AC 2010-1210: USING TECHNOLOGY-BASED EXPERIENCES TO CONNECT ENGINEERING DESIGN, SCIENCE, AND MATHEMATICS FOR SECONDARY SCHOOL TEACHERS

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Using Technology-based Experiences to Connect Engineering Design, Science, and Mathematics for Secondary School Teachers

Abstract

Educators are faced with an ongoing challenge of creating engaging, student-centered learning situations that relate classroom topics to practical application. As a result of their comfort with the use of information technology, contemporary students and teachers can find traditional classroom methods of lecture and guided laboratory experiments limiting. Recently, the need for increasing the number of students graduating in Science, Technology, Engineering, and Mathematics (STEM) fields United States has been recognized as a threat to continued economic development. This need, coupled with increasing technological literacy, has created an opportunity to leverage leading edge cyberinfrastructure in an outreach program targeting secondary school teachers. This paper demonstrates the implementation of a targeted outreach program that engages pre- and in-service teachers of mathematics and science using state-of-the-art virtual design and earthquake engineering technologies. The research places teachers into a intimate workshop-based program that uses engaging experiences to develop content knowledge and provide connections between education standards and practical application of theoretical concepts.

Introduction

One of the most difficult challenges in attracting students to engineering is conveying the idea that relating theoretical and analytical results to real-world phenomena can be interesting and engaging. Innovation driven by advances in science and technology is a key component of the US economy.¹⁻² However, this engine of economic development has multiple threats that will need to be addressed over the next generation. In 2003, the National Science Board reported³ that the most significant threats to our science and technology workforce include:

- Flat or reduced domestic student interest in critical areas, such as engineering and the physical, and mathematical sciences
- Large increases in retirements from the S&E workforce projected over the next two decades
- Projected rapid growth in S&E occupations over the next decade, at three times the rate of all occupations
- Anticipated growth in the need for American citizens with S&E skills in jobs related to national security, following September 11, 2001
- Severe pressure on State and local budgets for education of the future S&E workforce.

Along with the need for increased participation in science and engineering careers, the ubiquitous nature of cyberinfrastructure-enabled frameworks (e.g., Facebook⁴, MySpace⁵) has also increased the expectations of students when engaging them in an authentic learning experience. Researchers and national advisory panels have recognized the increased expectations of learners and made recommendations to increase the role of technology in learning environments.⁶⁻⁷ In 2001, the President's Information Technology Advisory Council (PITAC)

recommended the development of technologies for education and training that use simulation, visualization, and gaming to actively engage students in the learning experience.⁸ In the same report, PITAC also recommended the development of engaging, educational experiences that provide learners with access to world class facilities and experiences using actual or simulated devices. Simulated systems enable designers to explore the merits of alternative designs without physically building the system, reducing development cost and the risk associated with some forms of physical testing. In mathematics and science education, engineering simulations can be used as engaging tools to teach students important concepts as well as demonstrate the connections between the math and science learned in class and the potential practical applications in engineering design.

In engineering, leaders such as Richard Felder⁹⁻¹² have advocated the use of active, studentcentered instruction in courses. Educators have also been challenged to incorporate more authentic learning situations including the use of inquiry, project-based instruction, and increased opportunities for student collaboration and communication. Engineering professors Wankat and Oreovicz encourage others to incorporate "real" engineering through the use of simulators, experiential learning, and problem-based learning.¹³⁻¹⁶ Two of the guiding principles for the situated learning theory are that 1) new educational material should to be presented in an authentic context and 2) social interaction and collaboration are required for learning to occur. The work presented focuses on using situated learning experiences for both educators to expand their knowledge and for creating learning experiences for students of math and science.

Identifying techniques that help students develop better connections between mathematics and science in the classroom and addressing engineering problems would make significant strides towards addressing this projected shortfall of scientists and engineers. Opportunities to learn about engineering in high school are limited. Engineering programs (e.g., Project Lead the Way) are taken by those students already interested in engineering, limiting the potential of attracting new students to engineering careers. Mathematics and science teachers are traditionally trained in their core competencies (e.g., Algebra, Geometry, Trigonometry, Biology and Physics) that match the offerings in high school curricula.

