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# Effects of Professional Development on Infusing Engineering Design Into High School Science, Technology, Engineering, and Math (STEM) Curricula

Zanj Kano Avery
*Utah State University*

EFFECTS OF PROFESSIONAL DEVELOPMENT ON INFUSING ENGINEERING

DESIGN INTO HIGH SCHOOL SCIENCE, TECHNOLOGY,

ENGINEERING, AND MATH (STEM) CURRICULA

by

Zanj Kano Avery

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Approved:

| | |
|---|---|
| Edward M. Reeve, Ph.D.<br>Co-Major Professor | Kurt Becker, Ph.D.<br>Committee Member |
| Sherry Marx, Ph.D.<br>Co-Major Professor | Don Maurizio, Ph.D.<br>Committee Member |
| Gary Stewardson, Ph.D.<br>Committee Member | Byron R. Burnham, Ed.D.<br>Dean of Graduate Studies |

UTAH STATE UNIVERSITY
Logan, Utah

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# ABSTRACT

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by


Zanj Kano Avery, Doctorate of Philosophy

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Major Professors: Dr. Edward M. Reeve and Dr. Sherry Marx
Department: Engineering and Technology Education



The purpose of this study was to examine the effects of professional development (PD) on the infusion of engineering design into high school curricula. Four inservice teachers with backgrounds in physics, chemistry, industrial education, math, and electrical engineering participated in the 2006 National Center of Engineering and Technology Education (NCETE)-sponsored PD workshops at California State University, Los Angeles (CSULA) and provided three sources of data that were used to answer the research question, "What are the effects of PD on infusing engineering design into high school science, technology, engineering, and math (STEM) curricula"?

Three major themes emerged from the data. They were (a) incorporation of PD content, (b) challenges with incorporating PD content, and (c) benefits of incorporating PD content. It was shown that the effect that the NCETE PD had on the infusion of engineering design into high school curricula varied among each of the four teachers due to their subject area, educational backgrounds, and experiential knowledge. Implications of these findings may be used to inform the design and delivery of future STEM PD efforts.

(161 pages)

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# CHAPTER I

# INTRODUCTION

In the early 1900s, science and math were established as core academic subjects in our schools. Today in the U.S. there is a movement to include engineering and technology as core academic subjects alongside science and math. This trend reflects a need for all people to become technologically literate and a need to encourage more people to participate in careers related to technology and engineering.

Pursuant to making the study of technology more commonplace, the National Assessment Governing Board (NAGB), a government commissioned education board, announced plans to develop and administer the first nationwide technological literacy assessment for U.S. schools in 2011 (MacMillan, 2008). With the inclusion of technological literacy as part of the National Assessment of Educational Progress (NAEP), assessing students' technological literacy will be given greater attention and will require curriculum reforms that integrate science, technology, engineering, and math (STEM) standards into general education. This will open up new educational opportunities for new and existing teachers. In turn, schools will be required to either hire STEM educators or retrain existing teachers to deliver content in this area.

The delivery of technology and engineering instruction is heavily dependent on the conveyance of scientific and mathematical concepts and principles. Since science and mathematics are required subjects that some students have difficulty learning due to the lack of relevant reference frames (Forrester, 1996), some educators feel that the marriage between technology and engineering has the potential to provide a means of organizing science and math concepts in a manner in which students are more familiar. Moreover, technology and engineering education are part of the STEM disciplines that many say need be strengthened in order for the U.S. to compete in today's global society. Information from the National Academy of Sciences (National Research Council, 2006) and the National Science Board (2006), plus other prominent reports (Building Engineering and Science Talent, 2000; National Commission on Mathematics and Science Teaching, 2000; Wenglinsky, 2000;) indicate that there is a deficiency in our nation's technical workforce, thus inhibiting our ability to compete on a global scale.

If students are to be given a competitive edge in the world, it is not enough that they merely do science and math for the sake of conducting lab experiments, solving word problems or passing a state-mandated test. Rather, students need to learn how to use and apply scientific and mathematical principles to produce tangible outcomes. This is what STEM education brings to the table. For students to develop engineering-based thinking, a range of issues and challenges need to be addressed such as the development of generally accepted definitions, active advocacy, revisions of standards and curriculum materials, academic culture, and communication and collaboration, both across disciplines and among the range of constituencies and stakeholders (Custer, Daugherty, Zeng, Westrick, & Merrill, 2007).

Since technology pervades our society, it is important that students are introduced to STEM education so that they become more technologically literate and are able to function in a technologically driven world (International Technology Education Association [ITEA], 2000/2002/2007). In 2000, the ITEA released the *Standards for*

*Technological Literacy (STL): Content for the Study of Technology* in 2000. These standards identify what students should know and be able to do in order to be considered technologically literate. The purposes of these standards are not to define a curriculum but rather to depict what the content of technology education should be in Grades K-12 (ITEA, 2000/2002/2007). There are 20 standards total within the STL general-content framework that address the following five major categories:

1. The nature of technology,
2. Technology and society,
3. Design,
4. Abilities for a technological world, and
5. The designed world.

Chapter Five of the STL standards addresses the category of “design,” which concentrates on the development of cognitive processes intended to facilitate an understanding of the attributes of design, the engineering design process, and other problem-solving approaches. According to this framework, engineering design, which is laden with mathematical and scientific analysis is an integral component of technology education and is receiving greater recognition as a means of engaging student interest in fields related to science, technology, and mathematics.

In the teaching of technology, the concepts related to science and math serve as foundational building blocks to much of the content that is covered in engineering disciplines. The movement to include the study of technology, in conjunction with engineering design and problem-solving, as an integral part of the K-12 curriculum may require those who develop STEM professional development (PD) programs an opportunity to explore the many facets related to the development and delivery of effective PD programs. These facets include: (a) research plans, (b) development of a philosophical focus, (c) identification of a standards-based curriculum materials, (d) collaboration amongst STEM disciplines, (e) formulation of effective PD models, (f) research specific to pedagogical content knowledge, and (g) general justification and promotion of engineering and technology education as a recognized part of K-12 education (Custer et al., 2007).

If engineering is to be recognized as an integral part of science, technology, and math education, stakeholders, organizations and/or people directly involved have to share the burden of responsibility for these ideas to become reality (Bybee & Loucks-Horsely, 2000). Moreover, STEM education teachers must possess a profound understanding of the subject matter they are teaching to facilitate student learning (Shulman, 1987). The infusion of technology and engineering into high school curricula depends on the ability of inservice and preservice teachers to deliver instruction in this area. Just as students need to be provided with a curriculum to help guide facets of their learning, STEM educators need to be afforded opportunities, namely, PD programs, so that they can learn what is needed to assist students in unifying knowledge across STEM disciplines rather than learning in a compartmentalized fashion. Ultimately, inservice and preservice teachers need to be better equipped with developing and teaching instruction focused on STEM concepts and provided a supportive environment to do so.

## Purpose of the Study

In 2005 and 2006, the National Center for Engineering and Technology Education (NCETE) sponsored a series of PD activities that steered a number of research efforts at various universities, such as California State University, Los Angeles (CSULA), University of Wisconsin-Stout, Brigham Young University, and the University of North Carolina A&T. The purpose of these activities were related to the identification of core engineering concepts, the production of logic models of effective PD, and the development of successive engineering design challenges (Asunda, 2007; Asunda & Hill, 2007; Custer et al., 2007; Custer, Cunningham, Ereckson, Hailey, & Householder, 2008; Merril, Custer, Daugherty, Westrick, & Zeng, 2007; Tufenkjian & Lipton, 2007).

In 2006, two professional development workshops were held in the spring and summer for the purpose of showing STEM teachers how to integrate engineering design into their curricula. The 2006 NCETE workshop at CSULA were externally evaluated by the Western Educational Laboratory (WestEd) and this evaluation produced information related to examining teacher perceptions as to the usefulness of the PD workshops. Although these summary evaluations were useful in determining a list of recommendations and a set of best practices, there was, however, a lack of research pertaining to the effects that the PD workshops at CSULA was having on teaching practices. Therefore, this study investigates the possible effects that NCETE sponsored PD workshops at CSULA had on Teacher classroom practices and what curriculum changes resulted from these efforts.

## Research Question

Two years had elapsed between the 2006 NCETE sponsored PD workshops at CSULA and the current study. During the interim, teachers who participated in these workshops had ample time to modify their instructional materials to include what they learned into their classroom and laboratory projects. Based on what was presented in the NCETE/CSULA PD workshops, this qualitative case study concentrated on the following research question: “What effects, in terms of curriculum changes, took place at the secondary school level as a result of the NCETE-sponsored PD and how did the PD teacher participants use what they learned in the NCETE PD workshops in terms of content and pedagogy?

## Limitation of Study

This research study focused on the 2006 PD teacher participants rather than the teachers who participated in the 2005 PD pilot program due to certain improvements and enhancements that were made following the 2005 PD pilot program.

## Terminology

*Career and technical education (CTE):* A program of study that involves a multiyear sequence of courses that integrates core academic knowledge with technical and occupational knowledge to provide students with a pathway to postsecondary education and careers (California Department of Education, 2008).

*Engineering*: The profession of or work performed by an engineer. Engineering involves the knowledge of the mathematical and natural sciences (biological and physical) gained by the study, experience, and practice that are applied with judgment and creativity to develop ways to utilize materials and forces of nature for the benefit of humankind (ITEA, 2000/2002/2007).

*Engineering design:* The systematic and creative application of scientific and mathematical principles to practical ends such as the design, manufacture, and operation of efficient and economical structures, machines, processes, and system (ITEA, 2000/2002/2007).

*Engineering education:* Activities involving the teaching of engineering and technological concepts and principles, at school, college and university levels. The purpose of engineering education is to prepare people to practice engineering as a profession and also to spread technological literacy, increase student interest in technical careers through science and math education and hands-on learning. Engineering education often begins with technology education in K-12 schools and is continued at the college and university level (Douglas, Iverson, & Kalyandurg, 2004). Engineering education is a part of the STEM initiative in U.S. public schools. The NSF is supporting research in engineering education through the National Center for Engineering and Technology Education (NCETE) among others.

*National Center for Engineering and Technology Education (NCETE):* An NSF-supported collaborative network of scholars with backgrounds in technology education, engineering, and related fields whose mission is to build capacity in technology education and to improve the understanding of the learning and teaching of high school students and teachers as they apply engineering design processes to technological problems (NCETE, 2005).

*Pedagogical content knowledge (PCK):* PCK is one domain of knowledge that a teacher must have to effectively educate students. PCK provides teachers with an understanding of how to most effectively bridge the relationship between students and specific content so that students develop a deep understanding of it (Shulman, 1987).

*Pre-engineering:* Pre-engineering education focuses on preparing secondary level students for careers in engineering and engineering technology and provides students with a technological literacy related to engineering.

*Science:* The study of the natural through observation, identification, description, experimental investigation, and theoretical explanations (ITEA, 2000/2002/2007).

*Science education:* Instruction involving the teaching of scientific concepts and principles. The goal of science education is scientific literacy.

*STEM education*: The integration of science, technology, engineering, and math education.

*Subject matter knowledge:* The knowledge that teachers must have to teach a particular subject.

*Technology:* The modification of the natural world to satisfy human needs and wants. Technology uses technological equipment, skills, tools, and knowledge to solve problems and extend human capabilities (ITEA, 2000/2002/2007).

*Technology education:* Instruction involving the teaching of technological concepts and principles taught in the K-12 continuum. Technology education teaches students about the human-made world and how it impacts their daily lives. The goal of technology education is technological literacy. Technology education provides students with general technological literacy applicable to every career field (ITEA, 2000/2002/2007).

*Technological literacy:* An understanding of technology at a level that enables effective functioning in a modern technological society.  People who are technologically literate have the ability to use, manage, assess, and understand technology (ITEA, 2000/2002/2007).

## Summary

Because quality teaching is imperative to the infusion of engineering design into high school curricula, a paradigm shift in regards to the organization, structure, delivery, continuity, and consistency of PD within an engineering and technology education context is both momentous and exigent. For significant changes to occur certain conditions within the educational system need to take place; one of the most important of which is providing a variety of effective PD programs for teachers involved in STEM-related disciplines (Fullan & Steigelbauer, 1991). Literature pertaining to organizational and structural qualities of PD in general and PD specifically related to STEM education will be the focus of the next chapter.

# CHAPTER II

# REVIEW OF THE LITERATURE

To provide an adequate context for the research problem and the purpose of this study, a comprehensive review of relevant literature is presented. This review of literature explores the current state and future directions of STEM PD, especially as it concerns preparing future cohorts of teachers and teacher educators to receive and/or deliver STEM instruction.

## Overview

The following presents an outline of the topics that will be covered in this review of literature. First, a brief overview of the justification for PD concerning STEM education is discussed. Second, PD practices in education are explored to establish a fundamental understanding of its implications for STEM education followed by a discussion concerning evaluating outcomes of PD programs. Then, the evaluation of math and science PD programs are examined and concomitantly used to identify characteristics of effective PD that can be adapted to STEM education. Finally, research pertaining to NCETE PD specifically designed for STEM education is examined to provide background information while setting the stage for the methodology, i.e., data collection and analysis that will be used in this research study.

## Justification for STEM Education PD

The economic strength and global leadership of a country depends in many ways on the ability to advance research in science and technology. In essence, maintaining a competitive position in the world economy means that a foundation for learning must be consistent with continued leadership in innovation, exploration, and ingenuity in STEM fields. Since our educational system plays a major role in shaping these foundations, it is important to examine how teachers are being prepared through PD to meet the learning needs of their students. The discrepancy between what STEM teachers know and what they should know is especially important to the successful development and implementation of PD programs intended to assist teachers with infusing engineering content into their classroom instruction. An examination of practices that are common to all PD efforts in education can help to provide a general sense of the need, purpose, and limitations of PD while guiding the methodology used in this study.

*PD Practices in Education*

The fundamental purpose of PD is to enhance the quality of teaching for students. As stated by Glickman, Gordon, and Ross-Gordon (2004),

> Education is a human enterprise. The essence of successful instruction and good schools comes from the thoughts and actions of the professionals in the schools. So if one is to look for a place to improve the quality of education in a school, a sensible place to look is the continuous education of educators- that is, PD. (p. 370)

The design and implementation of successful PD programs relies on a clear understanding of what works as well as an understanding of what does not work in PD. By examining these issues, one can be better informed as to the pitfalls or shortcomings of PD. A brief examination of the overall limitations of PD workshops will be the focus of the following section.

