthermore, the science communication course provides a bridge connecting the students' knowledgebase and the demands of the structural engineering and geophysics courses. While a form of science communication is required for all clusters, the instructors in the "Earthquakes in Action" cluster worked closely with the cluster's teacher fellow to ensure that all milestones and deliverables associated with science communication were relevant and integrated to the structural engineering and geophysics curriculum.

The program outcomes for COSMOS correlate very closely to the engineering outcomes specified for accreditation of undergraduate engineering programs, such as the following:

- An ability to apply knowledge of mathematics, science, and engineering.
- An ability to design and conduct experiments, as well as being able to analyze and interpret data.
- An ability to design a system, component, or process to meet desired needs.

- An ability to function in multi-disciplinary teams.
- An ability to identify, formulate, and solve engineering problems.
- An understanding of professional and ethical responsibility.
- An ability to communicate effectively with written, oral, and visual means.
- The broad education necessary to understand the impact of engineering solutions in a global and societal context.
- A recognition of the need for and an ability to engage in life-long learning.
- A knowledge of contemporary issues.
- An ability to use modern engineering techniques, skills, and computing tools necessary for engineering practice.

2.2. Program Curriculum: Lectures, Activities, Field Trips, and Projects

Lectures are delivered using a combination of PowerPoint presentations with videos and animations, and chalkboard examples. The lectures are typically 30-45 minutes in length and are focused on high-level introductions of the challenging engineering topics. Mathematical expressions are provided when necessary but the derivations behind the differential equations and other complicated expressions are not provided.

Details regarding some of the highlighted hands-on activities, field trips, and the group projects that reinforce the lecture material are described below. For each activity, documentation has been created for the students, providing a description of the activity, relevant concepts, required equations, instructions how to execute the activity, as well as discussion questions. Documentation has also been created for the instructors, providing a description of the activity, objectives, outcomes, required materials, setup instructions, instructions for facilitating activity, and discussion questions. These documents, as well as photographs and videos of the activities, will be made available to promote broad dissemination and implementation of the activity-based curriculum.

2.2.1. Earthquake Engineering Activities

2.2.1.1. Introduction to Earthquake Engineering using K'Nex Structures

To introduce students to earthquake engineering, this activity consists of constructing a multistory building made out of K'Nex pieces and testing it on a shake table (see Figure 1). From the activity, students should understand how buildings respond to an earthquake and learn about types of building designs that are superior for withstanding an earthquake. The activity is a preliminary exercise to see how well students can predict structural response and understand methods to improve

Figure 1: K'Nex structure tested on the shake table

structural response without any background lecture or overview on earthquake engineering and structural design principles. Structures are attached to a table top shake table with Velcro and masses are added to the structure using washer weights.

The objectives of the activity are to provide students with a hands-on opportunity to design and construct a building that can withstand a given earthquake. The students are introduced to the capabilities of the shake table and how to apply structural engineering topics such as lateral bracing. After completing this activity, students should be able to understand simple mechanisms that improve a structure's resilience to earthquakes and obtain a visual understanding of how buildings respond to a given earthquake, including identifying load paths and critical members.

2.2.1.2. Determination of Forces through Balsa Wood 2D Truss Bridge

In this activity students are introduced to the concept of forces, components of forces, and analyzing 2D trusses for forces in each member. In teams of two, students calculate the demand in each member of a four bay bridge truss loaded at mid-span from the lower chord in order to optimize their design, identify critical members in the truss, and predict the applied load that will cause failure in the truss. The trusses are then tested experimentally to identify the failure load and compare predictions with actual results (see Figure 2).