Mathematics teachers have been challenged by the National Council of Teachers of Mathematics (NCTM) standards to rethink the teaching of mathematics as a field of study tightly integrated with other disciplines and that educators should help students to recognize the application of mathematics in different contexts.¹⁷ The NCTM Connection standard sets a goal of promoting technology-rich interdisciplinary connections with engineering. Rather than having students only learn of engineering as undergraduates, this standard tasks math teachers to integrate a practical introduction to the work of engineers, while addressing the age-old question "when are we ever going to use this?". In a search of all four of NCTM's journals, Teaching Children Mathematics, Mathematics Teaching in the Middle Grades, Mathematics Teacher (the three practitioner journals aimed at elementary, middle school, and high school teachers respectively) and the Journal for Research in Mathematics Education, fewer than 15 articles have addressed interdisciplinary connections between math and engineering since the NCTM Principles and Standards of School Mathematics document was published in 2000, which included the Connections Standard. These limited outcomes represent a lack of examples and resources for teachers of mathematics to show how mathematics is applied in engineering.

To address these needs, teacher education faculty from the Graduate School of Education teamed with faculty and staff from two School of Engineering research centers to develop a focused curriculum for pre-and in-service teachers of mathematics to explore real problems and issues in engineering design using mechanical engineering and earthquake engineering. The learning experiences provided teachers with examples of authentic learning environments that would allow their students to gain content knowledge while developing collaborative and research skills. The following section provides an overview of the program and evaluation results for each component.

Workshop Program

The curriculum introduced teachers to the connections between mathematics and engineering used to solve challenges in Modeling and Virtual Design and Earthquake Engineering Design. Participants could enroll in one or both components. Each component consisted of an intensive 3-day, 10 hours per day, learning environment that provided participants with hands-on experiences in engineering laboratories featuring state of the art technology and opportunities to work with the engineers using the technology in their work and study. Each session was developed to increase content knowledge as well as model pedagogical strategies appropriate for classroom instruction.

The two components were scheduled twice during the summer to provide the greatest opportunity for participation by pre- and in-service teachers. The program was promoted by distributing materials to students of the Graduate School of Education and to all of the high schools within a 30 mile radius of the university. Each component met from 9:00 AM to 7:30 PM and featured various learning environments including engineering and computer labs in addition to classroom instruction. The following sections provide detail of the activities and content of each component as well as an evaluation of each major program component.

Modeling and Virtual Design

Program Overview

The Modeling and Virtual Design component involved participants in a variety of experiences related to using models to gain insight into design issues. Instructional environments included the engineering design center, a computer laboratory and a classroom. Participants were involved in hands-on activities in the three environments that provided opportunities for them to investigate and explore models and conduct analyses.

Virtual Reality in Engineering Design



(a) Immersive model of a sabretooth tiger generated from point cloud data



(b) Three dimensional tracking interface for visualization

Figure 1. Immersive Interfaces for Engineering Design.

As an introduction to the application of mathematical theories in the development of engineering simulations, participants experienced a number of simulations, using both an immersive virtual reality simulation system and a vehicle simulation framework using a six degree-of-freedom motion platform. Educators worked with researchers to understand the mathematical models necessary to perform engineering simulations, including child safety in car seat design, transportation safety in fluid movement and tanker truck design, and roller coaster design. Center staff provided insights into the various aspects of the design process and the variety of issues that industry brings to engineers working in such an environment. In addition to participants exploring virtual models through the use of active-stereo glasses, participants were introduced to the details of how 3-dimensional simulations are created including how three-dimensional geometry and optimization concepts are used in the development of visual simulations and video games. Figure 1a shows an example of how medical scanning devices (e.g., CT, MRI) can provide a cloud of points that can be converted into a three-dimensional object.

The technology and mathematics discussed were then connected to children's and adolescents interests as aspects of design of the Nintendo Wii gaming platform was discussed as an example of an inexpensive means of interacting with a simulation environment. Differences between the research lab environment and gaming platforms were compared and discussed. Educators were shown how highly accurate three dimensional tracking systems similar to the one in Figure 1b use inertial tracking systems and ultrasonic emitters to achieve very precise calculations of positions while commodity systems such as the Wii is limited to capturing only accelerations and movement of the tracking device within a single plane.

Simulation Development using Virtual Reality Modeling Language (VRML)

After experiencing the simulations used in engineering design applications, educators were introduced to the Virtual Reality Modeling Language (VRML) in a computer lab context. VRML is a text-based markup language that can be used to create virtual worlds by modeling and manipulating three-dimensional objects. VRML worlds can be used in engineering design for creating virtual representations of products, as can be seen in Figure 2, or for creating entertaining worlds that are viewable using a web browser plugin.



Figure 2. Product visualization using VRML.

