# AC 2007-2518: A PROFESSIONAL DEVELOPMENT MODEL TO INFUSE ENGINEERING DESIGN CONTENT INTO THE HIGH SCHOOL CURRICULUM

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# A Professional Development Model to Infuse Engineering Design Content into the High School Curriculum


## Abstract

This paper discusses the development, implementation, and assessment of a professional development model for high school teachers that focuses on their ability to integrate the analytical nature of design and problem solving needed to deliver technological as well as engineering concepts. This professional development model is built around delivery of an "engineering design challenge" to the participating teachers. The engineering design challenge provides a means with which the engineering design process can be used by the teachers to infuse engineering content and analysis into their curriculum. The design challenge discussed here was delivered through more than 80 hours of professional development sessions to 12 math, science, and technology educators from the Long Beach Unified School District during the spring and summers of 2005 and 2006. A survey of teacher participants used to assess the program indicated that all of the teachers either increased or greatly increased their interest and ability to infuse the engineering material into their teaching. Most indicated that they have changed or plan to change their curriculum to incorporate the engineering concepts they learned and the majority will use the engineering design challenge in their curriculum.


## Introduction and Background

An increasing and significant number of business, academic, and political leaders, professional associations and coalitions continue to express their growing concern that our nation's deficiency in K-12 Science, Technology, Engineering, and Mathematics (STEM) Education is approaching a crisis level. Their numbers represent all areas of the engineering, technology, science, mathematics, business and political communities. A sampling presents an overview of current sentiment.

The American Society for Engineering Education (ASEE) has expressed significant concern about our nation's ability to maintain its leadership position in engineering and technology related research required to sustain the highly trained and technologically literate workforce required for economic growth, maintenance of national security, improved healthcare and to safeguard our environment[1]. ASEE and educators are now working to facilitate the development of a lifelong love for STEM subjects early in their educational careers. Likewise, several other organizations across the country are making similar recommendations related to the importance of STEM education (e.g. American Society of Mechanical Engineers[2]; International Technology Education Association[3]).

As has been identified by several sources, including those previously cited, essential ingredients for successful K-12 STEM learning experiences include the recruitment, training and mentoring of highly qualified teachers. This paper presents one model that addresses these issues by providing professional development designed to increase participants' awareness and appreciation of engineering design and problem solving, increase their knowledge, appreciation and use of appropriate math and science knowledge, and provide a model for them to infuse their

new knowledge and experiences into their high school courses. The desired result is to enhance the STEM pipeline by increasing student awareness of engineering and the work done by engineers, developing a sense of appreciation for the contribution made by engineers, and inspiring them to pursue STEM careers.

The impetus for this specific project stems from the creation of the National Center for Engineering and Technology Education (NCETE), which is one of the National Science Foundation's Centers for Teaching and Learning. One of the primary goals of the NCETE is to infuse engineering design, content, problem solving and analytical skills into K-12 STEM education in order to increase the quality, quantity, and diversity of engineering and technology educators. In turn, this will enhance students' understanding of engineering and the engineering design process as well as strengthen pathways to engineering professions for students.

California State University, Los Angeles (CSULA) is a core member of the NCETE and has partnered with the Long Beach Unified School District (LBUSD) to deliver a series of "engineering design challenges" appropriate for high school students that infuse engineering content, design and problem solving into the curriculum. The objective is to build a cohort of high school teachers at LBUSD who are capable of integrating engineering content into their curriculum to positively impact student learning related to technology and engineering. High school teachers from the LBUSD were a natural fit because of the district's move toward integrating engineering & technology academies (small learning communities) into their high schools. Teachers were recruited by an open call that was made through administrative contacts within the district.

The instructional module and design challenge discussed here were delivered through more than 80 hours of professional development sessions to 12 math, science, and technology educators from the LBUSD during the spring and summers of 2005 and 2006. This paper discusses the development and implementation of the model and assesses the effectiveness of the program to date by presenting survey data collected from the participants.