*Limitations of PD*

Traditionally, PD has been conducted through inservice school workshops. From a traditional model of staff development, the school or district commissions an outside curriculum expert or consultant to conduct a one-day training session on generic approaches to delivering subject content matter. Research in the field reveals that this approach is often met with disdain by teachers due to the lack of continuity and consistency (Little, 1994; Miles, 1995). Moreover, teachers, who are oftentimes left out of the PD planning loop, feel that PD lacks working theories of how adults learn and does not recognize the dynamics and complexity that coincide with teaching (Glickman et al., 2004). Notwithstanding these issues, the majority of PD received by teachers is still delivered via a generic, one-time workshop (National Center for Education Statistics [NCES], 2001).

According to the 2000 survey data from the NCES (2001), teachers usually spend a day or less in any one PD workshop. Only eighteen percent of teachers consider these generic, one-day PD workshops to be significantly linked to other improvement activities within the school (NCES). Furthermore, depending on the training content area, only 10% to 15% were documented as receiving relevant follow-up activities or resources. Twelve to 27% reported that their involvement in PD activities enhanced their teaching (NCES). The aforementioned data is consistent with the unenthusiastic views that many teachers hold regarding PD programs. Accordingly, alternative approaches to conducting PD workshops are the focus of many research efforts to improve the quality of teaching and learning within American schools.

*Alternative Models for PD*

As an alternative to the workshops model for PD, a new dimension of adult learning began to surface with the seminal work of Brown, Collins, and Duguid (1989 as cited in Glickman et al., 2004, p. 65). In their work, they proposed that education is misunderstood to the extent that it emphasizes the teaching of decontextualized, abstract knowledge. They maintain that long-term knowledge is a result of learners engaging in authentic activity that occur within specific, real-world situations. Hansman (2001 as cited in Glickman et al., p. 65), who refers specifically to adult learning, stated that learning is shaped through the nature of the interactions among learners, the tools they use within these interactions, the activity itself, and the social context in which the activity takes place. In other words, this alternative approach asserts that learning needs to occur in a more active and coherent academic environment for teacher learning to have an impact. This includes a setting that fosters a community wherein ideas can be exchanged and an unambiguous connection can be made in regards to overall school improvement.

Supporters (Darling-Hammond, 1998; Little, 1994; Smylie, Allensworth, Greenberg, Harris, & Luppescu, 2001) of this approach to PD emphasize the need for collaborative learning contexts, exploration of relevant subject matter, ongoing feedback plus follow-up activities, teacher research and inquiry, and involvement in useful tasks of instruction and assessment. In light of these issues, experts recommend networking among teachers to exchange ideas concerning effective practices, study groups, alliances with universities, peer reviews, on-line learning opportunities, and curriculum development projects (National Staff Development Council, 2001).

Although there are no one-size-fits-all models for PD, there are common denominators that must be considered by developers of these programs. Wilson (2007a) suggested that effective PD should: (a) focus on student learning, (b) focus on content needed for teaching, (c) incorporate teacher knowledge, (d) be embedded in the work of teaching, (e) employ collaboration, and (f) be a long-term endeavor. In addition to the above, Mundry (2007) suggested that PD should include: (a) clear and challenging goals for student learning, (b) adequate time, follow up and continuity, (c) coherence, (d) active research-based learning, (e) critical reflection on practice, and (f) evaluation of results. Before examining the research literature pertaining to the infusion of engineering design into high school programs, this review examines the needs related to PD for STEM education.

## PD Efforts in STEM Education

The movement to include engineering design and problem solving into high school programs represents a significant shift from the teaching of vocational skills that were commonly taught in traditional industrial/manual arts or "shop" classes. The transition from teaching "shop" classes to technology education began in the 1980s and continues today. Furthermore, with the release of the *Standards for Technological Literacy: Content for the Study of Technology* (ITEA, 2002/2002/2007), the field today has identifiable content that includes language concerning engineering design. Today many consider it important to emphasize the teaching of engineering design in STEM education (Custer et al., 2007; Lewis, 2006, 2007; Wicklein, 2006). For teachers to be able to teach engineering design, they must possess the necessary pedagogical content knowledge to introduce their students to engineering design. Since the infusion of engineering design into high school curricula involves the integration of STEM concepts and principles, PD programs designed to facilitate the delivery of this type of instruction are needed. Unfortunately, there are few PD opportunities related to teaching engineering content and STEM integration (Ross & Bayles, 2005).

According to Bybee and Loucks-Horsley (2000), in order for STEM education PD workshops to be effective, the following areas should be addressed.

1. Teachers need opportunities to deepen their content knowledge by learning about and developing skills related to technology.

2. Teachers need to integrate their content knowledge and pedagogy by using what they know about learning and how to teach their specific content.

3. Teachers need the necessary motivation, resources, tools and equipment to facilitate continuous learning and improvement in their practice so their knowledge and skills do not become obsolete.

In addition to the above, a lack of continuity weakens the effectiveness of Franklinevelopment opportunities. This stems from the fact that courses, workshops, and institutes do not coordinate their efforts or create long-term development plans so that teachers obtain both depth and breadth as it concerns their knowledge, skills, and abilities to provide an enriched learning environment for all students (Bybee & Loucks-Horsley, 2000).

### *Fundamental Skills*

Although STEM education represents a fertile ground for producing engineers, there are significant challenges associated with infusing engineering design into STEM high school programs. According to Ross and Bayles (2005), many teachers, especially as it concerns technology teachers, do not have fundamental skills in science and math and often “short circuit” implementation because they are anxious to build something. Many teachers do not explicitly discuss design challenges with students in the context of the scientific and mathematical concepts nor are they adept at integrating concepts from science and mathematics (Ross & Bayles). Since these are areas of knowledge and skills that may not be taught to teachers as part of their formal teaching preparation, outlets for teacher preparation are needed to facilitate learning in these areas. PD can help provide specific guidance to teachers who lack a profound understanding of engineering-related subject matter. In doing this, the evaluation of PD becomes critical to informing STEM fields and guiding the content, form and structure of programs that involve the infusion of engineering design into STEM high school programs.

## Evaluating Outcomes of PD Programs

According to Custer and colleagues (2007), the evaluation of the quality of PD as it pertains to engineering and technology education needs a great deal of attention. Guskey (2000) asserted that good evaluations involve thoughtful planning, the ability to ask good questions and a basic understanding about how to find valid answers. When evaluating PD, there are five important levels of information on which to reflect. They are: (a) participants' reactions, (b) participants' learning, (c) organization support and change, (d) participants' use of new knowledge and skills, and (e) student learning outcomes (Guskey).

Good evaluation provides meaningful information that helps guide the content, form, and structure of future PD efforts. This, in effect, provides a mechanism for identifying effective characteristics of PD that can be used to exemplify good PD practices and how they can be implemented within an engineering and technology education context. According to Wilson (2007a), the identification of such characteristics is not enough to guarantee successful PD experience, but can assist one in designing and analyzing problems. The following section examines several studies that focus on the evaluation of PD in math and science education.

*Organizational Qualities of Effective PD*

It is instructive to look at literature concerning the evaluation of PD and the effective practices that have emerged therein. These effective practices can be used to extrapolate models for engineering and technology education PD without having to "reinvent the wheel." Research pertaining to the evaluation of PD reveals the following effective organizational qualities: (a) the focus on specific content matter, (b) collaborative reflection and joint action, (c) innovation, (d) active learning, (e) long-range PD (Desimone, Porter, Garet, Yoon, & Birman, 2002; Kennedy, 2000; Learning First Alliance, 2000; Smylie et al., 2001; WestEd, 2000).

*Focus on Specific Content Matter*

Kennedy (2000) performed a meta-analysis that evaluated a pool of 93 studies that examined the effectiveness of various approaches to continuing teacher education in either mathematics or science. Of the 93 studies that were evaluated, only 10 showed benefits to student learning. The programs that were examined differed in many areas such as duration, intensity, focus on individual teachers instead of school-wide focus, and so forth. It was theorized that teachers who did not receive development in how to improve their teaching due to inadequate subject matter knowledge were not as effective as teachers who received development as to how students learn subject matter knowledge. In other words, program content, including management strategies, and knowledge of how students learn specific subject matter, is an important factor to student learning.

Furthermore, it was concluded that the more teachers understand how students learn, the more valuable the knowledge is, and the better teachers become at refining and improving their own practices. Such organizational aspects such as follow-up and duration can enhance PD programs if coupled with strong subject-area content. Overall, it was shown that PD programs that are less generic and focus on specific content matter (e.g., math and science) have a greater effect than those that are more generic in form.

*Collaborative Reflection and Joint Action*

In 2000, the U.S Department of Education commissioned WestEd, a nonprofit research, development, and service agency, to conduct site visits, case reports and cross-site analysis to examine and evaluate eight diverse schools that exemplified awardwinning PD programs that evidenced improvements in student achievement. The report was based on hundreds of hours of talking with teachers and administrators at the eight schools. Regardless of the diverse nature of each of these schools, a universal feature that contributed to each of their successes stemmed from the fact that staff development shifted from an isolated learning environment with occasional PD efforts to concentrated, continuous organizational learning founded on collaborative reflection and joint action. Of particular importance was the focus on “collaborative structures, diverse and extensive professional-learning opportunities, and an emphasis on accountability and student results” (WestEd, 2000).

*Innovation*

The Consortium of Chicago School Research conducted a study in 2001 regarding “high-quality” PD programs. Analyzing data from 1997 to 1999 citywide teacher surveys, the researchers found that programs that have a significant effect on teachers’ instructional practices are typified by an educational community that supports and fosters: (a) sustained, coherent study, (b) collaborative learning, (c) teacher experimentation, and (d) follow-up. In addition, the study pointed out a reciprocal relationship between strong PD offerings and a school’s overall orientation towards innovation was recognized (Smylie et al., 2001).

*Active Learning*

The U.S. Department of Education commissioned a longitudinal study to monitor the experiences of teachers who participated in PD programs aimed at developing specific, higher-order teaching strategies in math and science education. For data collection, a three wave longitudinal survey from 1997-1999 was conducted to document teaching practices in mathematics and science before and after a PD activity. The surveys were also used to examine the degree to which changes in teaching practice are predicted by participation in a PD activity. For the most part, it was established that teachers who were introduced to problems with no clear solutions increased their use of such strategies in their classrooms. This phenomenon seemed to occur especially when the PD activity was comprised of a collaborative format that included teachers from the same subject, grade, or school while providing "active learning" opportunities for teachers, as well as, being aligned with teachers' goals and practices (Desimone et al., 2002).

Desimone and colleagues (2002) concluded that PD that focused on specific instructional practices increases teachers' use of those practices in the classroom. They also concluded that there was an increase in the effect of PD on teacher's instruction when teachers engaged in a specific type of instructional practice, such as active learning opportunities. These conclusions are consistent with literature concerning adult learning (Belenky, Clinchy, Goldberger, & Tarule, 1986; Clark & Caffarella, 1999; Fiske & Chiriboga, 1990; Harvey, Hunt, & Schroeder, 1961; Kegan, 1994; Levinson, Darrow, Klein, Levinson, & McKee, 1978; Loevinger, 1976; Neugarten, 1977; Whitbourne, 1986).

## Identifying Content Matter of Successful PD

This section reviews studies that focus on identifying the successful content matter of PD programs. The following studies suggest that PD programs are more successful when they place more emphasis on: (a) higher order thinking, (b) pedagogical content knowledge, and (c) contextual problem-based learning.

*Higher Order Thinking*

Wenglinsky (2000) conducted a study for the Educational Testing Service concerning how the enhancement of teaching practices could improve teacher quality. The researcher analyzed data from the National Assessment of Educational Progress (NAEP), also referred to as "the Nations Report Card," to analyze questionnaires sent to students, their teachers, and their principals. In addition, the researcher collected data on 7,146 eighth graders who took the NAEP math assessment in 1996 and 7,776 eighth graders who took the NAEP science assessment in 1996.

The data revealed that the conveyance of higher order thinking skills, e.g., developing strategies to solve different types of problems, leads to improved student performance. They also found that PD in cultural diversity was also linked to higher math scores. Moreover, the study showed that PD that incorporated hands-on laboratory skills boosted science test scores. Conversely, it was shown that the more generic types of training (e.g., classroom management, interdisciplinary instruction, collaborative learning, etc.), had a minimal or negative impact on student scores.

*Pedagogical Content Knowledge*

Ball, Thames, and Phelps (2007) stated that PD needs to involve subject matter knowledge as well as pedagogical content knowledge (PCK). According to Shulman

(1987), PCK is one domain of knowledge that a teacher must have to effectively educate students. PCK provides teachers with an understanding of how to most effectively bridge the relationship between students and specific content so that students develop a deep understanding of it. Furthermore, every discipline, whether it be science, math, engineering, technology, business, education, medicine, and so forth, and every constituent of that discipline, has particular PCK associated with it (Schulman). To facilitate student learning according to today's educational standards, teachers need to have a profound understanding of their subject matter and need to be able to deliver instruction flexibly to help a diverse body of students construct knowledge in a manner that connects to real-world situations (Shulman). Teachers need to recognize the interdependence of seemingly separate fields of knowledge (e.g., science, math, technology, history, economics, reading, etc.) so that students will connect what they learn in the classroom to everyday life. These are tasks that require understanding how knowledge is generated and structured in the discipline and much more (Shulman). This kind of understanding provides a foundation for pedagogical content knowledge that enables teachers to make ideas accessible to others (Shulman). In general, PD can be used as a mechanism to facilitate these efforts while improving the quality of teaching for those unable to assist a variety of students in building knowledge related to engineering design and problem solving.

Despite evidence to support their effectiveness, the aforementioned models of PD are not widespread due to the organizational and financial challenges or obstacles of putting them into practice. For this reason, the generic, one-time PD workshops have endured and continue to be the standard (Darling-Hammond & McLaughlin, 1995; Little, 1994). Inventive and coordinated management of funding and teachers' time by means of government and administrative support needs to be engendered for quality PD to be pervasive (Porter, Birman, & Garet, 2000; Smylie et al., 2000; Wenglinsky, 2000; WestEd, 2000). More generally, some suggest that rigorous investigations into school policies and practices needs to be conducted to identify elements rooted in school culture that obstruct the enhancement of PD programs (Darling-Hammond & McLaughlin; Smylie et al.).