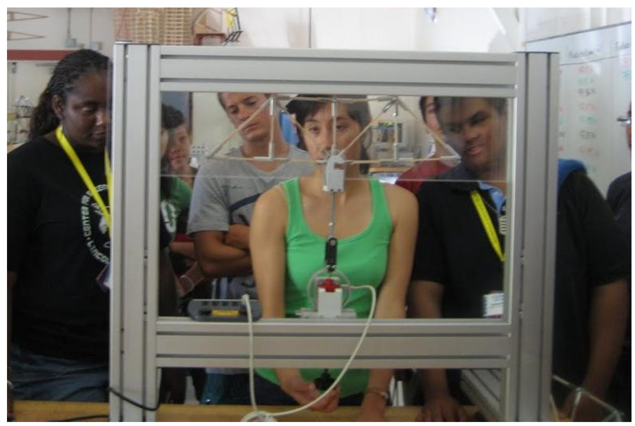

Figure 2: 2D Balsa Wood Truss Tested to Failure

The outcomes of the activity are the ability to conduct simple mathematics to calculate member forces in 2D trusses based on statics principles, to analyze a truss under a given loading condition and optimize its design, to predict structural failure, to validate predictions through experimental means, to gain hands-on experience on the use of materials and the construction of small-scale models, and to work in teams to compare results.

2.2.1.3. Hooke's Law and Vibrations using Spring-Mass Systems

In this activity, students explore Hooke's Law through experimentation with springs. They discover that an ideal spring deforms linearly and learn how to find an unknown spring constant given weights, a spring, and a ruler. In the second part of the activity, students find the period of the spring-mass system, conducting multiple experiments to average their results. Figure 3 shows students using the spring-scale for this activity.

The main objective of Part I of the activity is to provide a hands-on approach to demonstrating Hooke's Law. The students measure the undeformed length of a spring, and then find the deformed length of a spring under a given load. Using those two points, students plot a line and find its slope. This gives them k, the constant of their spring.

In Part II they learn how to find the period of motion and ultimately gain an understanding of some of the fundamental concepts related to single degree-of freedom harmonic vibration.

After completing this exercise the students will be able to estimate the spring constant of a spring. They will work in groups to evaluate their results and compare their spring constant to other groups' constants. Students will observe the linear behavior of a spring being stretched and how it correlates to slope of a line. They will also learn about reliability of data by observing the time it takes for the spring to complete 20 oscillations. They will complete this measurement 3 times for each mass, allowing them to practice data analysis techniques.

Figure 3: Spring-scale Activity to Demonstrate Hooke's Law and Period

2.2.1.4. Lollipop Demonstration of Frequency and Period

The *Lollipop Demo* utilizes four identical masses on four shafts of different lengths to show that each mass/pole system has a different period and its own unique natural frequency (see Figure 4). The objectives of the activity are to demonstrate to the students how stiffness affects the period and frequency. Additionally, this setup can be taken further to show the students that buildings have their own natural frequency and experience resonance when subjected to an earthquake with excitation content near that frequency. After this demonstration, students should understand how the mass and stiffness affect the period and frequency. Furthermore, students should understand that we design buildings so their own natural frequencies are outside the frequency range of earthquakes in a specific area in order to avoid resonance.

Figure 4: Lollipop Demonstration of Frequency and Period

2.2.1.5. Confinement Demonstration Using Sand and Duct Tape

The *Confinement Demo* involves making two sand castles, one without any confinement and the other wrapped with a Duct Tape mesh confinement. This demo helps students understand the principles behind rebar confinement used in concrete columns. The objective of this demonstration is to enhance the students' knowledge on principles of confinement and to give a

Figure 5: Sand with Duct Tape Confinement Supports Instructor's Weight

visual example on how confinement works. After the demonstration, students should understand the principles of confinement theory and how confinement can be used to significantly improve the strength and performance of a column. Additionally, students should realize that increasing the axial load causes the confinement to perform more efficiently.

2.2.1.6. Google SketchUp Tutorial

This activity introduces the students to the versatility and power of 3D modeling. The main objective is to provide the students with a hands-on activity to design a structure using Google SketchUp. It introduces the students to the creative side of designing structures. After completing this activity, students will learn about several types of design software and use Google SketchUp to create a 3D rendering of a simple building. The aim of this activity is that students will be able to develop 3D models of various components of their final projects and incorporate them in their final presentation for the course.