**Development and Implementation of the Professional Development Model**

Once participants begin to understand the theoretical engineering design process, it is important that they have opportunities to experience how it is applied to solve real-world problems. This professional development model is built around delivery of an "engineering design challenge" to the participating teachers. The engineering design challenge provides a means by which the engineering design process can be used by the teachers to infuse engineering content and analysis into their curriculum. Specifically, the design challenge is based on using math and physics to predict the movement of a building subjected to an earthquake, and how engineers use the engineering design process to select the "best" solution (in this case the proper building height) based on the given design constraints. The design challenge makes use of hands-on experiments by utilizing an instructional desk-top shake table to model the building behavior during an earthquake. Each teacher received a shake table, and comprehensive documentation covering earthquake engineering basics, shake table instructional manual, and the design challenge scenario. The engineering design challenge is organized so it can be expanded or contracted based on the needs of the teachers.

This professional development model was structured to accommodate the varied backgrounds and capabilities of the participating math, science, and technology teachers. Figure 1 illustrates the range in ethnicities, teaching areas, and gender distribution, of the teachers who participated in the program. It was felt that to ensure their success, the professional development model should be split into spring and summer sessions to allow the teachers enough time to study, reflect, and develop an implementation plan. The spring sessions were delivered over six consecutive all-day Saturday seminars and were designed to provide requisite math and physics knowledge, learn about engineering and the engineering design process, and build camaraderie. The summer sessions were delivered over an intensive one week schedule and were used to train the teachers on the use and implementation of the engineering design challenge. A summary of the main activities and objectives for the spring and summer sessions are listed in Tables 1 and 2 below. Feedback was solicited from each teacher by collecting anonymous one-minute papers at the end of each session. The one-minute papers provided a means for each teacher to comment on the main points of the day's session, the best and worst things about the session, and questions they most wish to have answered. The results of the one-minute papers were always reviewed with the teachers at the start of the next session and provided a means by which the workshop agenda could be modified to meet their needs.

Table 1. Activities and Objectives of the Spring Workshop

| Activity | Objective |
|---|---|
| Math Diagnostic Test | Establish baseline of teacher ability in order to determine individual training needs. |
| Intro. to the Engineering Profession | Expose teachers to the roles and duties of Civil, Mechanical, & Electrical Engineers. |
| Engineering vs. Technology Design | Compare the engineering and technology professions. Discuss the differences and similarities between the two design processes. |
| Engineering Design Case Study | Hands-on example of how engineering design process applied to a real problem. |
| Math and Physics Sessions | Deliver requisite math and physics (just-in-time approach) needed to perform the design challenge. |
| Teaching Teamwork | Team building exercise. |
| Pre-Summer Session Assignment | Research basic seismology and read a book about engineering design. |

An introduction to the engineering profession was presented by discipline specific engineering professionals. Discussions about the engineering design process and how it compares with the technology design process were probed. The teachers came to the consensus that the primary difference between the two is that engineering design relies on the application of math and science principles as a predictive element whereas technology for the most part does not.

An 8-step engineering design process was discussed in detail. It was stressed that the engineering design process requires both analysis and synthesis of information and the problems are usually open-ended with multiple solutions possible and often involve iteration. The teachers spent considerable time participating in an engineering design case study in order to develop a deeper understanding of the engineering design process and how it is applied to a real engineering problem.

The math and physics sessions were taught by CSULA math and physics faculty members. The topics covered the information needed to conduct the engineering design challenge. Specific math content included trigonometric functions and plotting of sine and cosine functions. The physics sessions were more intensive and covered Hooke's Law, harmonic motion, and damping. The content was delivered using a just-in-time approach. The mathematics and science knowledge needed for successful completion of the design challenge was identified along with the knowledge level of each participant. Prescriptive learning strategies were utilized to increase each student's knowledge to the required levels limited to the specific prerequisite information needed. No attempt was made to remediate the participants' general knowledge in these areas.