*Contextual Problem-Based Learning*

Haney, Jing, Keil, and Zoffel (2007) conducted a study to examine teachers' beliefs and classroom practices during a 2-year PD program. The PD program was designed to assist middle-school teachers in developing, implementing, and revising problem-based, interdisciplinary curricula focusing on locally relevant environmental health issues. The researchers used survey instruments consisting of Likert scales to measure: (a) context beliefs about the teaching environment, (b) self-efficacy, (c) teachers' beliefs about their constructivist teaching practices, and (d) the frequency with which teachers used traditional strategies (lectures, a text-driven curriculum, and isolated learning) and reform strategies (experiential learning, use of primary sources of data, and collaborative learning). The results of the study indicated that teachers' self-efficacy, beliefs about the classroom-learning environment, and reported use of reform-based classroom practices increased significantly over the course of the program. The results also indicated that teachers' beliefs about the likelihood of support from the school environment decreased significantly, and their outcome expectancy beliefs did not change significantly. The findings of the study were consistent with the research literature that indicates the positive effects of employing integrative curricula. The authors promoted the use of contextual problem-based learning curricula that incorporates local environmental health science issues as an integrative context.

The previous sections discussed outcomes of PD, which is important in developing a research framework and overall themes for STEM education. These studies advocate PD programs that place more emphasis on deepening and contextualizing the subject area knowledge of teachers, as well as facilitating teacher preparation to meet the individual needs of a diverse body of students. The following section presents research efforts specific to infusing engineering design into high school curricula and was used to help develop the research protocol for this study. This area of research is conducive to developing models for effective PD practices and identifies issues and challenges that may be exclusive to engineering and technology education.

## NCETE-Sponsored PD

Supported by a grant from the NSF, the NCETE was established to address the needs of: (a) preparing high school teachers to infuse engineering design into the curriculum, (b) recruiting and preparing future technology education teachers, (c) recruiting a diverse population of future university faculty in the discipline, and (d) creating a body of research that improves the understanding of STEM teaching and learning (NCETE, 2005).

Some of the main goals of the NCETE are to conduct research concerning: (a) how students learn engineering fundamentals and technological concepts, (b) how students learn creative problem solving, and (c) how teachers are prepared to deliver STEM concepts and principles. Consistent with these goals is NCETE's focus on facilitating student learning of engineering-related content and pedagogy within the framework of technology education. To support these goals, NCETE engaged in the delivery of research-based PD to STEM teachers within partner 9-12 schools with the intent of preparing teachers to integrate engineering design into their high school curricula. It is informative to examine NCETE's PD outcomes during 2005 and 2006 to gain a better perspective of PD models for STEM integration and education.

Certain enhancements to NCETE-sponsored PD were made based on the lessons learned during the first two years in accordance with areas of improvement identified through external evaluations. These areas of improvement were identified through external evaluations conducted by WestEd. WestEd employed surveys and questionnaires given to the teacher participants and workshops coordinators. The next section discusses these external evaluations as they pertain to data collected through site visit findings, review of best practices, and a discussion of what the technology teacher education (TTE) PD group has done to contribute to research in this field.

## PD Workshops for STEM Learning and Teaching

### *Year One*

In partial fulfillment of an NSF sponsored Center for Learning and Teacher (CLT)

Grant, the TTE branch of NCETE fulfilled its first-year goal of providing PD workshops to inservice STEM teachers in 2005. Each of the five NCETE TTE sites, which included California State University, Los Angeles, Brigham Young University, University of Wisconsin-Stout, North Carolina State University A&T, and the University of Illinois, recruited inservice high school STEM teachers to take part in a cycle of PD workshops concentrated on helping teachers infuse engineering design into high school curricula.

During 2005, there were different levels of implementation with the PD activities at each of the five TTE institutions (WestEd, 2000). For instance, some institutions completed a series of five spring workshops before the end of the school year, while others only completed two; there was a high retention of workshop attendees at some institutions while some institutions experienced lower retention due to loss of participants or had participants who could not get the time away from the classroom; some institutions had no problems securing engineering faculty before launching their PD workshops while others experienced greater difficulty getting engineering faculty to participate in the workshops; and each institution embraced different styles of instruction that ranged from “drill and kill” to unstructured discussion sessions. The variation in each institution’s style was useful in developing a series of best practices that each institution could learn from.

Examples of best practices that were identified during year one by WestEd (2000) include: (a) Working with teachers on their current curricula to infuse engineering principles, thereby making it easier for them to put what they learn into practice, (b) providing each participant with a comprehensive binder of materials to use as a reference manual in their own practice, (c) inviting preservice teachers to attend workshops to benefit from the insight of practicing teachers, and (d) reserving a year's time for planning to promote and assist the PD delivery processes.

### *Year Two*

*Recommended changes.* During year two, the TTE faculty decided to make the following changes in accordance with recommendations made by WestEd. These recommended changes were implemented after the first year of NCETE PD efforts with the following 2006 cohort of teachers to address certain weaknesses across the five TTE sites. They were intended to assist each of the five TTE sites with working towards the goal of infusing engineering design into high school curricula. First, WestEd (2000) suggested making the PD schedule more convenient for many of the teachers because teachers do not like being absent from their classes. Although NCETE offered funding for substitutes, the teachers preferred teaching their own classes. Teacher participants suggested changing the schedule so workshops would take place after school, in the evening, on weekends, or exclusively in the summer.

Second, it was suggested that teachers should follow-up with their fellow cohort members and the faculty who conducted the PD; having teachers share their experiences with teachers from their cohort, as well as verify that they are implementing the material correctly. To do this, it was recommended that faculty make classroom visits during year two to observe implementation and student response, and conduct follow-up meetings and classroom visits with Cohort one participants. To ensure proper implementation and encourage institutionalization, it was suggested that all TTE institutions maintain regular communication with past TTE cohort members.

To increase the likelihood of successful implementation, it was recommended that teachers needed more planning time during the PD sessions to allow ample time to develop lessons from the PD material; Constraints to be considered when planning lessons included scheduling, materials, and student academic level. Moreover, it was found that the NCETE PD workshops needed to provide the necessary guidance to teachers in delivering the lessons to help ensure effective teaching and improved student understanding. Planning for increased discussion time on implementation and lesson preparation tailored to the engineering design process (Not only would this increase the teachers' comfort levels, but it would also promote institutionalization).

In addition to the above recommendations, it was suggested that teachers be empowered to develop and create their own lesson plans so that inservice teachers can permanently infuse the engineering design process into their existing STEM education curricula. The rationale being that once teachers are able to develop and create their own lesson plans, they will be able to deliver the material with greater confidence.

*Year two best practices.* WestEd evaluations of the various PD efforts at the five TTE institutions (CSULA, BYU, UW-Stout, NCSU-A&T, U of I) were conducted to identify a set of best practices to be used as a standard across all NCETE partner TTE sites. After the second year of PD, a number of best practices were identified through WestEd's (2000) external evaluations. These best practices included: (a) Collaborating across disciplines (e.g., science, technology, engineering, and math), (b) involving NCETE fellows in the TTE PD program, and (c) improving interaction with each cohort and among cohorts while aligning workshops activities with extant PD literature. Due to a shift in the NCETE research agenda imposed by new NSF initiatives, critique and recommendations made after implementing these changes were not evaluated. Specifically, there was a shift from a teacher training approach to a more research-oriented approach to PD. The lack of evaluation of the 2006 cohort was also attributed to NCETE's decision to replace WestEd with a totally new external evaluation team. Without getting into specifics, NCETE came to the conclusion that WestEd was not meeting their expectations as external evaluators and thus decided to contract new services.

Overall, the feedback gained through the first two years of NCETE activities was essential to the improvement of future STEM PD programs. Although STEM education is making significant advancements in developing effective models for PD, there is a long road to travel before engineering education is recognized as an integral part of K-12 curriculum. For this to happen, a continual program of research must be conducted to determine best practices based on existing mathematics and science PD literature as well as building on available literature from engineering and technology education research.

## NCETE PD Research Studies

In 2005 and 2006, a series of NCETE PD activities transpired which steered a number of research efforts across the five TTE sites. These research efforts included: (a) the identification of core engineering concepts, (b) the production of logic models of effective PD, and (c) the development of successive engineering design challenges

(Asunda, 2007; Asunda & Hill, 2007; Custer et al., 2007). These PD activities, which emphasized assessment-driven and open-ended problem solving within an engineering design context, were accomplished through the collaborative efforts of personnel working within the STEM disciplines. Furthermore, these efforts employed activity-based engineering design challenges, intensive discussion, field trips to engineering organizations, and a variety of other activities to enhance teacher's subject matter knowledge, pedagogical skills, and understanding of student learning.

In the following paragraphs, studies that are specific to STEM PD are discussed. The studies are informative to the design of this study in terms of establishing a better understanding of the landscape of NCETE PD efforts. The outcomes of the following studies may be useful to designers of STEM PD as they involve the following aspects of STEM PD: a) Implementation, b) Preparation of STEM teachers, and, c) Instructional delivery. The first study examined the effects of NCETE PD on teacher thinking, student thinking, and curriculum.

### *PD in STEM-Related Areas*

*Implementation.* Nehring (2007) conducted a goal-free evaluation of the effect that a NCETE PD program had on teacher practices as they implemented a lean manufacturing curriculum incorporating engineering design into their technology education courses. Seven participants were interviewed for the study which consisted of five teachers, one teacher intern, and one student teacher. There were three research questions that drove the study:

1. What impact did the PD have on the teacher thinking?

2. What impact did the PD have on the curriculum?

3. What impact did the PD have on student thinking?

A qualitative research approach was employed to collect data for the study, which included a 1-hour, open-ended interview with each participant. The data collected were reviewed and analyzed for themes relating to the PD's impact on teachers' thinking, curriculum, and students.

Four themes emerged from the data related to the impact on the teachers' thinking, including: (a) The benefit of collegiality, (b) the development of new knowledge, (c) an overall enjoyment of the experience, and (d) suggestions for improvement. The themes relating to the impact on the teachers' curriculum included: (a) the addition of new content to existing curriculum, (b) a concern of time, (c) the impact of laboratory equipment, and (d) the impact of the course in which they chose to implement the PD project. The themes relating to the impact on student thinking included: (a) a more complete picture of manufacturing, (b) exposure to technical knowledge not normally available, and (c) an overall enjoyment of the experience.

Nehring (2007) stated that as a result of the PD workshops, (a) teachers were better prepared to teach the engineering content, (b) teachers introduced new content knowledge and concepts to their classroom and laboratory activities that they would not have normally taught, (c) teachers believed that the students developed a greater understanding of the manufacturing process and some students' views of manufactured products may have changed to a more analytical observation. Suggestions for improvement included: (a) providing teachers with additional curriculum handouts, (b) developing a more structured scope and sequence, (c) recruiting teachers from similar subjects with similar facilities in which the lean manufacturing project would be implemented in, and (d) including the same age range of students. In this section we looked at the effects of implementing STEM PD. In the following paragraphs a study concerning the preparation of STEM educators will be discussed.

*Preparation of STEM teachers.* Asunda and Hill (2007) described a process of preparing STEM education teachers to deliver engineering-based concepts by way of technology education courses. This process was formulated through a multi-site case study of the NCETE PD activities during 2005 and 2006 that were aimed at facilitating the teaching of engineering design, problem solving, content, and analytical skills in middle and secondary school curriculums. Through a series of 15 interviews, along with video footage, observations and artifacts, PD emerged as a core theme and encompassed the following eight subthemes: planning, communities of practice, PD administration and learning environment, PD for technology education teachers, PD activities in the classroom, assessment, expertise, and meaning making.

Asunda and Hill (2007) concluded that if engineering-related content and pedagogy is to be successfully infused into the K-12 level curriculum, there needs to be a systematic and flexible approach to conducting PD that incorporates components such as project-based learning, collaborative learning, successful planning, and the use of a wide variety of strategies that supports a diversity of learners. “Such an approach should be informed by policy makers, teacher educators, school administrators, and the wider community by actively supporting such ventures through participation in research studies that seek to find out more on how we can improve teacher preparation practices as well as curriculum materials" (Asunda & Hill, p. 27).

In this section, the preparation of STEM teachers was discussed. The following study focused on the creation and delivery of engineering design challenges by high school teachers. It was informative to this study because it examined the effects of PD on teachers abilities to create their own content as well as deliver it to their students.

*Instructional delivery of engineering content.* Custer and colleagues (2007) conducted a study to explore the extent to which high school technology education students understood and were able to communicate an understanding of constraints, optimization, and predictive analysis (COPA). Using COPA as a conceptual base, a cohort of NCETE practicing and preservice technology teachers designed and developed a unit of instruction to deliver COPA concepts to high school technology education students. The main purpose of the study was to provide knowledge of how to increase student learning of engineering and engineering design through constraints, optimization, and predictive analysis. The researchers used a mixed methods quasi-experimental, pretest/posttest, no control group design. The treatment was used as the independent variable and the pretest/posttest as dependent variables. The student participants in the study received a pretest, treatment, and a posttest. In addition, following the posttest, focus groups were used to generate qualitative data that provided a more in-depth analysis of the data. Notwithstanding the importance of the student learning outcomes of the study it was observed that there were distinct implications for curriculum and PD. As the authors stated,

> One key factor has to do with an overt shift from procedural/activity-based curriculum and instruction, which as been typical for technology education, to an overt concept-based focus. The importance of this shift certainly extends beyond this research study or engineering curriculum. In this era of standards-based instruction, the technology education field must learn how to balance the historical appeal of engaging activities with curriculum development that is specifically designed to teach concepts (standards). (Custer et al., 2007, p. 14)

The study also indicated that the infusion of engineering-related content and pedagogy within a technology education context requires better preparation for existing and preservice technology education teachers to develop and teach instruction focused on engineering-based concepts.

## Summary and Conclusion

Significant work is needed to provide a model of PD specific to STEM education (Custer et al., 2007). In light of this, NCETE engaged in teacher training activities to infuse engineering design within high school programs during 2005 and 2006. Up to this point, a number of research efforts have been conducted by NCETE to advance the field of engineering and technology education. Several themes and recommendations for STEM PD have been established providing a platform for future research efforts (Custer et al.). However, much remains to be done. Although there is a plethora of literature on PD, few research studies have been conducted on either the relationship between characteristics of PD in STEM and change in teachers' classroom teaching practice (Boyle, Lamprianou, & Boyle, 2005). Therefore, this study examined the effects that the NCETE/CSULA PD workshops had on teachers' classroom practices, as well as, teacher perceptions in terms of the effects that the PD had on student thinking and learning.

# CHAPTER III

# METHODOLOGY

## Purpose

The purpose of this qualitative case study was to investigate the effects of NCETE- sponsored PD on infusing engineering design into STEM high school curricula. A qualitative case study analysis was used to generate a description of the case, present themes, assertions and interpretations of teacher experiences following the 2006 PD workshops at CSULA. Ultimately, this study investigated what, if any, curriculum changes took place at the secondary school level as a result of the NCETE-sponsored PD and how the PD teacher participants used what they learned in the NCETE PD workshops in terms of content and pedagogy. In the following section, a discussion of the workshops being investigated is discussed to help contextualize aspects of this study.