2.2.2. Geophysics Activities

2.2.2.1. Continental Accretion Demonstration

In this activity students learn about plate tectonics. They use a variety of foods to model different geologic features at a plate boundary and the different types of rock that will accrete at subduction zones. The main objective of this activity is to show how different types of rock are folded and faulted at the edge of continents through accretion and subduction. Students learn about different types of rocks on the sea floor and how they become jumbled together as the plates move together. Students work in teams to create their sea floor and see how the different rocks fold and fault together during subduction, which is created by shifting the surface of the sea floor against a rigid boundary representing the continental plate in the subduction process. Figure 6 demonstrates the food-based Continental Accretion activity. Students particularly enjoy this exercise since they have the opportunity to eat the food once it has been completed.

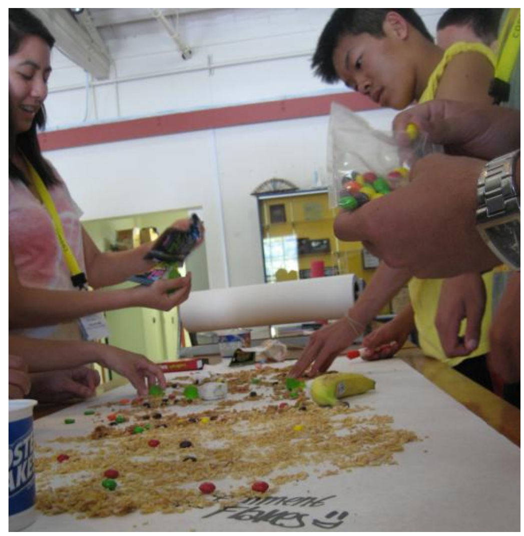

Figure 6: Continental Accretion Example Using Food

2.2.2.2. Reading Geologic Maps

In the activity, students learn to read geologic maps and the various features they display. Students gain knowledge of how to read maps and take information off of them. They also learn about the different rock types on the maps, including those that are found in the local region of the site of the summer program. Before beginning the activity, students are introduced to different types of sediment and rock. Outcomes include students working in teams to discover different places and objects on the map.

2.2.2.3. Evaluation of Seismic Waves using Long Springs

In this activity students see the difference between S and P waves using Slinkys, which provide students with a visual way to observe the waveforms. Students learn about how seismic waves propagate and how recording the waves allow scientists to understand where and in what direction a fault ruptured during an earthquake. Students complete a worksheet in order to gain an understanding of the process of triangulation of a quake's epicenter and the different types of seismic waves.

2.2.2.4. Geologic Half Life with Pennies

This activity provides a hands-on demonstration of how the concept of a half-life works for radioactive material through the shaking of pennies in a box. Initially all of the pennies are placed heads up in the box, which is then closed and shaken. Upon inspecting the shaken box, students see that approximately half of the initial population of heads-up pennies remains. The non-heads-up pennies are removed, the shaking process is repeated, where each successive iteration should show an approximate loss of half of the heads-up population. The data from shaking pennies allows students to construct a half-life curve and shows radioactive decay. This can then be linked to how rocks can be age dated. The method to create a geologic time line using radioactive decay is also introduced. After completing this activity, students should have a basic understanding of half-life and radioactive decay. They should also have an idea of geologic time and how rocks can be age dated.

2.2.2.5. Google Earth Tutorial

In this activity, Google Earth is introduced to the students. They learn how to navigate the software and how to import a .kml file of interest into their own file. The main objective is to learn how to take files from the USGS website regarding fault and earthquake data and apply them to the Google Earth map. Students will be able to layer .kml information onto maps in Google Earth and will learn how to explore regions and find plate boundaries. It is expected that this material will be an instructive component of the students' final projects, discussed in a later section.

2.3. Field Trips

In addition to the lectures and hands-on activities, the students are able to see some of the design concepts learned first-hand through field trips to various buildings and testing facilities. The main geophysics field trip takes students on a walking hike of Torrey Pines State Reserve to observe the evolution of the geology of the region including the formation of geologic structures over time. Students also construct geologic maps during their hike (see Figure 7).