The programming language is based in

the x-y-z plane and participants wrote procedures to produce real-world objects. The tasks required the participants extend their mathematical thinking to the 3-D world through positioning basic objects including cones, cylinders, spheres, and rectangular solids in the x-y-z plane and then performing translations as needed to form interesting objects including ice cream cones, shelters, and column entrances.

The participants gained first-hand experience in working in an environment that provided insight into the world of three dimensional animation and games as well as addressing specific mathematics content within the context of writing programs. The connections between these applications (e.g., the modeling and graphics knowledge needed to create Shrek or Monsters, Inc.) and mathematics education standards were highlighted and discussed in the context of the VRML modeling experience. Figure 3 shows a concept from the new state standards that



Figure 3. VRML representation of a threedimensional geometry concept.

increase the expectations of student understanding of three dimensional geometry concepts. The combination of using mathematical logic and coordinate geometry to produce powerful visual models of real objects provided a rich context for learning that modeled the type of teaching and learning environment that could be provided for students to address MST Standards.

Mathematical Modeling to Develop Simulations of Physical Phenomena

The combination of engineering researchers and education faculty resulted in the identification of opportunities for educators to develop an understanding of how engineering models are developed. These hands-on modeling experiences focused on using a simple, yet engaging context, that could be used to elicit critical thinking and the application of mathematical concepts as educators strove to develop a simulation of a physical phenomenon. As the participants worked through the exercises, the engineering and education faculty pointed out opportunities for reflection on the application of mathematics to solve the problem and asked questions to initiate discussions of their experiences.

One example activity focused on developing a mathematical model for water exiting from a hose. Participants discussed in class what they knew about the situation and what they wanted to know when they conducted experiments with actual hoses outside. As students collected a variety of data to help develop the model, they wrestled with issues such as how to measure the angle of the water, the velocity of the water, what height meant in terms of vertical distance from the ground or from the exit point of the hose, and many others. Once they had gathered the data they returned to the classroom to complete their analyses via graphing calculators and to reflect on the activity. The general sense was that the nature of the activity provided students with a wonderful context that naturally gave rise to significant mathematics that they teach in their classrooms and connected the mathematics in a meaningful way to the world around them, including the importance of precision in model development. The discussions in the classroom provided an opportunity to link the material/experiences from labs to the NYS Core Curriculum for Mathematics and to share ideas as to how to implement some of the content in a classroom setting.

At the completion of the three day session, the participants evaluated the institute for relevance and meaning to their teaching situations. The next section presents the evaluation results for the engineering design component of the program.

Participant Evaluation: Modeling and Virtual Design

An electronic evaluation was used to assess the participants' response to the workshop program. Table 1 contains summaries of the responses to 12 items that were measured on a Likert scale from strongly disagree (1) to strongly agree (5). The data reflect the responses of 15 participants and include 10 high school math teachers, 4 middle school teachers, and 1 elementary teacher.

Assessment Item	Average Participant Response
Your overall rating of the 3 days:	3.6*
Your overall rating of the instruction:	3.8*
The ideas/activities presented in this workshop were relevant to my teaching situation.	4
The ideas/activities presented in this workshop were connected to the NYS curriculum standards.	4.3
I am likely to integrate the ideas/activities presented in this workshop into my instruction.	4.2
I am unsure as to how VRML could be used to study mathematical phenomena with my students.	2.1
I am motivated to further explore VRML programming.	4
I do not see myself implementing interdisciplinary topics in my classroom.	1.8
I see little value in using non-routine problems/tasks for purposes of assessment.	1.5
This workshop has allowed me to see/make new connections among topics.	4.4
I think if my students did projects similar to those in this workshop they would have a deeper understanding of the M/S/T content.	4.4
This workshop has provided me with exposure to some practical ways in which I can implement ideas of modeling and virtual design in my classroom.	4.4

Table 1. Student Evaluation Responses for Modeling and Virtual Design Component.

* Items 1 and 2 were on a 1-4 Likert Scale (poor to excellent).

The student evaluations of the program provided a very favorable review of the program and the ability to use the topics presented to assist in connecting authentic engineering design applications to mathematics standards. The structure of the sixth, eighth, and ninth evaluation questions created some confusion in the minds of the students that resulted in a high variability in student responses. The participants were also asked to comment on the institute regarding the three types of experiences and their relative value. Sample responses are included below.

Visiting each of the labs was very relative to the discussions during this course. Also, it put concrete meaning to much of the mathematics we study and teach. We are now able to share with our students many interesting real-world occupations using advanced mathematics. I really enjoyed learning the VRML program and how it applies so perfectly to mathematics. I think this seminar showed how important mathematical concepts are outside of the classroom and promoted exploration and intrigue in the learning process. I am very interested in attempting to use some of these strategies in my classroom to increase student engagement and show them the utility of mathematics. The seminar was very informative and implemented a numerous amount of activities and strategies that can be applied at the high school level.