## Workshops Being Investigated

The NCETE professional workshops were broken up into two phases consisting of a spring and a summer workshop. The spring workshop phase consisted of six Saturday meetings from 9:00 a.m. to 5:00 p.m. This schedule was intended to reduce any interference with the teachers' respective teaching schedules. The theoretical framework and methodology of the six spring Saturday workshops focused on the following actions: (a) setting the scene, (b) creating a cohort, (c) describing the engineering profession, (d) diagnosing abilities, (e) providing foundational instruction, and (f) establishing a methodology (engineering design, E. Lipton, personal communication, September 15, 2008). Particularly, the spring phase was dedicated to providing each of the teachers with the necessary math and science content knowledge needed to succeed in engineering problem solving and to introduce the engineering design process. In addition, the spring phase included STEM applications and activities, as well as presentations given by guest speakers from the CSULA engineering department (i.e., electric and civil engineering instructors), pedagogy (i.e., project-based learning involving active, collaborative learning, open-ended problem solving, critical thinking, and tangible outcome), and outside experiences (i.e., tour of CSULA engineering facilities and a field trip to Cal Tech's seismic research facility).

The summer workshop phase consisted of five, eight hour-long sessions that were given within a one-week period. The theoretical framework and methodology of the summer workshops were aimed at: (a) introducing an exemplar teaching model called the earthquake engineering design challenge, (b) providing teachers practice with how to solve design problems, (c) teaching the teachers how to infuse engineering design into high school programs, (d) studying curriculum models, and (e) learning how to assess engineering design. Specifically, the summer phase concentrated on giving the participants instruction and practice in the application of an exemplar-teaching model related to the design of earthquake resistant buildings.

It is important to note that the goal of the workshops was not to have each teacher infuse the earthquake engineering design challenge into their instructional materials. The earthquake engineering design challenge was used as a teaching exemplar that demonstrated how teachers could integrate engineering design challenges into their instructional materials. The earthquake engineering design challenge required students to scientifically and mathematically predict the impact of earthquakes on buildings of different heights. Students could test their predictions using a shake table, building models, and testing their designs using computerized ultrasonic sensors.

*2005 NCETE/CSULA PD Pilot Program*

In 2005, NCETE piloted the NCETE-sponsored PD at CSULA. During the 2005 NCETE/CSULA PD, areas that needed improvement were identified. These improvements were implemented during the 2006 PD program. Specifically, the teachers received four sessions of math instruction and two sessions of physics instruction. Overall, it was reported that the workshops were successful with the exception that the participants felt that there was an overload of math content and not enough physics content (Westrick & Ory, 2006).

*2006 NCETE/CSULA Teacher Participants*

In 2006, NCETE launched its second year of PD at CSULA with a different group of teacher participants. The 2006 group consisted of five males and two females. In accordance with the aforementioned concern about the overload of math in the 2005 PD, the PD coordinators at CSULA decided to add an extra session of physics instruction and eliminate a day of math instruction during the 2006 PD. This action resulted in an equal balance of math and physics content. According to a workshop coordinator, this was the only difference in terms of how the PD was conducted in 2005 as compared to the PD conducted in 2006. (D. Maurizio, personal interview, March 25, 2008).

*NCETE/CSULA PD Theoretical Framework and Methodology*

Aspects of the NCETE/CSULA PD were shaped by a distinct theoretical framework and methodology for training a group of high school teachers how to infuse engineering design into high school curricula. The theoretical framework of the workshops is defined as the principles or ideas that helped shape the design and flow of the workshops as it related to the integration of STEM concepts and principles. Inherent within this theoretical framework was a rationale for the workshops that included reasons for why the workshops were beneficial to student learning and, more specifically, why engineering and technology education should be an integral component of general education. The theoretical framework, in turn, helped to shape the workshop's methodology.

The methodology of the workshop is defined as the processes used to convey information and practices to the workshop participants. These processes or delivery techniques included hands-on activities, PowerPoint presentations, science and math tutorials, practice in engineering problem-solving and overall discussions about philosophies concerning the infusion of engineering design into high school curricula.

The goal of the 2006 NCETE PD activities at CSULA was to facilitate the teaching of engineering design to high school students. Specifically, NCETE learning outcomes that were associated with the CSULA PD goals were as follows: (a) develop teachers' instructional decision making to focus on the analytical nature of design and problem solving needed to deliver technological and engineering concepts; (b) facilitate teacher initiated change in program design, curricular choices, programmatic and student assessment, and other areas that will impact learning related to technology and engineering; (c) develop teachers' capabilities as learners so that they assume leadership for their PD activities, including recruiting and mentoring their colleagues; (d) create a pool of highly skilled cooperating teachers who would accept preservice technology teachers into their classrooms and mentor the next generation of technology/engineering teachers to effectively teach students of diverse backgrounds; (e) develop engineering analysis and design skills in technology teachers, including strengthening their mathematics and science knowledge and skills; and (f) develop curriculum integration and collaboration skills in practicing technology teachers so that they could effectively collaborate with science and mathematics teachers (D. Maurizio, personal communication. September 16, 2008).

Moreover, Westrick and Ory (2006) noted that the NCETE workshops at CSULA were aimed at: (a) providing the participants with instruction and practice in the application of a specific engineering design problem, (b) testing participants' math abilities and develop a remediation plan as needed, (c) providing the foundational math instruction needed to succeed in the engineering design problem, (d) providing the foundational physics instruction needed to succeed in the engineering design problem, (e) providing the participants with instruction and practice in the engineering design method.

*Description of the Sample Population*

Although there were originally seven teacher participants in the 2006 workshops, one retired (early), and another dropped out for health reasons (he was diagnosed with cancer). Therefore, the final pool consisted of five teachers. Out of these five teachers, four teachers from the 2006 cohort participated in the study as discussed below. The teachers and their fictional names who participated in this study had the following academic backgrounds: Malia, physics and chemistry; Brian, chemistry; Victor, industrial education and physics, and Franklin, electrical engineering.

*Invitation to Participate*

An invitation to participate in the study (see Appendix A) was sent out on May 15, 2008, by one of the CSULA coordinators to gain a sense of how many teachers wanted to participate in the study. Out of the pool of five teachers, four responded and agreed to participate. After approval of the study, a follow-up email was sent out to the teachers to inform them of the upcoming study and to see if they were still available to participate. Although there were five teachers in the sampling pool, one was unresponsive to the request to participate in the study. Thus, the final sample consisted of four teachers.

*Research Participants and Selection*

When selecting participants for a qualitative study, one looks at whether or not a participant will add value to the experience or phenomenon being studied (Morse, 1998). To partake in the study, teachers had to: (a) have participated in an NCETE PD workshops conducted by the Technology Teacher Education (TTE) Program at CSULA during 2005 or 2006, and (b) have the ability to communicate their experiences with infusing engineering design (or the lack thereof) into their instructional materials. This study focuses on these four teachers from the second cohort who participated in the 2006 NCETE PD workshops at CSULA.

## Procedures

A qualitative case study analysis was used to obtain a detailed description of the effects that the NCETE/CSULA PD workshops had on STEM teaching practices. Case study methods are used when a researcher is seeking a deep understanding of an instance or event: a case. Case study research is bounded by a particular time, event, or place and provides a structured means of investigating events, collecting data, analyzing data, and reporting the findings of the study (Cresswell, 1998). As a result, the researcher may gain a deeper understanding of why something occurred as it did, plus be able to identify important future research areas. To overcome intrinsic biases and the problems that come from single method studies, the following three data sources were used as a means of triangulating data in this study (Stake, 1995): (a) teacher participant interviews, (b) teacher documentations including course materials, lesson plans, and/or design briefs, and (c) classroom observations.

### *Data Collection*

The data in this study were collected from four inservice high school teachers who participated in the 2006 NCETE PD workshops at CSULA. Each teacher was interviewed during September of 2008 to gain insights into the effects that the experience had on each of their instructional practices. The interviews were transcribed and analyzed using an iterative, spiraling, or cyclical approach that examined recurring themes, patterns, and categories, and, in effect, were used to code the data and identify salient points and relevant structures (Miles & Huberman, 1994; Stake, 1995; Tesch, 1990).

*Teacher participant interviews.* When seeking to gain in-depth knowledge from subjects about a particular experience, qualitative interview questions are the instrument of choice for many researchers (DeMarrais, 2004). With the goal of constructing a complete picture from the words and experiences of the participant, the researcher used interview questions and probing questions derived from an interview guide (see Appendix B). Specifically, the teachers were asked to describe any changes in their teaching methods (e.g., delivery of engineering-related content and pedagogy) as a result of the workshops and the successes and pitfalls of infusing the engineering-related content and pedagogy knowledge acquired in the workshops into their high school classes.

There were no control conditions in this qualitative case study. Data collection methods consisted of four teacher interviews that proceeded through the analysis of detailed statements, reoccurring patterns and themes (Glesne & Peshkin, 1992). This process helped to provide descriptions of the experiences of the teachers following the NCETE PD workshops. Triangulation of data was achieved through the collection of the following data sources: teacher interviews, teacher documentations, and classroom observations. In addition, triangulation of data involved corroborating evidence from different sources to shed light on a theme or perspective as stated by the teachers (Merriam, 1988).

After receiving teacher consent, a 1-hour interview was conducted with each teacher before or after school at their respective school sites and all interviews were documented using an audio recorder. After a backup copy of the interview was made, a verbatim transcript was generated from each of the audio interviews. The information collected during the interviews was used to impart a detailed view of each individual case. All interviews were conducted in-person.

*Interview guide.* In this study, the interview questions were based on the following research question: What are the effects of PD on infusing engineering design into high school STEM curricula? An interview guide was used to direct the researcher during the interviews and was used as a standard protocol for each interview. The interview guide consisted of seven main open-ended questions and a series of probing questions. The purpose of these probing questions was to extract more in-depth information needed to elucidate meaning of an event or experience that the teacher may have neglected to mention as part of the infusion process. The interview questions were adapted in part from an interview guide developed by Nehring (2007) for a similar type of study conducted at University of Wisconsin—Stout concerning the effects of a lean manufacturing NCETE sponsored professional workshops in engineering and technology education.

*Teacher documents.* In addition to conducting teacher participant interviews to study each case, teacher documents such as course outlines, lesson plans, and design briefs were collected from September 2008 to February 2009 and reviewed to probe ways in which the teachers have revised their classroom and laboratory practices. According to Stake (1995), this method assists in the search for the convergence of information and is directly associated with data situations in the development of a case study. Examining teacher documents provided further insight into the effect that the NCETE/CSULA PD had on the infusion of engineering design into high school curricula that may have been derelict in each of the individual teacher interviews. In other words, these documents were used to gain a sense of specific outcomes that resulted from each of the teachers' involvement with the NCETE/CSULA PD workshops.

Evaluation of teacher documents was facilitated through the use of a seven-step engineering design process model (see Appendix C) that contains a checklist consisting of each step of the engineering design process as presented to the 2006 teacher workshops participants. The researcher evaluated the teacher documents to see how closely the teacher documents aligned with each of the seven-steps.

*Classroom observations.* Classroom observations were conducted during the winter of 2009 to triangulate the findings of this study and provided firsthand information about what it was like to be in each of the teachers' class. These observations were used to corroborate statements made during each teacher interview, especially as it concerned how each teacher was using what they learned in the workshops. Overall, the classroom observations helped to gain a better understanding of student behaviors as it concerned STEM learning. These observations were recorded as field notes.

*Workshop documents.* An auxiliary source of information was used to inform this study in regards to gaining an understanding of the organization and structure of the 2006 NCETE/CSULA workshops. Workshop documents, which were provided by the CSULA PD coordinators in the summer of 2008, were used to inform and instruct the teachers on how to infuse engineering design into their instructional materials. Workshop documents, including items such as PowerPoint presentation, handouts, questionnaires, and STEM learning activities, were helpful in analyzing and linking teacher statements to what actually transpired during the workshop.

*Data Analysis*

The analysis of data was performed using a qualitative case study approach. Case studies are particularly useful in depicting a holistic portrayal of individual experiences and results regarding a program (Patton, 2002). There is no standard format that exists for analyzing and reporting case study research (Cresswell, 1998). Each qualitative case study is unique; therefore, each analysis of a study is unique (Patton). The analysis of data was customized, and revised to specifically address the research question (Miles & Huberman, 1994).

Data were organized in a way that illustrated how each teacher was applying what they learned in the workshops in their classrooms to develop a case study narrative. The narrative is a readable story that integrates and summarizes key information around the focus of the case study. The narrative was structured so that the results could be understood and interpreted by readers unfamiliar with the project (Cresswell, 1998).

Being that each teacher was unique in terms of experiential knowledge, their cases revealed different findings that began to emerge during the interviews and continued to evolve as the data analysis process spiraled (Cresswell, 1998). The findings are presented in a way that summarizes them into relevant themes within each of the teacher's individual statements that reveal certain sub-themes pertinent to the effects that the workshops had on infusing engineering design content into high school curricula.

After reviewing each of the teacher's individual responses, visual images or tables of the data were created to identify themes that were common to each teacher's individual case (Spradley, 1980). This was done to package the information collected through the interviews. To do this, each teacher's case was cross-compared to isolate themes or patterns from their individual responses. From these individual responses, relevant themes emerged which were used to generate overall thematic findings. For example, individual teacher cases were compared to tease out commonalities within each of the teachers' experiences and how each of the teachers implemented what they learned in the workshops. These commonalities highlighted the strengths and weaknesses of the NCETE/CSULA PD workshops. The process of data analysis can be compared to a funnel in that the data seemed somewhat unconnected and too widespread to have any meaning, but as the data were analyzed, progressively more unambiguous themes emerged (MacMillan, 2008).

Aspects of this study included: (a) demographic information about the teachers (collected prior to the interviews), (b) ways in which the teachers integrated engineering-related PD content and pedagogy into their instructional materials, (c) major differences in instructional methods noticed about the teachers after the PD workshops, (d) indicators of successes and failures, and (e) key quotes from the teachers concerning how the NCETE PD workshops impacted their instructional practices.

The analysis of qualitative case study data adheres to a rather logical sequence of steps that employ an iterative model. This iterative, model conforms to a meticulous data analysis spiral consisting of the following general procedures (Miles & Huberman, 1994).

1. Data reduction—finding a focus, managing data, reading and annotating
2. Data display—categorizing data, linking data, connecting categories
3. Conclusion drawing and verification—corroborating evidence, producing an account.