Figure 7: Geophysics Hike to Torrey Pines State Reserve

Another field trip that directly relates to some of the concepts presented in lectures on preventative seismic design brings students to the San Diego Office of Emergency Services building and the San Diego Transportation Management Center building, which are two of the few base-isolated structures in the area. In addition to learning about emergency response procedures during disasters such as fires, earthquakes, and terrorist threats, as well as traffic management issues, the students are taken on a tour of the buildings. Of specific interest are the basements where the buildings rest on a number of rubber bearing dampers that isolate the buildings from the ground in the case of an earthquake. The field trip provides a practical application of the theoretical concepts learned during lectures regarding the mitigation of structural seismic response (see Figure 8).

Students also visit the numerous large-scale structural research facilities on the UCSD campus where they see first-hand the significance of testing structural systems and components for seismic design. These trips include a tour of a the large, high-performance shake table at the Englekirk Center, which is significantly larger than the table-top shake tables they use for experimentation of their projects. The trips provide the students with a much more visual understanding of structural testing requirements and scaling issues (see Figure 9). Additionally, the students gain insight into the research within the structural engineering field that is being performed at the university.

Figure 8: Base Isolation System at San Diego Office of Emergency Services building

2.4. Team-Based Projects

Although the lectures, hands-on demonstrations and activities, technology use, and field trips provide the students with a strong connection to the course material, the independent team-based projects are the most successful in sparking an interest in earthquake engineering in the students and increasing their understanding of the material. Through small-scale models using hands-on laboratory settings as well as computer-based simulations, students gain a quantitative and conceptual understanding of earthquakes and structural engineering principles with the goal of designing safer buildings and prevent loss of life.

Figure 9: Visiting large, high-performance outdoor shake table at UCSD's Englekirk Center

During the four-week program students conduct small research projects that involve background literature searches to learn about science and engineering concepts. In teams of three or four, students design and construct small-scale models and test them on a shake table, develop predictions of structural response, and compare expected structural behavior with measured response observed through the experiments. The two basic areas of research and learning for the projects are in geophysics of earthquakes (the geological character of specific areas of seismic interest), and the structural design of building components and systems (the modeling of earthquake related structural response).

In teams, students conduct their project that integrates geophysics and structural design issues. Main components of the project include independent and group research (information/data collection and analysis), communications of results and ideas (descriptions, data organization, and visualization), design and construction of demonstration models (tested to failure then retrofitted), an oral presentation (10-15 min/group in-class PowerPoint presentation of the project), and a digital poster presentation.

2.4.1. Project Considerations

2.4.1.1. Geologic and Geophysical Considerations

On a small scale, the type of rock beneath the foundation of a building can have a very significant impact on how a building behaves during a quake. Students are asked to use their knowledge of the past and their analysis of the present to make predictions about the future through a process of layering information or data. Each team is given an international region of interest and must map the area and investigate landmarks and the population in the region. The teams must research the geography (oceans, rivers, mountains, valleys, coastal plains, flood plains, etc.), geology (physical nature of the Earth below the area including faults, rocks, soils and seismic response), infrastructure (roads, rail, air, water, fuel, power, etc.), buildings (types of buildings and materials used), and people (population density, preparedness, needs, history) of the region.

Students synthesize the available data about the rocks beneath our feet, as well as the people and their infrastructure, to reveal the various types and the distribution of earthquake hazards in their region, which enables them to make geophysics predictions and recommendations.

2.4.1.2. Structural Engineering Considerations

The main objectives of structural engineering are to understand the interaction between buildings or civil infrastructure and the ground, foresee the potential consequences of strong earthquakes on urban areas and civil infrastructure, and design, construct and maintain structures to perform in compliance with seismic building codes. The structural engineering portion of the group projects involves studying the forces that move the Earth and those that affect the buildings we inhabit. Students make models of their structural designs to test on a small table-top shake table that simulates earthquake ground motions.