I really enjoyed being introduced to computer programming and particularly liked the programming that was relevant to high school mathematics (such as the plane standards for NYS). I definitely was able to see the connection between math and science in this workshop and will most likely use some of topics in my own classroom.

Both the quantitative and qualitative data reflect a highly valued and rated institute that teachers found to be informative and practical for their teaching practice. An interesting outcome in both the quantitative and qualitative feedback was the interest in learning more about the VRML programming language. None of the educators in the program had programming experience and the development of VRML models and animations required developing an understanding of programming syntax and structure while applying mathematical concepts to a new context (i.e., the development of a visual simulation).

Earthquake Engineering Design

Program Overview

The Earthquake Engineering Design (EED) component involved participants in a variety of experiences that developed their understanding and insight of fundamental mathematical and scientific concepts that are the basis of earthquakes, earthquake analysis, and engineering design mechanisms that address earthquake related issues. Instructional environments included the earthquake engineering laboratory, a computer laboratory and a classroom. Participants were involved in hands-on activities in the three environments that provided opportunities for them to investigate and explore models and conduct analyses relating the mathematical concepts to Earthquake Engineering Design.

A variety of hands-on and web-based activities engaged participants in developing foundational knowledge of earthquakes and earthquake design issues, as well as of emergency response management issues. These included developing models of the earth to illustrate the composition and layers, web-based structures that were tested for vulnerability to earthquake stresses, and 5-story models of wood columns connected with glue that were tested on the shake table. Each of these experiences included group presentations where aspects of mathematics were discussed within the context of the activity and connected to the content at the middle and high school. Some of the mathematical topics that arose from the activities included intersections of loci of points when locating centers of seismic disturbances, logarithmic scales to describe magnitude of earthquakes and to compare sizes of earthquakes (and related phenomena that are measured in similar scales including PH and decibels), cost analyses on individual and large scale design including options of rebuilding or retrofitting existing structures in a Sim-City type computer

environment, and measurement and scaling in cross-sectional models of the earth and in blueprint production and analysis.

The earthquake engineering research facility tour provided participants with knowledge of current cutting-edge practices in the field of EED and the problems that engineers attempt to address in the design process. The participants were then presented with the task of designing a 5-story model that would be assessed on its ability to withstand an earthquake as simulated with the shake table. Figure 4 shows participants with their building model. The participants then explored design issues related to their 5-story models and the aspects of elementary mathematics underlying structural design.

Another aspect of the work was presented by the coordinator of education services for the earthquake engineering research center. The coordinator provided insights into the various aspects of the center and particularly the earthquake engineering educational outreach website with its wealth of resources for students and teachers at the middle and high school. Figure 5 shows an example web-based application that can be used by educators to teach high school students about earthquake engineering design. Participants were provided with



Figure 4. Participants with 5 story building model.



Figure 5. Web-based Earthquake Engineering educational module.

significant opportunities to spend time online exploring the many resources within the teaching website as well as related sites.

The participants evaluated the institute at the completion of the 3 day session and the results indicate a very positive experience that was relevant and meaningful to their teaching situations.

Participant Evaluation: Earthquake Engineering Design

An electronic evaluation was used to assess the participants' response to the EED institute. Table 2 contains summaries of the responses to 13 items that were measured on a Likert scale from strongly disagree (1) to strongly agree (5). The data reflect the responses of 8 participants and include 6 high school math teachers and 2 teachers who did not specify a level.

Assessment Item	Average Participant Response
Your overall rating of the 3 days:	3.4
Your overall rating of the instruction:	3.3
The ideas/activities presented in this workshop were relevant to my teaching situation.	3.3
The ideas/activities presented in this workshop were connected to the NYS curriculum standards.	4.4
I am likely to integrate the ideas/activities presented in this workshop into my instruction.	3
I am unsure as to how earthquake engineering design principles could be used to study mathematical and/or scientific phenomena with my students.	2.1
I am motivated to further explore earthquake engineering design and its classroom potential for the middle and high school.	3.4
I do not see myself implementing interdisciplinary topics in my classroom.	1.9
I see little value in using non-routine problems/tasks for purposes of assessment.	1.5
This workshop has allowed me to see/make new connections among topics.	4.3
I think if my students did projects similar to those in this workshop they would have a deeper understanding of the M/S/T content.	4
This workshop has provided me with exposure to some practical ways in which I can implement ideas of modeling and virtual design in my classroom.	4
This workshop has provided me with resources related to emergency management response that I can use in my classroom.	4

Table 2. Student Evaluation Responses for Earthquake Engineering Design Component.