Table 2. Activities and Objectives of the Summer Workshop

| Activity | Objective |
|---|---|
| Earthquake Engineering Basics | Develop fundamental understanding of basic seismology, earthquake engineering, and building response to seismic motion. |
| Equipment Setup and Calibration | Learn how to use the instrumentation and software and calibrate the shake table. |
| Field Trip to Caltech Seismology Lab | Learn more about earthquakes and its impact on people and the built environment. |
| Engineering Design Challenge | In-depth training on how to conduct the design challenge scenario. |
| Reflective Analysis and Implementation Plan | Discussion and feedback. Development of an implementation plan for the design challenge. |

During the summer workshops, basic earthquake engineering principles, and content that built upon the spring math and physics workshops specific to the design challenge, were taught by the first author. A significant amount of time was devoted to calibrating and using the equipment as well as allowing the teachers to experience the design challenge scenario. Their training was further enhanced by touring Caltech's seismology lab, where they learned about earthquakes, how they are measured, and their impact on the built environment in an urban area like Los Angeles. Finally, the teachers developed and shared an implementation plan on how they were going to integrate the design challenge into their curriculum.

**The Engineering Design Challenge**

The design challenge scenario involves teams working with the City of Los Angeles to recommend an optimal building height for a site that has a nearby active fault[4,5,6]. Each team is given 12-, 18-, and 24-inch tall models representing the building height options and three design earthquake magnitudes. The design constraints the teams must consider are economic, construction costs, and seismic performance. Each constraint is assigned a point value and the building height that yields the total highest score is the alternative the teams consider further.

The economic and construction costs constraints are assigned a fixed point value based on the building height as shown in Table 3. Point values for the seismic performance are calculated based on *predicted* building response of the three model heights to the design earthquakes. The teams conduct simple experiments using their knowledge of math and physics learned during the

spring workshops to calculate the model displacement. In this way, predictive analysis is used in the decision making process, which is fundamental to engineering design. Their predicted values of displacement are entered into a matrix as shown in Table 4.

Table 3. Point value assessments for building height and weight.

| Building height | Point value for building height | Point value for building weight |
|---|---|---|
| 24-story | 20 | 5 |
| 18-story | 18 | 4 |
| 12-story | 16 | 3 |

Table 4. Matrix of predicted building displacements (inches).

| Model height | M = 6.0 | M = 7.0 | M = 8.0 |
|---|---|---|---|
| 12-inch | *Teachers input predicted values of displacement* | | |
| 18-inch | | | |
| 24-inch | | | |

The total scores for each building height and earthquake magnitude are then calculated according to the equation:

$$\text{Total Score} = [(A) - (B) - (C \times 10)]$$

where A is the point value for building height, B is the point value for building weight, and C is the predicted displacement in inches. For a given earthquake design magnitude, the alternative with the highest score would be selected for testing by experimentally measuring the displacement on the shake table to verify the analysis. The percentage difference between the measured and predicted displacement is calculated and, if significant, the team may revise its recommendation. This allows for iteration (also fundamental to the engineering design process) to be incorporated into the design challenge. Testing of their solution on the shake table also allows team members to make the connection between theory (math and science principles) and practice (experimental evidence).

Teams were provided an opportunity to first use their intuition to choose the optimal building height. Almost all felt that the tallest model (24-inch) would achieve the highest score since the tallest model receives the largest point value for building height. However, when they used math and physics to work through the analysis it became apparent that all design constraints must be considered in order to achieve good design, which is fundamental to the engineering design process.

**Evaluation and Assessment**

Two cycles of the professional development workshops have been completed (2005 and 2006) to a total of 12 LBUSD high school teachers. Evaluation and assessment of the professional development workshops has occurred both formally and informally.