2.4.1.3. Project Descriptions

Four main project types are conducted by various teams are described below (see Figure 10):

- **Design and retrofit of shear and flexural reinforced concrete bridge columns** with the objective of learning about mechanisms of shear versus flexure, concrete confinement, structural design, axial versus lateral loads, and structural ductility. Students gain experience working in teams to design a column, test it, and retrofit it. Through this process, they learn about construction techniques and the importance of base column connections and confinement.

- **Design, repair and/or retrofit of timber building structures** and evaluation of their seismic performance. Students gain experience communicating, collaborating, and coming up with an effective structural design based on principles learned in lecture. Through this project students will have a better understanding of how timber structures perform in earthquakes and recognize the importance of diagonal bracing, shear walls, and strong connections between wood members. A preliminary structure is constructed without lateral bracing in the walls or floors, is tested on the shake table, and then either repaired or given a retrofitted design with bracing to improve its performance.

- **Resonance control using a tuned mass damper:** Students research various tuned-mass damping systems and then apply their knowledge to create their own tuned-mass damper such as a pendulum system or slosh tank. Through a hands-on experience, students collaborate to develop through trial-and-error a creative tuned-mass damping system for a small table-top shake table structure, and refine their system until it performs properly. Students gain an understanding of the basic equations and theories governing tuned-mass damping systems, learn how to work together in teams, and how to efficiently collaborate with each other to come up with creative and successful designs.

- **Design of a base isolation system to dampen structural building response:** Students research and design different base isolation techniques and develop ways to build their choice of base isolation devices at very small scale. Students learn how to work in a team to create a base isolation system for a given structure, continually modifying their design so that the end result can resist single direction earthquake or sine motions.

Specific structural concepts and key words were developed for each project and are provided in the project specific documentation. Teams are required to research these terms to familiarize themselves with both basic and advanced structural concepts and design principles. Additionally, teams are given model requirements such as geometrical constraints and construction recommendations.

The overarching goal for the project is to develop an understanding of geophysics and structural engineering that will allow students to design improved structures, present recommendations for disaster mitigation, and make predictions about earthquake hazards around the globe. A specific goal for the geophysics component is that students can identify local (site specific) earthquake related hazards that pose threats to people and buildings. A specific goal for the structural engineering aspect is that students can describe structural design issues caused by earthquake shaking and identify methods to mitigate these issues.

Project outcomes include:

Figure 10: Group Projects (clockwise from top left: Reinforced Concrete Columns, Timber Structures, Tuned Mass Dampers, and Base Isolation)

- Use tools and technology for research and learning
- Perform a literature and/or Google based search of geophysics and structural engineering concepts to classify and explain physical science and engineering phenomenon
- Design a model structure and predict load patterns and failure behaviors
- Test a model structure and acquire data
- Compare predicted structural response with experimental results
- Present structural designs clearly through hand sketches and computer aided design visualizations
- Develop and demonstrate effective problem solving skills
- Demonstrate geophysics and structural engineering concepts through written and oral communication
- Demonstrate the ability to effectively work in teams

3. Curriculum Context within Proven Educational Theories

The curriculum described above was developed based on well-known educational theory such as experiential learning and problem-based learning (PBL). Experiential learning is the process through which knowledge is developed via the use of engaging, hands-on activities and experiences that draw on prior understanding in order to form new connections. Kolb [2] (1984) discusses experiential education with regard to six major tenets:

(i) Learning is best conceived as a process, not in terms of outcomes
(ii) Learning is a continuous process grounded in experience

(iii) The process of learning requires the resolution of conflicts between dialectically-opposed modes of adaptation to the world
(iv) Learning is a holistic process of adaptation to the world
(v) Learning involves transactions between the person and the environment
(vi) Learning is the process of creating knowledge (pp. 26-36) [2]

These six principles help to describe the educational process as one that is based on first-person experiences of the learner. In this view, learning is the exchange of ideas and concepts between the learner and his environment resulting in the solidification of concepts and the establishment of knowledge. A significant goal of the curriculum for the COSMOS high school summer program is to focus on the students' ability to conceptualize abstract and advanced topics in geophysics and earthquake engineering through the use of hands-on inquiry. The curriculum model, composed of short lectures with correlated pair or small group activities, seeks to enhance the effectiveness of the instructional process through application of experiential education techniques.