* Items 1 and $\overline{2}$ were on a 1-4 Likert Scale (poor to excellent).

The participants were also asked to comment on the institute regarding the 3 types of experiences and their relative value. Below are some the responses.

I think the seminar provided many non-routine situations that can increase exploration and the learning of important concepts. I really enjoyed building the structural model and testing it using the shake table. In addition, I was exposed to many virtual resources that helped further explain and explore earthquakes, which really helped in my understanding of the concept. I like how the course integrated math, science, and technology and showed the ways in which interdisciplinary planning can be beneficial to student learning. I really enjoyed the tour of the earthquake lab and the explanation of the different equipment and tests that were going on. I thought the part of the workshop that allowed students to create a building to be tested on the shake table was very beneficial to enhance problem solving skills and team work. I think that a little more instruction on design strategy in terms of earthquake engineering could have been discussed so that groups had a better idea of how to create structures that can withstand the impact of disasters.

This course was very interesting and I definitely plan on using some or all of the lessons on the Connected Teaching Website in my classroom. I really enjoyed building the model and putting it on the shake table and think that students would love this activity. The tour through the lab would also be interesting to take students on and I hope that I am able to in the future. I like the 3 day courses. Although they are intense it is nice to only have to set aside 3 days all summer for them. I would recommend that other classes follow this schedule.

Both the quantitative and qualitative data reflect a highly valued and rated institute that teachers found to be informative and practical for their teaching practice. In addition, the students were evaluated during the institute with a pre- post-test on their knowledge of Earthquakes and Engineering. Results indicated strong growth in knowledge in these areas following the 3 days of instruction.

Summary of Outcomes and Future Directions

The teacher education program was very successful in attaining the goal of improving teachers' understanding of the connections that exist between mathematics and engineering design, refreshing and renewing their skills in using state-of-the-art technology, and developing ideas about how content and technology can be applied in relevant, rigorous, and meaningful instruction in mathematics aligned with state learning standards and core curricula. Participants displayed enthusiasm both during the institute and in responding to summative evaluation questions. Their responses reveal an interest in bridging the disciplines and seeing mathematics as more than a set of rules and procedures to be followed. In addition, they view assessment broadly and see the types of activities presented in the institute as being reflective of the state content they are expected to teach in their classrooms.

The participants were able to gain first-hand experience in working in an environment that provided insight into the world of 3-D games as well as addressing specific mathematics content within the context of writing computer programs. One participant commented that it was great to see the connections between what they were doing and how the animations in Shrek or Monsters, Inc. work. The combination of using mathematical logic and coordinate geometry to produce powerful visual models of real objects was a rich context for learning that modeled the type of teaching and learning environment the participants should provide for their students to address the mathematics standards. The general sense was that the nature of the activity provided students with a wonderful context that naturally gave rise to significant mathematics that they teach in their classrooms and connected the mathematics in a meaningful way to the world around them. The discussions in the classroom provided an opportunity to link the material/experiences from laboratories to the Core Curriculum for Mathematics and to share ideas as to how to implement some of the content in a classroom setting.

The attendance for the institute was the one issue that was problematic. Participants were generally members of the university student body and thus their enrollment was in part reflective of their contact with the instructors and the graduate program. There was wide spread dissemination of the promotional materials about the institute via the western New York mathematics teacher list serve as well as letters to school districts, but there seemed to be a lack of population interested in such a program. This is reflective, in part, of the status of the need for Continuing Education Units as a part of professional certification. Participants could have received 2 graduate credits or CEU's upon completion of the institute. However, the population that will be needing to enroll in courses that provide them with CEU's has yet (for the most part) to complete their Master's degree programs and thus are taking courses that generally are for 3 credit hours and have outlined plans for completing their program. Furthermore, the cost of the program has participation as a financial commitment of several hundred dollars which the target audience will see as comparable to opportunities at local district teacher centers and thus does not provide incentive to extend themselves beyond their local district. One additional factor that is likely to have influenced participation is the current focus on implementation of the new NYS Core Curriculum and the many local efforts at developing courses and syllabi that reflect the new standards. Once the transition to the new standards is generally complete teachers focus will again return to furthering their knowledge of teaching and learning mathematics and science.

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