*Data reduction.* The first step in the qualitative case study analysis process is data management (Miles & Huberman, 1994). This process helps to facilitate the organization of data into file folders, index cards, and computer files. Following the organization and conversion of audio-recordings into text, the transcripts were read thoroughly while methodically reviewing the audio recordings several times. By doing this, an overall understanding of the material was developed (Tesch, 1990). During this process of review, notes were jotted down in the margins of the transcribed interviews. Since all the data that were collected was not used in the study, these memos and reflective notes served as an initial sorting-out process to filter the data. These memos consisted of "short phrases, ideas, or key concepts" (Cresswell, 1998, p. 144) that occurred to the researcher that helped to categorize major organizing ideas. During this process, evidence was found to portray multiple perspectives about each category.

*Data display.* Each participant's interview was analyzed for a detailed understanding of the effect that NCETE sponsored PD had on teaching methods. Subsequently, each teacher interview was scrutinized to expand the researcher's understanding of each teacher's perception. Finally, a cross-comparative analysis of all of the teachers' experiences were performed after each individual interview was scrutinized to determine what the common experiences were with regards to infusing engineering content into their classroom and laboratory instruction (Yin, 1989). During this analysis phase, significant statements were extracted from each transcribed interview to formulate meanings that emerged from the data. These meanings were color coded and clustered into themes that were used to integrate these themes into a narrative description of the phenomenon being studied.

Descriptions were created to summarize each of the statements made by the teachers during the interviews. Using the transcribed interviews, different color markers were used to highlight specific statements made by the teachers. For the examination of the teachers' experiences with infusing engineering design into their instructional materials, the descriptions were grouped into categories of similarity. Themes were then developed from each of these categories. The emerging themes were scrutinized to determine if they were truly a theme and not a sub theme or an anomaly (Wolcott, 1994). During the analysis of the data, the narratives of the teachers' statements were written as separate accounts to avoid losing the individual value of each of the teacher's statements. These individual statements were then compared with other teacher statements for connections or similarities of data that fostered the development of themes based on the effect that the NCETE sponsored PD had on their instructional practices. Teacher and workshop documentations were highlighted for important information relating to the effect of NCETE sponsored PD on content and pedagogy. Coding schemes were created using the descriptions to summarize the highlighted information (Strauss & Corbin, 1990).

The descriptions from each of the teacher's interviews were categorized based on similarities, which lead to the development of themes, which described the categories. The themes were then scrutinized to determine if they were authentic and, in Chapter V, an interpretation was provided in light of the researcher's own views and views of perspectives in the literature (Erlandson, Harris, Skipper, & Allen, 1993). These elements were used to create the narrative.

*Conclusion drawing and verification.* According to Lincoln and Guba (1985), interpretation involves making sense of the data or what can be called the lessons learned. These interpretations may stem from a social science construct or idea, or an amalgamation of personal insights when compared or contrasted with a social construct or idea. At this point in the analysis, the researcher had the capacity to form a more pragmatic view of what transpired in regards to the effect that the NCETE sponsored PD had on infusing engineering-related content and pedagogy into STEM classroom and laboratory projects.

## Summary

In summary, this qualitative case study organizes three sources of data concerning NCETE PD workshops at CSULA, namely interviews, teacher documents, and classroom observations. The content of these three sources of data were examined to ascertain patterns and themes in the data. It is important to note that the teachers who participated in this study were between 2 to 3 years removed from the workshops. Since a couple of years had passed since the workshops, it was assumed that the teachers had time to reflect and implement what they learned in the workshops. These patterns and themes were further analyzed and compared with other PD literature. The goal was to see how curriculum change is taking/has taken place at the high school level as a result of these efforts. By doing this, standards for PD specific to STEM education can be established, scrutinized, and enhanced (Custer et al., 2008).

For working models of engineering and technology education to become realized, an in-depth analysis of how teachers have implemented what they have learned through the NCETE/CSULA workshops is exigent and momentous. In the next chapter, findings related to the effect that the workshops had on teaching practices are examined.

# CHAPTER IV

# FINDINGS

The purpose of this qualitative case study was to examine the long-term effects of PD on infusing engineering design into high school STEM curricula. These particular PD workshops, sponsored by the NCETE, focused on training teachers how to infuse engineering design into their instructional materials. This study examines how four inservice teachers' who participated in the 2006 workshops at CSULA used what they learned in the workshops to modify their instructional practices. Triangulation of data in this study was collected through interviews, teacher documents, and classroom observations. The collected data resulted in three relevant themes emerging, including the following:

1. Incorporating PD content into instructional practices.
2. Challenges with incorporating PD content into instructional practices.
3. Benefits of incorporating PD content into instructional practices.

The following four individual teacher case studies have been put into the context of each of the themes to show what occurred related to theme.

## Case Study #1: Malia

### *Incorporation of PD Content*

Malia attained a bachelor's degree in biology. Although she was credentialed to teach biology, she had been teaching physical science and chemistry classes for 6 years at the time of the interview. She had experience teaching gifted and non-gifted students and also mentioned that she mentored other teachers on how to teach science.

Malia was not taught how to infuse engineering-based content into her classroom instruction as part of her formal teaching preparation. Prior to her participation in the NCETE PD workshops, Malia had no previous experience with teaching engineering. The NCETE PD workshops provided a foundation for pedagogical content knowledge that enabled her to make engineering accessible to her students. Out of the four teachers in this study, she was the only one who integrated the earthquake engineering design challenge into her instructional materials.

When asked how much of the earthquake engineering design challenge she incorporated into her physics instructional materials, Malia replied that she did “the whole thing.” She said that she saves this “project for the very end because it’s such a big project.” As she talked about how she implemented the earthquake engineering design challenge in her classroom, she evidenced a design brief that she gave to her students explaining the details of the project. The design brief was presented in the context of a business letter that stated how her students were hired by the city to help them consider constructing a 12-, 18-, or 24-story new high-rise building in a downtown area.

As shown in the earthquake engineering design challenge brief that she provided, Malia translated what she learned in the workshops to introduce facets of engineering into her instructional materials. She immersed her students in an engineering-like experience and provided them with a list of engineering specifications with which they needed to comply. The specifications included such items as: (a) economics (building height), (b) construction costs (building weight), and (c) seismic performance (displacement at the top of the building). She said that these specifications allowed her students to see that engineers use an iterative approach to design and problem solving guided by a specific process, namely, the engineering design process. Excitedly, Malia declared that "it really has opened [the student's] eyes to realize that with engineers there is not just one answer." As she noted, oftentimes, when engineers work through the engineering design process, they do not develop one answer to a particular problem, but, rather, generate a number of alternative solutions. After these alternative solutions have been identified, engineers determine which solution best meets the criteria of the project while satisfying the constraints that they have to work within.

Criteria are the things that a product must have to satisfy a customer need or problem. For example, in the case of the earthquake engineering design challenge, the building must be 12, 18, or 24 stories in height and must be able to withstand a 6.0 to 8.0 seismic disturbance on the Richter scale at any time. In addition, Malia mentioned that there are many constraints that go along with the earthquake engineering design challenge "and it all depends on what you emphasize." Common constraints are things such as cost, construction materials, time, knowledge, available technology, workforce capacity, and so forth. Overall, she stated that she tried to make the earthquake engineering design challenge as realistic as possible so that her students can gain a better perspective of what engineering is and how engineers work.

At the end of the project, she said that her students had to present their findings based on sound scientific and mathematical analysis, as well as experimental data. She explained how "it's really interesting to see how many kids will say [that they] think

[they] should build a smaller building because of the cost." From this, she noted how engineering education enhanced the quality of her students' ability to think critically and deeply before making decisions about their design work. Additionally, she discussed how the workshops provided her with an understanding of how to couple the relationship between her students and specific engineering content so that her students were able to develop a better understanding of the engineering design process and engineering in general. She said that the part of the workshops that impacted her teaching the most "was being able to show engineering at a level for students to understand."

Based on what she learned from the NCETE PD workshops, Malia explained how she wanted her science class to connect her students to real-world situations by giving them "the experience of being an engineer…this is how engineers work in a company and things like that...it's lots of fun." Most notable was the fact that Malia infused engineering design into other existing classroom and laboratory projects based on what she learned from her NCETE PD experience. She noted how this was accomplished by using the theoretical framework and methodology conveyed through the workshops. She "realized that if you could do it with [the earthquake engineering design challenge] you could do it with any lesson."

When observing her morning physics class, it was evident that Malia weaved in the theoretical framework and methodology of the workshops into as many areas of her teaching as possible. For example, when I arrived, I noticed an array of tools, equipment and supplies around Malia's desk area that she was using to help her students build something. Upon closer examination, her students were busy working on a hands-on physics activity that involved building a windmill that could do the most work in order to lift as much weight (pennies) as possible. Being that each penny weighed a specific amount, she explained how she multiplied the number of pennies by the individual weight to calculate the total force needed to lift the pennies. The amount of force was then multiplied by the distance that the pennies were lifted. By multiplying force time distance, students calculated how much work their windmills accomplished. Before they constructed their windmills, each of the student groups needed to develop a plan that consisted of drawings and the materials they would use for constructing their windmill projects. She said that she wanted them to visualize their work prior to construction versus using a pure trial and error approach to their design solutions. She acknowledged how this approach was somewhat divergent from the engineering design process model presented in the workshops due to the lack of scientific and mathematical analysis prior to constructing the windmill. However, she noted how she still employed the idea of using active, project-based, hands-on learning approaches to teaching science versus traditional instructional delivery methods.

As will be discussed in greater detail below, Malia expressed a need for more authentic engineering design challenges that required students to calculate before they build. She said that the main impetus for doing the project as explained above was to have her students design and build the subject windmill so that they would have a working model to use as a reference for calculating the amount of work performed by the system. Nevertheless, she said that she was still applying many of the concepts and principles communicated in the workshops.

While observing the classroom, it was interesting to see how no two projects were alike. Some of the reasons why Malia said that she loved the engineering teaching model were because it allowed her students to embody the concepts and principles that she needed to teach. She said it also provided opportunities for her students to exercise their creative problem-solving skills.

*Challenges*

Although the infusion of engineering design challenges allowed for greater amounts of creativity in her classroom, Malia said that one of the things that was challenging for her was assessing the qualitative characteristics of her students' work. She said "I can grade them on the science concepts but it's hard to grade them qualitatively on what the projects look like. You know?-how it performs." She explained that grading engineering design challenges is completely different from how students are graded in traditional science classes.

The second challenge that Malia mentioned dealt with issues concerning group work or team participation. She said, "when you're doing group work, it's really hard to know whose really working and who is not…." As reflected in this statement, there is always a tendency for some people in the group to do more work than others. To avoid this quandary, Malia required that "each [student] do [a certain] part.... Each of them has to do their part and show what they have done. They also get a grade for their group project." By doing this, she could better assess which students were contributing and which ones were not. She said that this also gave her students greater incentive to participate because each of them knew that they would be held individually accountable.

This way, noncontributing students could not rely on the rest of the group to carry them or bear the burden for their lack of work.

In addition to the above challenges, Malia talked about how it was challenging to find available engineering design challenges that she could immediately integrate into her instructional materials. She explained that, “when it comes to engineering challenges, there are a lot of challenges out there that are not pertaining to specific science concepts so it’s hard to implement it into my curriculum.” She added,

> The hardest thing is incorporating the math or doing the math ahead of time and finding things at their level…they can learn the science concept but the math that proves this concept or that is incorporated into the lesson is usually at a higher level than my freshman students.

As indicated by her statements, the shift from a curriculum-centered approach, to a project-based approach, to learning that identifies and conveys a specific set of science and math concepts presented a major challenge for her. For example, she pointed out that “mousetrap racecars are really common but what part of science does it really pertain to?” In accordance with the engineering design process model that she learned about in the workshops, she emphasized that authentic engineering design challenges require that students “actually calculate before they build instead of the other way around…that’s been my hardest challenge.” A trial and error approach to design was contrary to the engineering design process that was conveyed through the workshops and she expressed that “I don’t want to do projects like that.”

The third challenge that Malia mentioned pertained to the time-intensive nature of engineering education. She explained that “there is not a lot of time for it…. I can’t spend, you know, two weeks on every project.” Malia said that she had to consider how engineering design challenges benefited student learning in a manner that would prepare them for state testing requirements. While Malia expressed a desire to integrate more engineering design into her instructional materials, she had to contend with the ubiquitous nature of standardized testing due to the amount of time needed to perform more complicated engineering design challenges.

Last, Malia talked about challenges with how she sometimes lacked money to buy materials for hands-on activities. She explained that when she did not have the necessary funds in her budget for buying materials, she would just “suck it up and pay for it.” In the same sentence, she laughed while saying, “But at least it’s a tax write-off, right?” Although Malia stated that she overcame many of her challenges, she mentioned that time was the only one that she could not overcome. She said that, “although there are lots of challenges…it’s totally worth it.” Proudly, she affirmed that, “I do it every year and will continue it.”

*Benefits*

In regards to the benefits of implementing what she learned in the workshops, Malia articulated, “The benefits for me are that it really opened my mind to how to teach science and how to make science fun.” She said that, oftentimes, as will be illustrated by her statement below, students have difficulty understanding abstract science concepts and principles. Moreover, she expressed how some of her students lacked a general interest in science education. For these reasons, she felt that alternative modes of instruction were needed to make science more interesting and relevant to her students.

In addition to making her classes more fun, she explained how the workshops helped her “students learn how to solve problems because a lot of kids problem-solve all the time…they don’t realize they do…so it’s natural for them.” By pointing out the naturalness of problem solving, she said that her students were given a basic understanding of the variety of potential uses for what they learned in her class. She felt that these real-world connections prepared her students to: (a) make career decisions, (b) develop team building proficiencies, (c) improve their decision-making skills, and (d) utilize creative thinking processes.

Pursuant to helping her students make real-world connections with science in relationship to engineering design, Malia explained that many students told her, “I don’t get science. I don’t understand.” and she asked them, “Well, don’t you try to fix your purse when it breaks? Well, there you go…you are doing the engineering process” She said that they responded by saying, “I never thought of it that way.” She added, “…it helps me make science more engaging and more hands-on for the kids. It’s been wonderful for the kids.”