According to Kolb [2], experiential learning exists across four modes, including (i) concrete experience, (ii) reflective observation, (iii) abstract conceptualization, and (iv) active experimentation (p. 30). The primary components of learning processes exist along two continuums relating concrete experience to abstract conceptualization and reflective observation to active experimentation. The COSMOS program incorporates activities with elements from broad ranges of these spectra, e.g., some activities were heavily observation-based while others involved active, trial-and-error problems; some relate concretely to lecture material while others encouraged students' abstractions of lecture topics. In this way, activities in the program are meant to stimulate students in a variety of ways and to be effective as a complete curriculum to accommodate different personal learning styles.

In addition to the experiential nature of the program, certain components are also developed to allow students to manipulate and understand course material through the solution of relevant engineering problems. Savery [3] describes Problem-Based Learning (PBL) as a "learner-centered approach that empowers learners to conduct research, integrate theory and practice, and apply knowledge and skills to develop a viable solution to a defined problem" (p. 9). Savery also describes an alternate description of PBL from Torp and Sage that consists of "focused, experiential learning organized around the investigation and resolution of messy, real-world problems" (p. 12). These "messy" problems are discussed to be critical to the success of the PBL approach, as they encourage students' engagement in and application of knowledge to such problems.

Savery [3] also cites Hmelo-Silver's description of PBL as learning in which students grow through "facilitated problem solving" (p. 12) centering on complex problems for which a variety of solutions exist; students should collaborate in groups to identify what needs to be done to solve the problem at hand, engage in self-directed learning, to apply existing knowledge, and achieve reflection of what was learned and the effectiveness of strategies employed. Thus, Savery [3] argues, "critical to the success of the [PBL] approach is the selection of ill-structured problems (often interdisciplinary) and a tutor who guides the learning process and conducts a thorough debriefing at the conclusion of the learning experience" (p. 12). The essentials of PBL are listed by Savery as the following:

(i) Students must have the responsibility for their own learning
(ii) The problem simulations used in PBL must be ill-structured and allow for free inquiry
(iii) Learning should be integrated from a wide range of disciplines or subjects
(iv) Collaboration is essential
(v) What students learn during their self-directed learning must be applied back to the problem with reanalysis and resolution
(vi) A closing analysis of what has been learned from work with the problem and a discussion of what concepts and principles have been learned are essential
(vii) Self and peer assessment should be carried out at the completion of each problem and at the end of every curricular unit
(viii) The activities carried out in PBL must be those valued in the real world
(ix) Student examinations must measure student progress towards the goals of PBL
(x) PBL must be the pedagogical base in the curriculum and not part of a didactic curriculum (pp. 12-14) [3]

The majority of these components are integrated into the COSMOS program's term projects. Students are given open-ended problems with real-world contexts that require interdisciplinary study between geophysics and earthquake engineering topics for solution. Students are then expected to collaborate in teams, with the instructors' guidance, to develop solutions often following a trial-and-error procedure. The formative process of the group projects is punctuated by a synthesizing report and presentation, which requires the students' reflection on their final products and the steps taken along the way. Of note is that item (x) listed above, which requires that PBL be the basis for all learning within the program, was not satisfied. Due to the time constraints of the summer program as well as the students' knowledge base, PBL is applied only through the capstone projects and some hands-on activities. Regardless, the components of the program that are based within PBL concepts show high effectiveness in helping the students to synthesize information and formulate knowledge of geophysics and earthquake engineering.