At the end of the 2005 and 2006 summer workshops a written survey was administered to the two groups in order to collect assessment data. The survey was designed and written by a doctoral student at the University of Illinois at Urbana-Champaign who is conducting research specifically on the NCETE professional development workshops[7]. The survey contained multiple choice and open-ended text questions. The survey target population was teachers who participated in the program. Therefore, the survey population and sample size was 12. A total of 9 responses were received, which corresponds to a response rate of 75 percent. Survey research methods suggest that for small populations an adequate sample to provide sufficient accuracy is 50 percent of the population size (Rea and Parker, 1997)[8]. Since the response rate was 75 percent of the population size, the findings and observations are believed to be representative of the teachers who participated in the program. Bar graphs of those questions that provide useful information for this paper are presented on Figures 1 and 2.

Figure 1 shows that the teachers who participated in the program represent a range of ethnicities, teaching areas, and are gender distributed. The results on Figure 2 show that all of the teachers (100 percent) indicated that the workshop either increased or greatly increased both their interest and ability to infuse the material into their teaching. Almost all (90 percent) of the teachers indicated that they plan to change or have already changed their curriculum to incorporate engineering concepts that they learned. When asked what engineering concepts they will be using; most cited that they will incorporate the engineering design process into more of their teaching and use more predictive analysis.

Figure 2 also shows that two-thirds (67 percent) of the teachers indicated that they will use the engineering design challenge in their teaching. Many cited that they will incorporate the design challenge as a module lasting anywhere from 20 hours to 6 weeks. When asked what they thought their students would learn from the design challenge, the common themes were real-life application of an engineering problem and the importance of predictive analysis in the engineering design process.

**Summary**

The paper presented the development, implementation, and assessment of a professional development model delivered to 12 Long Beach Unified School District high school teachers during 2005 and 2006. The purpose of the professional development program was to increase teachers' awareness and appreciation of engineering design and problem solving, and to provide them a means to infuse their new knowledge and experiences into their curriculum. The professional development model was built around delivery of an "engineering design challenge" that provided a means with which the engineering design process was used to infuse engineering content and analysis into their curriculum. The design challenge utilized an instructional desk-top shake table to represent the building behavior during an earthquake.

Important to the success of the program was splitting the workshops into two separate sessions (spring and summer), which allowed the teachers time to study, reflect, and develop an implementation plan. The spring sessions were primarily used to provide requisite math and physics knowledge, and to learn about engineering and the engineering design process. The

summer sessions were used to train the teachers on the use and implementation of the engineering design challenge.

Evaluation and assessment of the program was conducted for each group of teachers by administering an end of program survey. The results of the survey show that all of the teachers participating in the workshops either increased or greatly increased their interest and ability to infuse the engineering material into their teaching. Further, nearly all of the teachers indicated that they have changed or plan to change their curriculum to incorporate the engineering concepts they learned and the majority will use the engineering design challenge in their curriculum.