In addition, Malia discussed how engineering thinking was applicable to a variety of careers even those not directly related to engineering. As indicated by her words, Malia used what she learned in the workshops to show her students the multifold benefits of engineering education. She said that the kids will say that, “I’ve learned more in this class than I’ve ever learned in any of my middle school science classes” and it is not just content but “learning about life things…how to do things…how to, you know…use those kind of skills.” Malia also talked about how her students’ “critical thinking has changed immensely.” For example, “You see the kids at the beginning of the year and the kids at the end of the year and I don't have to tell them how to do [the earthquake engineering design challenge] because they're figuring it out by themselves…It's pretty amazing how they all can figure things out." She added,

> A lot of kids will say, "This is the only class that I have to think in." For a kid to have to think is really different from a kid who has to sit there and regurgitate information and so they have to actually pay attention to what I'm saying and what I'm reading and what I'm thinking and they say they love it. I love it because it really has made it challenging for them, but, at the same time, it's very enriching and rewarding for them.

Malia articulated that the outcomes of student learning were not always reflected in their GPAs, but as Delyser and colleagues (2003) pointed out, a seemingly deeper understanding of more complex material was achieved. She expressed:

> There are a lot of kids who go, "You know, Mom, I didn't do well on this test but you have to realize that I've done this and I can do this"-and it's amazing how it transforms their thinking.... They say that they know how to think better than [they] ever have before.

She added, "I did not realize how empowering it was until it happened…it takes them a while- they don't get it right away…but they really like it." Although employing what she learned in the NCETE PD workshops required a big investment of time, energy, and resources, Malia expressed that it was, nonetheless, beneficial, as well as gratifying on multiple levels especially when she saw how her students were motivated to learn more about STEM disciplines and even more so, how some of her students even considered a career in engineering after taking her class.

## Case Study #2: Brian

*Incorporation of PD content*

Brian, a chemistry teacher, started his teaching career as a long-term substitute teacher who worked with troubled youth for three years. He spent 2 years teaching English in Costa Rica. At the time of the interview, it was his third year teaching chemistry at the school he was interviewed at. Brian mentioned that he years started out as a chemical engineering major and later decided to switch his major to chemistry. He also entered the workshops with no engineering teaching experience and no prior involvement with STEM integration. He did not incorporate the earthquake engineering design challenge into his classroom instruction due to the inherent limitations of using the earthquake engineering design challenge for teaching chemistry. Although Brian did not incorporate the earthquake engineering design challenge into his classroom instruction, he used the theoretical framework and methodology of the workshops to inform his teaching practices.

Brian said that what he liked most about the engineering design process was how it gave students "the opportunity to think for themselves and solve a problem and make something work." He explained how he used what he learned in the workshops to help "students to open up their minds and want more instead of just having them memorize this situation and instead of looking at a situation and analyzing it." Given this perspective, after completing the NCETE PD workshops, Brian incorporated more goal-oriented, student-centered (versus curriculum-centered) approaches to teaching. He noted that instructional strategies that are student centered provide an opportunity for students to develop critical thinking and problem solving skills from a reference frame that is relevant and meaningful. In an effort to provide relevant and meaningful, student-centered approaches to teaching chemistry, Brian developed performance-based learning activities so that his students could explore science through active investigation versus the traditional lecture-based delivery. This way, he said his students could take greater ownership over the processes of their own learning while making relevant and meaningful real-world connections. This approach also created more opportunities for his students to interact with himself and each other. A specific example of how Brian employed the theoretical framework and methodology of the workshops is discussed in the following paragraph.

Brian explained how he developed “miniature challenges” based on what he learned from the workshops due to time limitations. He said that miniature challenges were more conducive to teaching chemistry than challenges that required more than one class period to complete. This way, he could teach what the students needed to learn within the time allotted for him each period. A specific example of these miniature challenges was evidenced in a document he provided called the “Engineering Conversion Challenge.”

He framed the challenge within an engineering context wherein the students played the role of an engineer stationed in Columbia and needed to replicate an item given to them in twenty minutes or less, hence, the name “miniature challenge.” The students were told that the only company that sold the parts for replication was stationed at a local “hardware store” (his desk in the front of the classroom) and thus used the

British measuring system. The following items, which were given in British standard units (inches, quarts, and pounds), and were used in the challenge included: squared black paper, semicircular glass, toothpicks, cork, and molding clay. The procedure was to use what they had learned about conversion factors and significant figures to replicate the figure within a 20-minute period. Calculations and exact measurements were required before “buying” the materials at “the hardware store.” The idea was to teach his students “how to use what they learned about conversion factors rather than having them do conversion factors.” Not only did the *Engineering Conversion Challenge* involve converting numbers from metric to the British measuring system, he also explained that it taught his students how to use what they learned about the principles of density.

When asked if these changes to his teaching practices were a result of what he learned in the workshops, he said that he would have probably tried to incorporate things like that because he wanted the kids to be engaged but the workshops gave him a different teaching perspective. He said, “I think it has given me a different perspective on how I can institute these types of design challenges and the simple things that I can do to get my kids moving.” Ultimately, Brian could have simply told his students to replicate the item; instead he said that he wanted to contextualize the lesson and apply what he learned in the workshops to transform content knowledge into a form that was more relevant to his students. Moreover, Brian unified his content knowledge with what he learned in the workshops to develop effective strategies to communicate and deliver instruction on specific concepts in chemistry.

*Challenges*

When Brian was asked to discuss challenges that he faced with incorporating what he learned in the workshops into his classroom instruction, he replied, "I was not taught through the methodology of challenges… I was taught to memorize and use rote memory and I would have loved to have challenges because I love figuring things out" Brian pointed out that general education has relied on a model of teaching that is very passive and structured around a curriculum or teacher-centered approach to learning wherein students are expected to listen, take notes, and memorize information in order to pass a standardized examination. In light of these issues, Brian mentioned how the chemistry curriculum was limited and required him to "move through the materials."

Having the opportunity to visit one of his morning chemistry classes, I observed the massive amount of information and materials that he had to deliver within one class period. At the beginning of the class, he asked his students if they had any questions about the previous night's homework. In response, the students asked if he would review a homework problem concerning how atmospheric pressure affected the boiling point of water. After answering questions about the homework, he transitioned into a lecture about ionic and molecular bonds and compounds. After he finished explaining how to do the homework problem, he asked his students to write down three or four sentences explaining what they learned about ionic and molecular bonds. Next, he discussed the interaction of electrons within materials and why some materials were better conductors than others.

He also talked about the properties of other materials such as diamonds and graphite. Although Brian said that he did not have time for engineering in his class, he did occasionally talk about engineering applications as they related to certain topics that he discussed during his lectures. For example, during his lecture, he interlaced how engineers had designed a device using nanotubes to detect particular chemicals that might be used in a terrorist attack.

Towards the end of the class, he explained what a phase diagram was and how it could be used to determine what temperature and pressure water would change from a solid into a liquid (and vice versa), and from a liquid into a gas (and vice versa). He concluded the class by conducting, what he referred to as a “dry ice experiment” wherein he took some crushed dry ice, scooped it into a plastic test tube, and then placed the dry ice into a glass of water while squeezing the plastic test tube to exert pressure on the dry ice within the plastic test tube. By doing this, his students were able to see the solid (dry ice) turn into a liquid. After it was exposed to the air it quickly converted back to its solid, dry ice state.

Based on what I observed during this class period, it was evident that Brian was indeed limited in his ability to do full-blown engineering design challenges because of the fact that he had to cover a lot of material in a one and a half hour period. Furthermore, although he had announced that there would be an exam during the class period, time prevented him from issuing it. Instead, he assigned it as a take-home exam in which the students were to complete before the next class meeting. From this perspective, it was easy to see why Brian mentioned how, in order for him to do engineering in his chemistry class, he needed miniature, less time-intensive engineering design challenges that his students could complete in 20-30 minutes.

Ever since he started teaching his chemistry class two years ago, Brian said that his greatest challenge involved making his chemistry class more interesting and engaging for his students. He explained how he did not want his chemistry class to resemble the traditional, lecture-based mode of instruction. Brian had been trying to incorporate more of the theoretical framework and methodology that he learned in the workshops into his classroom instruction but acknowledged that, “the challenges are coming up with the challenges.” This echoed his previous sentiments related to the challenges he faced with time.

He went on to say that, “I can’t have an open-ended challenge that takes two weeks…. It just won’t work—so I need like little mini lessons, little mini challenges that the kids can do.” Because there are no explicit standards for developing learning challenges, Brian found it challenging to come up with instructional materials that: (a) were grade level appropriate, (b) addressed specific content standards, (c) were economically feasible, (d) were not time intensive, and (e) were engaging for the students. He mentioned how teachers required additional support and guidance in this area and also needed to consider: (a) their instructional goals, (b) what students will be expected to know and, (c) what kinds of knowledge, skills, and capabilities students should be able to demonstrate before engaging in a performance-based learning challenge.

In reference to performance-based learning, Brian talked about the challenge of “trying to make it work within the classroom environment with limited supplies and time constraints." He explained how the delivery of engineering education content requires a greater investment of time, energy, and resources in comparison to core academic subjects that concentrate on one discipline of thinking (i.e., math, science, history, English, language arts, etc.). In addition to these challenges, Brian explained that his district is very standards-based and how standards-based educational reform efforts, such as *No Child Left Behind* (NCLB), have increased the amount of pressure on him in terms of teaching to the test.

*Benefits*

When Brian was asked to explain the benefits of what he learned in the workshops, he said, "Oddly enough, it makes my life easier as a teacher." By this, he explained how the PD helped him to better facilitate learning by "coaching" the students through a problem-solving exercise as opposed to showing them the answers and asking them to memorize them to pass a test. As he continued to talk about the benefits of applying what he learned in the workshops, he revisited his previous comments about impacting student learning. He reiterated how an engineering design challenge "makes the kids more engaged…. The kids learn the material better because they are actually internalizing what they are trying to figure out." Brian further declared that when the students solve problems on their own:

> They are going to remember it a little bit better instead of just hearing it in a lecture. I am not telling it to them-they are telling it to themselves and to their neighbor and they are writing it out and they are trying to figure it out.

As his words indicate, Brian was very passionate about captivating the interest of his students, at the same time, providing them with learning challenges or opportunities to construct knowledge on their own rather than having them memorize information and regurgitate it on a test. In the couple of years that he has been applying what he learned in the workshops to his chemistry classroom instruction, he noticed changes in student learning outcomes. He said, “From my experience the students can understand the material faster and they retain it longer.” Brian’s view, which was consistent with Rhem (1998), was that problem-based learning benefited students by promoting meaning making over merely collecting facts.

In addition to the above benefits, he summed up his statements by mentioning how the information and practices presented in the workshops facilitated student learning and has brought greater effectiveness to his teaching:

> I think there are a lot of benefits…it even saves time…it takes less time for me to teach something because I don’t have to teach it three times… it’s a time saver in the classroom…if I do it correctly.

When asked if the workshops helped him to improve student understanding of the field of engineering and engineering design in general, he said that he does not discuss engineering with them as much as he would like but that he incorporates engineering-like experiences in his instructional materials: “No I don’t talk to them about engineering in this class—I haven’t had the opportunity to…but I think I’ve been incorporating all the engineering experiences I’ve had throughout the course.” After giving the question more thought, he contradicted his above statement by mentioning how he talked about engineering when he has “time to shoot the breeze,” but he does not talk about engineering, because, as he put it, “it’s not my class environment. Could I do it? Yes, I can probably institute that very easily but that's not something that I've actually been doing in my class." Revisiting his earlier statements, Brian felt that incorporating engineering design challenges into his classroom instruction was not compatible with what and how he needed to teach. Instead of incorporating engineering specific to the types of challenges that were presented in the workshops, he realized the benefits of using the theoretical framework and methodology of the workshops which he, in turn, used to develop miniature design challenges for teaching chemistry. Overall, this was how he took what he learned from the workshops and translated them into his teaching practices.

When asked how students apply what they learn in his class in their every day lives, he replied:

> Some kids talk to me forever and come to me with information about how the class applies to the real-world. My goals as a teacher is to make the class fun…to keep the class from being boring and the other one is to make it real to the students so that they can apply it to the real-world.

As discussed earlier, due to the abstract nature of the science he was teaching (chemistry), Brian felt that it was important for him to bridge the gap between real-world situations and his chemistry education content. He felt that without real-world relevancy, it is increasingly difficult for students to make meaningful connections as they learn core academic concepts while increasing their understandings of abstract concepts and principles.

# Case Study #3: Victor

*Incorporation of PD content*

Victor, who had a degree in industrial education, was also credentialed in physics and math. At the time of the interview, he had been teaching STEM-related courses for more than 20 years. After attaining his degree in industrial education, he decided to take engineering courses to help accentuate his understanding of STEM concepts.

Due to his experiential knowledge, it was difficult to surmise what he actually learned from the workshops. It was like asking a college-level calculus instructor what he learned from a kindergarten counting exercise. He considered that everything he taught paralleled what was presented in the workshops. He excitedly said,

> I'd already been doing stuff like that…it's like anything else, if you've never been exposed to that kind of stuff, the learning curve is very high. But after you've been doing the same stuff for ten, twenty years, you're almost at the acme of it all and it's just very small refinements you're making along the way-just trying to smooth out the rough edges.

Victor also did not incorporate the earthquake engineering design challenge as part of his instructional materials but, rather, incorporated more of the theoretical framework and methodology of the workshops that he deemed relevant to his area of teaching and personal interests. Victor felt that the theoretical framework and methodology of the workshops helped to enhance and reinforce his teaching practices. As he put it, he was, "ahead of the curve" in regards to teaching engineering-based content within a high school context. In terms of what he did incorporate from the workshops, he stated, "the teaching method is one thing that the workshops solidified," explaining,

> What the workshops actually did for me was to give me an engineering

> model where you define the problem, I present the physics, and the chemistry, then the mathematical tools, then we make an actual model.

In other words, Victor said that as a result of what he learned in the workshops, he infused more of an engineering design approach into his existing laboratory projects wherein a greater degree of science and math concepts were applied prior to the physical construction of a product or artifact. He noted how these actions were consistent with the theoretical framework and methodology of the workshops being that he placed a greater emphasis on the application of scientific and mathematical tools prior to building something. He mentioned how this was a key component that separated the engineering design process from other design processes. He further emphasized how his students

> use a mathematical model and then they do the actual lab…so it's the mathematical model or the engineering model that puts you in the range of what the final solution should be and that's the part that [the workshop] solidified in my head…. I mean, that was the main thing that I got out of the whole thing.