4. Curriculum Context within National Science and Mathematics Standards

The curriculum for the summer program, though including some advanced topics, is developed within the framework of national standards for both science and mathematics education for 9^{th} through 12^{th} grade students. The development of a hands-on curriculum helps to fulfill many of the Content Standards for science, including the inquiry-based nature of the program, the discussion of physical concepts such as forces and seismic energy, and the discussion of Earth processes. Additionally, the use of instructional technology, the discussion of the societal implications of earthquake engineering, and background information on the historical perspectives of seismology and engineering fulfill a large share of the Content Standards. Science Program Standards B, C, and D are also met with regard to the program being relevant and appropriate, coordinated with a study of mathematics, and involve access to appropriate and sufficient educational resources. Please refer to "National Science Education Standards" by the Center for Science, Mathematics, and Engineering Education (CSMEE) for a more thorough description of these standards.

It is the nature of the curriculum that the science components of lectures were highly connected with standard high school Geometry, Algebra, and Pre-Calculus topics. Though the program is more focused in the sciences of geophysics and earthquake engineering, the curriculum is well aligned with the Math Standards and Expectations from these areas, as well as those for Measurement and Data Analysis and Probability. Please refer to “Principles and Standards for School Mathematics” by the National Council of Teachers of Mathematics for a more thorough description of these standards.

5. Assessment

The previously described tenets of Experiential Education and Problem-Based Learning are applied in a variety of contexts within the “Earthquakes in Action” cluster of the COSMOS program. Activities presented in conjunction with lectures focus on allowing students to make connections among the concrete topics within geophysics and structural engineering lectures. The activities also encourage a development of knowledge through the process of engagement and the understanding that comes via experiencing a described concept in some physical form. Many of the activities, especially the capstone projects, involve inquiry into geophysics and engineering problems. In these situations the instructors act as aides to facilitate the students’ group problem-based learning.

Of additional significance are the field trips and site visits which allow students to experience and correlate lecture topics within real-world applications. The interdisciplinary nature of the COSMOS program through its science communication element allows students to discuss experiences within the context of a variety of scientific fields. Implementation of technology in the teaching laboratory, while not exhaustive, is also proven to be helpful in effectively communicating and applying lecture topics. The math and science components of the program meet numerous qualifications for national standards for education in grades 9 through 12, which promotes the notion that the curriculum could be effectively applied in the traditional classroom setting as well. Overall, the success of the COSMOS Earthquakes in Action program has shown that a hands-on and engaging curriculum is the best model for presenting the described topics to high school aged students.

During summer 2010, student comprehension and retention of course material was qualified through pre- and post-program surveys. The pre-survey was informal and was used to assess the level of math preparation of each student and their future career interests. Of the 20 students, approximately 1/4 had pre-calculus or calculus backgrounds. Since three of the seven group projects required a higher level of math comprehension, the information about students’ level of math preparation was used to select balanced project teams. Additionally, from the pre-survey only a handful of students expressed interest in engineering as a major in college.

Following the summer program, a post survey was administered that allowed the students to evaluate the various components of the course (lectures, activities, projects, and field trips), as well as the instructors, teaching assistants, and teacher fellow for the cluster. Feedback overall was very positive. Most students really enjoyed all aspects of the course and the balance between different learning techniques. The students who executed the shear column project expressed their frustrations with the testing apparatus, which led to difficulty in getting accurate results.

This feedback has been incorporated into future plans for the COSMOS program as described further below.

In order to assess whether the main program goals were met, which were to spark interest in the earthquake engineering and geophysics topics presented, and encourage students to pursue math- and science- related majors at public, in-state universities, an additional survey was administered via email 6 months after the program.

The survey asked the students how interested they were in science and math before and after participating in the program. Most were interested before and their interest grew as a result of the program. The survey also asked how interested the students were in earthquake engineering and seismology before and after participating in the program. Most students' knowledge of earthquake engineering and seismology prior the summer program was limited to plate tectonics learned in 6^{th} grade. Almost all showed an increase in interest in these fields following the program.

> "My interest in engineering increased QUADRUPLEfold! Since I had a strong interest beforehand, the university-level exposure just affirmed that I want to pursue STEM."