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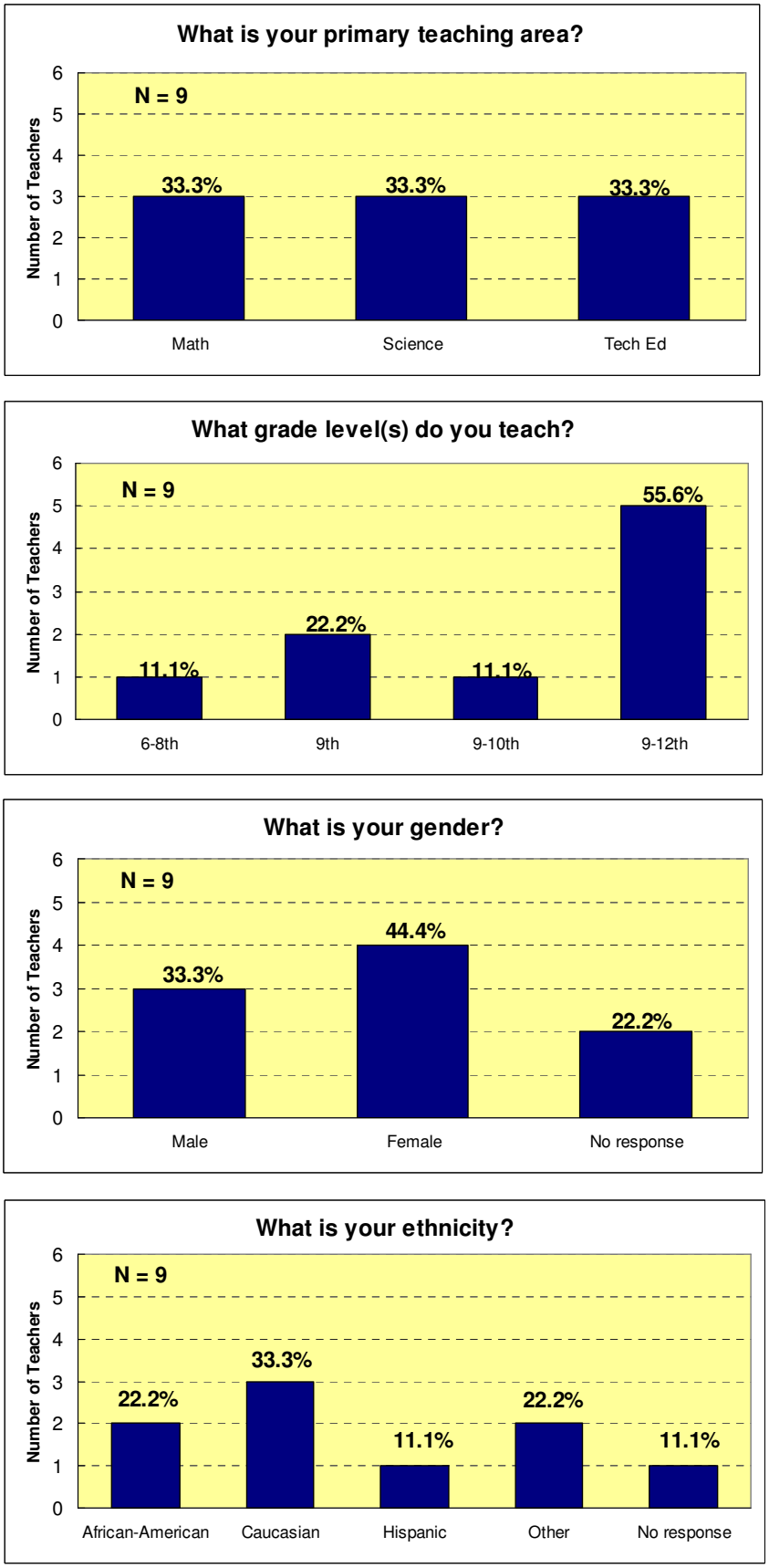
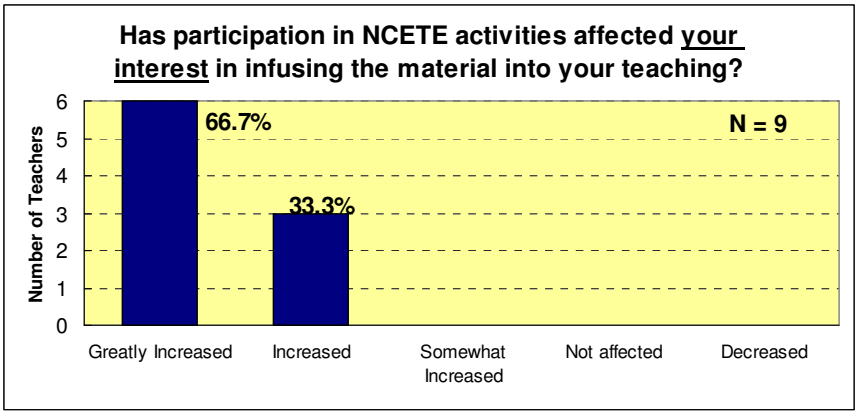
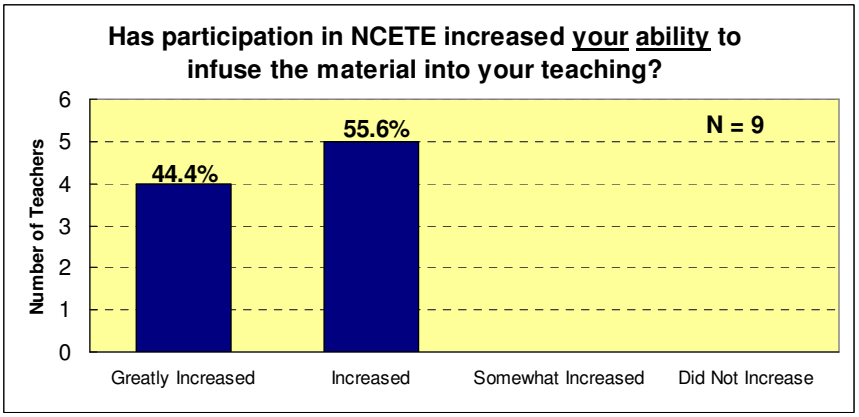
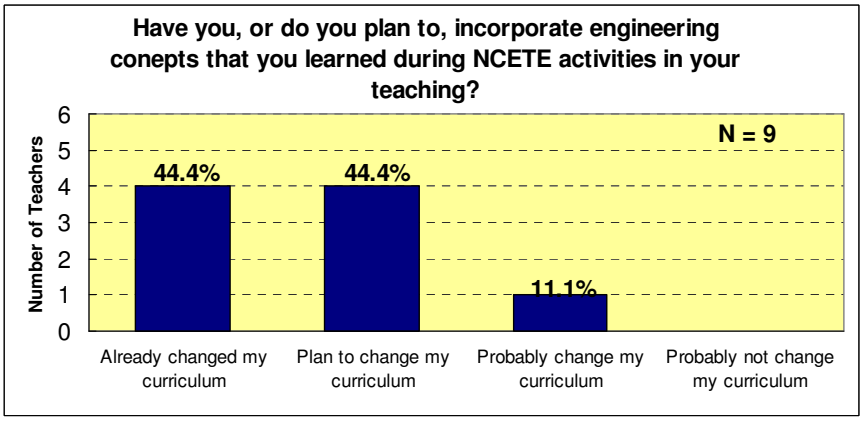