In reference to what he gained most from his participation in the NCETE PD experience, the engineering design process model was foremost in Victor's memory. Principally, the engineering design process model presented in the workshops placed heavy emphasis on using scientific and mathematical analysis to inform the design of a physical product or artifact. As Victor pointed out above, the application of these scientific and mathematical tools "puts you in the range of what the final solution should be." Victor said that he was impressed with how the workshops distinguished engineering design from other fields. He mentioned how the workshops helped him to "solidify" his instructional practices through discussions of how engineers utilized mathematical models based on science to analyze their designs, thus significantly reducing the amount of trial and error, and, in effect, waste, when attempting to arrive at a design solution. He said that this concept was especially useful when considering the cost of materials needed to perform his electronic labs, especially as it concerns purchasing expensive electronics components such as integrated circuits.

At that point in the interview, I was still unclear as to what Victor actually got out of the PD experience so I asked if he felt the workshops was helpful, and he replied:

> Well, yeah, in retrospect, but if I would of known that I only needed one part to complete and finish what I wanted do, one meeting would have been enough but you never know.. I finally got something out of it.

As discussed in Chapter III, the spring workshops focused more on the specific subject matter knowledge needed to provide each teacher with the necessary science and math background to perform the earthquake design project with their students. Victor explained that he was very comfortable and familiar with the science and math content of presented during the spring workshop and how that part was mundane to him. As stated above, if he had known that he only needed one part of the workshops (i.e., the information, equipment, and practices needed to develop a soil hydration lab), then one meeting would have sufficed for him.

Rather than using the earthquake engineering design challenge, Victor developed a soil hydration lab utilizing some of the equipment, specifically, the shaker table that was given to him in the workshops. He mentioned how this project was a direct result of the workshops because,

> Number one…there was always something in the back of my mind to do something like that, but being exposed to the information from the workshops, I was able to put everything together with the equipment that we were given.

As evidenced in a document collected from Victor, the soil hydration lab, which takes approximately two weeks to complete, required his students to measure soil hydration by recording the time it takes for the soil to become saturated. Other objectives included finding: the void ratio, the porosity of the soil, the soil's water content, and the specific gravity of the soil. In their lab report, students were expected to list the objective of the lab, the materials they used, the procedures they employed, their results (charts), their analysis, and their conclusion.

The soil hydration lab was somewhat of a variation of the earthquake engineering design challenge presented in the workshops. Rather than shaking a small-scale building structure, from a civil engineering point of view, Victor used the shake table to study the effects of an earthquake on soil erosion patterns or how soil is affected by resonance produced by earthquakes. The development of this lab illustrated how Victor used what he learned in the workshops to satisfy his own teaching needs plus showed how the workshops contributed to his classroom instructional materials. In other words, Victor applied what he learned in the workshops and made it relevant to his own area of teaching and personal interest.

*Challenges*

When asked if he had any challenges implementing the soil hydration lab, he could not think of any although he did mention overall challenges with teaching engineering within a high school context. Due to the time intensive nature of doing engineering design challenges, Victor declared, "The biggest challenge that I had is time-there is not enough time. I have more labs than I can really cover in a school year.... We barely finish on time." When asked how he overcame these challenges that arise from time constraints, he responded: "I don't think you can." He said, "You can deal with everything except time. Time is the major thing."

After thinking about the challenges he faced a bit more, Victor discussed how he sometimes struggled with various levels of student learning and how these various levels of learning affect group dynamics. Due to the scope and nature of some of his laboratory projects, he encouraged students to work in groups. He discussed how group work was reflective of how engineers work in a real-world setting and provided the following perspective about doing group projects: "In engineering, you always have to do group projects, I mean, it's just the way life is… nobody works by themselves." He felt that it was important that students gain exposure to working in groups because of the active involvement that is required from the process.

While conducting classroom observations, Victor showed me his student roster which contained each students' standardized test scores and used this to further corroborate that students in his classes were at different levels of achievement and the rate of learning depended on which students were in his class. He said that sometimes 25% of his students would be behind in their work, which definitely put a drag on the entire class. Victor felt that his other major challenge stemmed from the fact that, "the group suffers because somebody's not at that intellectual level…so, the big picture is to take that difference and narrow it down because when you narrow that difference down then everybody benefits from it." Unclear on what his definition of "narrowing down the difference," he was asked how he managed to do this. He replied, "It just has to work itself out," and explained that conflict was a natural human condition.

*Benefits*

Metaphorically speaking, Victor was a "tough shell to crack" when it came to determining what benefits he received from the NCETE PD workshops. Victor stated that, "If you're looking for maximum benefits, you're not going to get them because [of] where I am intellectually." As reflected in his words, Victor felt that the workshops made modest contributions to his knowledge base due to his past experience and years of practice teaching STEM subjects. For Victor, the information and practices conveyed in the workshops served more as a review session for him rather than a seminal learning experience.

"What I set out to do is to produce as many engineers as I can with what I have…this gives [my students] an option." As expressed in his statement, Victor felt that his high level of self-efficacy was instrumental in inspiring as many of his students as possible to pursue engineering careers. When asked how he sees students applying what they have learned in his class in their everyday lives, he reiterated his commitment "to introduce them to the engineering field…that's all I wanted to do." When asked if he believed the workshops helped to improve student understanding of engineering and engineering in general, he said, "they solidified it" and reaffirmed how the workshops reinforced his existing instructional practices.

After conducting the initial interviews, I had the opportunity to spend more time with Victor a few months later in which he invited me to visit and observe three of his engineering and technology-related classes. During my visit, he discussed how he encouraged his students to apply to 4-year university engineering programs. Although only a small percentage of his students chose to apply to these engineering programs, he expressed great delight and a feeling of accomplishment with knowing that he impacted the lives of these small few.

Overall, he felt that the major benefits to students regarding what he taught provided a career pathway for them to consider as they started thinking about life after high school. The workshops helped to reinforce this resolve. Even if his students did not choose engineering as a career, he felt that the knowledge, skills and abilities that were afforded through his classes, at least, showed his students the benefits of learning and applying science and math principles. This appreciation and greater sense of relevancy towards science and math education will be discussed in greater detail as we examine the narrative of Franklin.

## Case Study #4: Franklin

Prior to his participation in the NCETE workshops, Franklin worked as an electrical engineer who made a career change to become a high school teacher. Being that he had industrial experience as an engineer, it seemed fitting that he taught Career and Technical Education (CTE) classes such as robotics, digital electronics, computer programming, and physics. Franklin received a B.S. in electrical engineering and also had a credential in physics with an authorization in math.

### *Incorporation of PD Content*

When interviewed about what he gained from the NCETE PD experiences, Franklin explained, firstly, that he did not include the earthquake design challenge as part of his instructional materials. The main reason he stated for not doing this was because it did not fit into his curriculum. This was due to the fact that the school that Franklin taught at integrated Project Lead The Way® (PLTW), a not-for-profit organization that provides pre-engineering lesson units for middle and high school students. PLTW has established partnerships with public schools, higher education institutions and the private sector to increase the quantity and quality of engineers and engineering technologists graduating from our educational system. PLTW was designed to provide high school students the rigorous ground-level education they need to develop strong backgrounds in science and engineering. PLTW identifies what content to teach, what materials to use, and what supplies will be needed to support instructional delivery of STEM concepts. It also provides assessment instruments for grading student work and/or projects. Although he mentioned that his teaching practices were influenced by the workshops, as will be discussed later, there was no physical evidence to support how he used what he learned. Therefore, Franklin was the only teacher in this study whose data could not be triangulated. Aspects concerning the type of instruction he was delivering and why the triangulation of data was not achieved is discussed in the following paragraphs.

When observing one of his classes, Franklin performed a birthday counter project designed by PLTW with his students. The project involved teaching students how to design electronic circuits to display their birthdates using electronic components such as breadboards, logic gates, LED displays, resistors, and jumper wires. Students were responsible for hand sketching their circuits and used Boolean algebra to inform their circuit designs. After they completed their hand sketches, their work was converted into a computerized drawing. Students also used a spreadsheet program to help them plot the functioned needed to make their circuits work.

Franklin invited me to walk around the room so that I could gain a better understanding of what the project entailed and the procedures that the students needed to perform to complete the project. For instance, one of the students showed me his project binder/notebook that contained his personal work (i.e., sketches, diagrams, mathematical calculations, notes, etc.) plus the PLTW curriculum content that provided all the instructional materials needed to complete the project. As the student explained to me the procedures that he used to arrive at his design solution, Franklin walked around the classroom inspecting his students' work and their progress with the projects. Afterward, he gave a brief lecture on logic gates; he then assigned a classroom activity to give his students more background and practice so that they could complete their birthday counter projects. The birthday counter project was not related to any of the NCETE PD content. Hence, the triangulation of data could not be performed.

During the initial interview, Franklin explained that he was influenced by the theoretical framework and methodology of the workshops, which, he said, informed his pedagogical practices. Despite the fact that he could not produce any tangible examples of what he incorporated, he said that he "took away a lot of things" from the NCETE PD experiences. For instance, he explained that when he took the workshops, it was during his first year of teaching and what the workshops actually did for him was help him to look at his previous position as an engineer and view it within a teaching context "so it was a wonderful model to have for a reference point." He said, "I wanted to do what they were talking about and they gave me a good model that I could use as a reference point in my own practice." Franklin said that the main thing that he incorporated was "the philosophy of the workshops…the attempt to sort of integrate [science, technology, engineering, and math] at the same time and the fact that it is possible to do it and that you will get better results." He explained how he was endeavoring to infuse more science and math concepts into his career and technical education classes and by using what he learned in the workshops, enabled him to do integrate these fields of knowledge with greater effectiveness.

Due to his engineering training, educational background, and work experience, he expressed that he was "very much familiar and comfortable" with the science and math content conveyed in the spring phase of the workshops. Franklin articulated that he was already integrating physics and math into his classroom and laboratory projects prior to his participation in the workshops. For example, he talked about how he had students measuring the power of electrical motors so that they could better understand the relationship between energy, force, and torque. He also expressed how teaching his students to use science and math within an engineering context allowed his students to better recognize the relevancy of core academic subjects.

Franklin added that when his students used science and math "to inform their process, they would get better results." He punctuated his statement and said, "So you see how I took some of the threads of what they did in the workshops both in integrating the math and science content at an appropriate level for the activity—so that's one way it was readily integrated." He made it abundantly clear that after completing the workshops, he felt that he was better prepared to organize and structure a student-centered learning environment for his career and technical education classes that was both relevant and rigorous.

It was not clear as to why Franklin participated in the PD workshops. After inquiring about this issue with one of the PD coordinators, it was revealed that Franklin was identified and selected by the principal of the school he taught at (D. Maurizio, personal communication, October 15, 2009). The question also arose as to whether or not he knew he would be teaching the PLTW curriculum: At the time of the workshops the school he taught had not yet implemented the PLTW curriculum; They were merely considering whether or not they would implement it.

*Challenges*

Franklin's school was a regional magnet school that sought out and admitted students with talent in and a passion for math and science. Students admitted to Franklin's school had a strong academic record—that is, excellent grades (especially in math and science), above average test scores, excellent behavior record and recommendations. Those students who gained admission earned at least a 3.0 cumulative grade point average in middle school and A's or B's in their math and science classes. Their test scores in total math, reading and language were usually at the $70^{th}$ percentile and higher. Not only was the school centered on math and science education but it emphasized career and technical education.

For the above reasons, Franklin replied that he did not have many challenges with implementing what he learned in the workshops. Because it was a small learning community that adhered to an academy model centered on math and science, he noted how his school environment was more conducive to teaching engineering-based content.

Due to the fact that Franklin's school environment was based on an academy model, teachers from various disciplines such as math, science, English, history, and technology worked together in a collaborative manner to provide their students with an interdisciplinary learning experience. The ultimate goal of this small school setting was to integrate as many educational content standards as possible so that students could capitalize on areas where core academic subjects overlap. Furthermore, the intent of this smaller school model was to make learning more meaningful by linking it to life experiences and community, while providing adequate time and support for mastery of knowledge and skills. For these reasons Franklin expressed that he did not face major challenges with infusing engineering-based content within his technology-related courses because he "had an ideal situation for it."

Although he expressed having an ideal teaching environment, he did face some challenges. Due to STEM education's capacity to extend across a variety of academic subjects, Franklin said that he was challenged with establishing a better balance between theory and practice. In order for his students to get the full experience of STEM learning, Franklin said that he was challenged with providing content that allowed his students to oscillate between traditional and more progressive forms of learning such as those promoted by problem or project-based approaches to learning. In light of these issues, Franklin expressed that his biggest challenge was developing strategies for integrating hands-on activities to effectively engage his students in challenging and meaningful activity-based lessons. This topic, which was covered in the workshops as part of a presentation on project-based learning, included the methodology of active learning (hands-on), collaborative learning (teams), open-ended problem solving, critical thinking, and tangible outcome (physical product or artifact).

During his first year of teaching, Franklin said that he was trying to figure out ways to develop experiences and contexts that made his students willing to learn core academic subjects, such as science and math, as well as structuring information in a way that his students could internalize and embody. As he mentioned earlier, he was very much familiar and comfortable with the STEM content presented in the workshops, but he “had to work on the student experiences and to try to figure out how to make the student experiences something that was compelling…there is a lot to be said for delivery so that was where the challenge was.” Franklin felt that variables, such as learning contexts, emotions, and learning outcomes, were important factors in producing explicit adaptive behavior. He said that he was not given a blueprint for developing his robotics class but rather was told what the school wanted and he had to figure it out. When asked to explain how he overcame this challenge, he replied, “I just did it! I would say there aren’t very many challenges…I already knew the content.” In the final analysis, Franklin seemed to not be an ideal candidate for the NCETE workshops because his school had already been attempting to organize math and science learning within a career and technical education context. Rather than participating in the workshops, it is reasonable to think that all he required was a workshop that focused on how to create engineering design-related lesson plans.

Not long after completing the NCETE/CSULA PD workshops, Franklin's school made the decision to implement the PLTW curriculum. The STEM teachers at his school, including him, attended a PLTW summer teacher preparation program to help prepare them to deliver the PLTW curriculum content. The NCETE PD coordinators at CSULA were aware that the PLTW curriculum might be implemented and felt that the NCETE/CSULA PD would be a good primer for him (D. Maurizio, personal communication, October 15, 2009).

*Benefits*

Being that Franklin worked in an academic environment wherein professional exchange of ideas and reflection was highly encouraged, and, in fact, supported by his district, allowed him to critically examine facets of teaching that are directly related to student learning and achievement. When he was asked how he saw his students applying what they learned in his class in their everyday lives, he said that students showed an increased interest and motivation to learn more about engineering and technology, in addition to an increased motivation for learning science and math. Based on his earlier statements, Franklin mentioned how he was compelled to create a learning environment that engaged the interest of his students, provided a greater degree of relevance, and established specific goals for student learning. This information pertaining to increasing interest in STEM learning was also presented in the workshops as it related to using active learning strategies that teachers could use to foster hands-on approaches to learning, motivate students to want to learn, having students apply knowledge, and encouraging students to experiment.