When asked what college major the students were thinking of before participating in the program and whether the program changed their inclination towards a specific major, only two students were interested in civil engineering prior to the summer program, and their participation in the program reinforced their decision to pursue it as a major in college. Several were interested in other forms of engineering prior to the program, and the majority of students were interested in pre-medicine or another science related field. Almost all of the students indicated that the program increased their interest in engineering with a few actually now considering it as their major in college.

> "My participation in this program has allowed me to maintain an avid interest in earthquake engineering/seismology and I view it as a career option. Cluster 4 opened my eyes to the world of civil and structural engineering."

> "I did NOT consider engineering AT ALL before this program. Now, my top choice is biomedical engineering (it will allow me to pursue either medicine or engineering after undergrad)."

The survey also collected a baseline for how science and math concepts were normally taught in the students' high school classes, as well as their preferred learning style (audio, visual, hands-on, lectures, self-reading/study). Students typically received information in standard lecture and laboratory format with very limited opportunities for presentations and group work. Most said they prefer visual and hands-on activities for learning rather than lecture-based instruction.

> "I thought the teaching was amazing. I remember during the program that some of the students in our cluster were talking about how we learned so much more in one month in this program than we did the whole school year. I was able to focus

and understand the material, with no physics background. Now that I'm in physics, I'm constantly able to apply things we learned to new material."

"I wasn't used to talking in front of many people. But, because of this program, and a bunch of presentations assigned to us, I'm forced to learn how to speak in front of people and it led me to do well on presentations."

Finally, the survey asked the students if the way the material that was presented in the summer program affected their ability to learn and retain the material. All students glowingly praised the opportunity to experience learning through a variety of mediums.

6. Conclusions

The authors conclude that these experiential practices have successfully presented earthquake engineering and seismology material to high school students and increased student interest in pursuing STEM degrees. The COSMOS philosophy of hands-on learning can be extended to high school and college classrooms in order to enhance to effectiveness of engineering education. This paper discusses the applicability of experiential education practices in high school and college environments, and provides recommendations for new components to be implemented in future years of the described summer program.

In future years of the COSMOS program, the current instructors expect to implement numerous improvements to the "Earthquakes in Action" cluster based on feedback from previous iterations. With regard to the students' activities and projects it is hoped that data acquisition and processing can be more widely implemented as a component of the experimental procedure. The set-up, collection, and review of data from an experiment are crucial elements within the geophysics and structural engineering fields of research. It is anticipated that, with little additional effort, the described activities and projects can be modified to include elements of data gathering and discussion of experimental versus theoretical results. Additionally, the experimental design of some of the projects can be improved through the use of higher-quality laboratory equipment. One example of this is the use of a digital load cell and actuator system to test the students' shear-governed column specimens with the hope that traditional failure modes can be generated more easily than has been the case in the past. Implementation of improved laboratory equipment and experimental setups should also allow the students to run their experiments more independently, aiding in the PBL approach to the course.

The goals and outcomes of the COSMOS program should also be mapped to the program outcomes defined by the Accreditation Board for Engineering and Technology (ABET), which deals with the accreditation of engineering departments at colleges and universities. The goals of the COSMOS program, especially those of the "Earthquakes in Action" cluster, align well with the ABET anticipated program outcomes, and these should be compared in the future in order to map the effectiveness of the program in engaging students in a college-level academic environment. Targeted surveys of the students' experiences prior to, during, and after attending COSMOS should aid in qualifying the extent of the connection between the ABET outcomes and those of the program at large.

While this paper provides an introduction to the "Earthquakes in Action" program curriculum and its context within well-known educational theory and national math and science standards, the ambition of the research is the development of curriculum for broad dissemination. This will be accomplished through the curriculum exchange session at the ASEE Annual Meeting in Vancouver, Canada in June 2011, where lecture material, hands-on demonstrations and activities, and student research projects related to the mitigation of structural response (such as tuned-mass dampers and base isolation systems) will be presented. The teacher and student documentation developed for several activities will be made available, as well as photos and videos demonstrating the success of the methodology behind the program.

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8. References

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