Figure 1. CSULA Teacher Participant Survey Results.



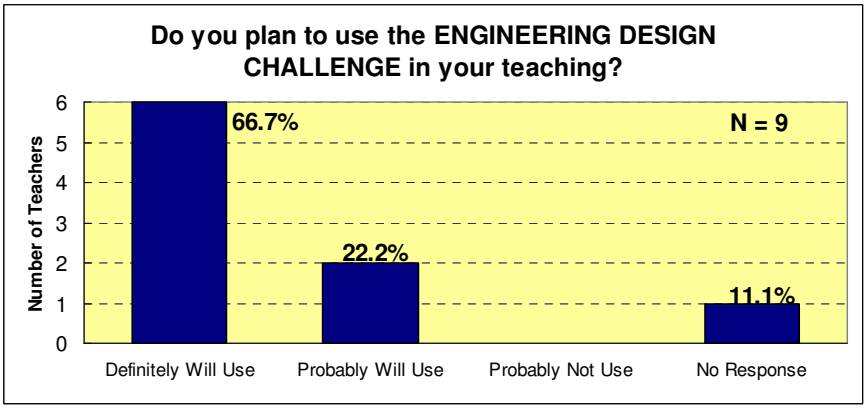




Figure 2. CSULA Teacher Participant Survey Results.