Franklin brought up the idea of intrinsic and extrinsic rewards and explained how, after taking his robotics class, some of his students decided to participate in activities outside of the classroom and how "they had taken that knowledge and gone farther with it." He seemed proud of the fact that his students were intrinsically, as well as extrinsically motivated to transcend and go beyond what they learned in his class. He talked about how some of his students applied what they learned in his robotics class to compete in statewide robotics competitions which he sponsored. He also mentioned how some of his students took college-level manufacturing courses at a local community college to gain more expertise in building custom-made parts for their robotic designs. This, in effect, gave them the necessary knowledge, skills, and capabilities to become more competitive.

In reference to the benefits of incorporating what he learned in the workshops, he added,

> It also informs what I do in the club and so the students, you know, only participate if they are intrinsically motivated…they have that motivation and those that participated in clubs have put in a huge amount of work into expanding their skill set.

Referring to what he learned in the workshops, Franklin expressed how much he has "grown with it over the last 3 years…my understanding has expanded so has [my students]." Overall, Franklin thought that the workshops were "well focused" and was mostly impressed by how the workshops staff "integrated these three different fields…engineering, science, and math in a way that was approachable for teachers" who did not necessarily come in with a strong math or science background.

It is informative to note how Franklin, who was a strong advocate for project-based learning in his CTE classes, had not determined what value that engineering design challenges added to his physics course. Since he was responsible for getting through a certain amount of material to prepare his students for what they needed to know after they left high school, he did not focus on doing engineering design challenges in his physics class. He stated,

> I have a reputation for being the king of projects…I mentor the robotic club…I teach all these CTE classes…I am very much involved in technology [but] now I'm teaching physics and the first thing I did was get rid of projects that were being used by the previous teacher…I saw projects and I didn't see the rigor attached to those projects…I didn't know what the previous teacher was doing with the projects or how he used them in the classroom.... I didn't see how they were connected to the curriculum yet.

Franklin explained that doing projects "for the sake of doing projects" was not conducive to his teaching goals and responsibilities. He went on to say that he will probably incorporate some projects overtime but the reality was that his students needed a lot of math rigor and a reasonable introduction to physics versus giving them projects that were not aligned with educational content standards for physics. In other words, academically speaking, he felt that "it would actually be a distraction in the physics classroom to do a large number of projects."

He stated that he was not trying to teach them how to build things; rather, he was trying to teach them how to think about things that they build. Having earned a degree in engineering, Franklin felt that he knew the amount of rigor needed for his senior students to successfully transition into a 4-year college engineering program and felt compelled to "give them a nice stepping stone." Although he believed that engineering design challenges were great motivational tools that connected knowledge across many domains, they did not have a place, at that time, in his physics curriculum. During the time of the interview for this study, it was Franklin's first year of teaching physics. He stated that it was going to be a learning experience for him and until he determined the value of doing engineering design challenges in his physics course, he would exclude them from his physics instructional materials.

## Summary

This chapter examined notable findings that were considered in the context of the following three themes.

1. The information and practices that the teachers incorporated from the workshops into their teaching practices.

2. The challenges that each teacher faced as they attempted to incorporate what they learned in the workshops

3. The benefits of incorporating what they learned in the workshops into their teaching practices especially as it relates to student learning outcomes.

Four qualitative case studies were presented using information collected from the following resources: (a) teacher interviews, (b) classroom observations, and (c) examination of teacher documentations.

The teachers that participated in the NCETE PD workshops during the spring and summer of 2006 had different educational backgrounds and experiential knowledge. Two of these teachers (A and B) entered the workshops with no previous experience teaching engineering. Conversely, the other two teachers (C and D) entered the workshops with previous experience teaching engineering-related content.

For the two teachers with no previous experience (A and B), the workshops seemed to make a greater impact on their thinking in terms of integrating STEM concepts into their classroom and laboratory projects in comparison to Teachers C and D. These differences are examined in greater detail in the next chapter.

# CHAPTER V

# CONCLUSIONS, DISCUSSION, RECOMMENDATIONS, AND SUMMARY

## Conclusions

The purpose of this study was to address the following research question: What effects, in terms of curriculum changes, took place at the secondary school level as a result of the NCETE-sponsored PD and how did the PD teacher participants use what they learned in the NCETE PD workshops in terms of content and pedagogy?

Data to answer the above research questions were gathered through teacher interviews, teacher documents, and classroom observations. Review of these data revealed three major themes: (a) incorporation of PD content, (b) challenges with incorporating PD content, and (c) benefits of incorporating PD content. Conclusion related to the above research questions will be discussed in the following sections.

### *Conclusions Related to Theme #1: Incorporation of PD Content*

Each of the teachers incorporated different aspects of the information and practices they received through the workshops. Although there was little uniformity in what each of the teachers incorporated, convergent findings did emerge from the data. These findings were: (a) Connecting theory with practice, (b) coupling students with engineering design content, and (c) use of equipment.

*Connecting theory with practice.* An integral part of STEM education deals with educational theories and issues concerning how to teach students problem-solving and analytical skills, and how to apply this knowledge within real-world context. The findings of this study revealed that the NCETE PD workshops had an effect on helping the teachers to connect these educational theories with classroom practices. Educational theories that underpinned the NCETE PD framework advocated the idea that: (a) Students should be able to apply what they learn in novel situations and (b) schools should promote and facilitate a learning environment where teachers can encourage students to discover basic truths, laws, and assumptions on their own in order to improve the quality of learning (Dyer, Reed, & Berry, 2006). These theories were not only discussed during the workshops, they were put into practice by involving the teachers in learning activities that helped them to internalize what they learned. Additionally, the workshops provided a basis for how the teachers could better integrate these theories into their classroom practices through contextualized problem-solving activities and real-world applications. This way, students could become engaged in a manner that allowed them to see the relevance of their learning (Forrester, 1992).

It seemed that the teachers viewed themselves more as facilitators of learning rather than authoritarian figures. They expressed how their students learned better if they "coached" the students through problem-solving exercises rather than giving them the answers and asking them to memorize information to pass a test. These views were consistent with the statements of Rhem (1998), who asserted that when students learn by means of contextualized problem solving activities and real-world learning situations they: (a) achieve higher levels of comprehension, (b) develop more learning and knowledge-forming skills, and (c) develop more social skills. Moreover, the teachers felt that problem-based and real-world learning benefited students by promoting meaning making over merely collecting facts (Rhem).

In addition, the methodology provided the teachers with varying levels of knowledge, skills, and abilities related to the following facets of engineering education outlined by their statements: (a) engineering language, (b) function and justification for engineering education, (c) fundamentals of engineering study as it relates to the philosophy of technology education and technology education standards, (d) general education philosophy, (e) subject matter knowledge, (f) pedagogical approaches to teaching engineering, and (g) engineering education as a combination of various disciplines as it relates to STEM education. As noted in the statements provided by the teachers, it seemed significant to them that the workshops had a clear purpose: To infuse engineering design and problem solving into high school curricula. Specific examples of how this was achieved are the topic of the next section.

*Coupling students with engineering design content.* Based on the data collected in this study, it was concluded that the pedagogical content knowledge conveyed through the workshops helped each of the teachers couple their students with engineering design content. According to Shulman (1986), pedagogical content knowledge is one area of knowledge that is necessary for teachers to effectively deliver instruction. By using what they learned, the teachers became more informed as to how to design learning experiences that enhanced their students' knowledge and understanding of engineering design and problem solving.

In order to assist the teachers in coupling their students to engineering design content, the NCETE PD workshop staff employed an engineering design process model that was an iterative approach to engineering design and problem solving which consisted of the following steps: (a) Identify the need, (b) define the problem/specifications, (c) gather information, (d) develop and evaluate alternative solutions, (e) select the optimal solution, (f) refine and implement the solution, and (g) test and verify the solution. This seven-step process helped the teachers to facilitate the delivery of science, technology, engineering, and/or math concepts. These facets of engineering established a learning/ teaching foundation for each of the teachers to either infuse engineering into high school programs or to enhance and/or reinforce existing teaching practices.

Furthermore, despite their experiential knowledge, teaching area, or educational backgrounds, these workshop components helped to give the teachers a different perspective of how to deliver their subject matter content and/or how to enhance the quality of their instruction, especially if they had previous experience teaching STEM concepts like in the cases of Victor and Franklin. Moreover, each teacher incorporated various components of what they learned in a manner that was relevant to the subject matter content they were teaching.

Some of these components used to couple their students with engineering content included: (a) discussions involving the difference between engineering design and other design processes, (b) how to use the engineering design process to teach within a high school context using appropriate levels of math and science concepts, (c) understanding different types of engineering disciplines, (d) practical application of the earthquake design project within a classroom context, (e) team participation, and (f) problem-based learning strategies including active learning strategies, collaborative learning, open-ended problem solving, critical thinking and tangible outcomes. To support these efforts, resources such as engineering instructional materials, tools, and equipment are needed and will be the focus of the next section.

*Use of resources.* Based on the data collected in this study, it was concluded that the provision of resources, such as instructional materials, tools, and equipment, are needed to support the delivery of engineering design content and is critical to sustaining STEM PD efforts. As revealed in the findings of this study, two out of the four teachers used the equipment (in some form or another) that was provided to them by the workshop staff. Malia used all of the equipment given to her and performed the entire earthquake design challenge with her students. Victor only used the shaker table to develop his custom-designed soil hydration lab. Without being provided these resources, the teachers probably would not have been able to maintain the information and practices conveyed through the workshop. This is especially essential due to the high cost of equipment, such as data collection instruments (sensors), hand tools, machine tools, testing equipment, computers, software, and so forth, necessary to perform engineering design challenges. If these needs are not met, it makes the teaching of engineering design content economically unfeasible. This issue of will be revisited as it becomes relevant to the theme related to challenges with incorporating PD content (i.e., resources).

As previously noted, the purpose of the 2006 CSULA/NCETE spring and summer workshops was to train high school teachers how to infuse engineering design challenges into their STEM high school programs. The earthquake engineering design challenge was merely used as a teaching exemplar or model for the teachers to experience how the delivery of engineering design and problem solving would look like from a teaching/learning perspective. Although the ultimate goal was not to have the teachers integrate the earthquake design challenge into their instructional materials, the decision not to incorporate the project raised some key issues in relationship to the challenges involved with doing projects such as these in the classroom. These issues will be discussed later in the document as it becomes relevant to the conclusions concerning curricular alignment. Table 1 provides a visual representation of the NCETE/CSULA PD content that each teacher incorporated into her/his instructional materials.

### *Conclusions Related to Theme #2: Challenges with Implementing PD Content*

Another overarching theme that emerged from this study concerned the challenges with infusing engineering design and problem solving within a high school

Table 1

*PD Content Incorporated into Teachers' Classroom Instruction*

| Content | Malia | Brian | Victor | Franklin |
|---|---|---|---|---|
| Earthquake engineering design challenge | ✓ | | | |
| Coupling students with engineering design content | ✓ | | ✓ | ✓ |
| Use of all or some equipment | ✓ | | ✓ | |
| Theoretical framework and methodology | ✓ | ✓ | ✓ | ✓ |

context. Challenges with implementing the NCETE PD content were as follows: (a) Group participation, (b) time and standards-based pressures, (c) availability of authentic engineering design challenges, (d) creation of engineering design content, (e) resources, (f) instructional delivery, and (g) curricular alignment.

*Group participation.* As noted in the findings of this study, two of the four teachers mentioned that they sometimes struggled with getting students to contribute an equal amount of work when performing group projects. Malia explained how she sometimes found it difficult to discern which students were contributing and which students were not. Group work is time consuming and may involve covering fewer topics than a lecture-based approach but research reveals that group work helps students to develop an enhanced ability to solve problems and indicate better grasp of the material (Cooper, 1990). Despite these benefits, teachers contend with a variety of issues when students are engaged in group work such as those previously discussed by Malia, such as creating projects that fit the students' skills and abilities, and assigning group tasks that allow for an equal distribution of work or input.

*Cooperative learning.* Victor also mentioned that team participation was a challenge. He talked about the importance of teamwork and how it was important for students to develop team building skills that are reflective of the real-world of work. To better assess the work of each of her students, Malia explained how she assigned each of the students in the group an individual task to ensure that each student was making an equal contribution. Therefore, it was concluded that when doing group projects, it is important that teachers develop a system that assesses the contributions of each member of the group rather than grading the group as a whole (Davis, 1993). This way, students who do not contribute to the group do not unfairly reap the rewards of those who in fact made contributions. These issues resonate with literature pertaining to cooperative learning. Johnson and Johnson (1994) noted that effective cooperative relationships, whether it be peer tutoring, partner learning, peer mediation, families, adult work groups, as well as student work groups, have five basic elements. They include: (a) Clearly perceived positive interdependence, (b) considerable face-to-face interaction, (c) clearly perceived individual accountability and personal responsibility to achieve the group's goals, (d) frequent use of the relevant interpersonal and small-group skills, and (e) frequent and regular group processing of current functioning to improve the group's future effectiveness. Additionally, for a cooperative learning environment to exist there needs to be a reward system for students who accomplish a common goal. If only one or a few students in the group contribute work to achieve the desired goal then a cooperative group does not exist. As stated above, to gain a cooperative relationship, each student needs to be held accountable and oversight must be provided by the teacher (Johnson & Johnson).

*Time and standard-based pressures.* Based on the finding of this study it was concluded that available classroom time was a major impediment for doing engineering design challenges in the classroom. Although each of the teachers felt that students should be able to apply what they learn in novel situations, standards-based educational reform efforts, such as NCLB, which is based on the belief that setting high standards and establishing measurable goals can improve individual outcomes in education, have increased the amount of pressure that educators face to prepare their students for testing and meeting annual yearly progress reports. This is due to a shift that focuses less on minimum competency to high proficiency standards for students (Dyer et al., 2006). With these shifts, a greater level of accountability limited the degree to which the teachers in this study were able to incorporate what they learned in the workshop into their classroom instruction. Dyer and colleagues noted that these challenges force teachers to concentrate less on student outcomes rather than school inputs thus reducing the amount of student-centered, contextualized learning in the classroom.

As revealed by the statements of Malia, Brian, and Franklin (in reference to his physics class only), the ability to do more engineering design challenges was impeded by academic pacing requirements induced by standards-based pressures. As it concerned Malia, Brian, and Franklin, this was problematic in the sense that they needed to cover a specific set of concepts in a certain amount of time. It was noted by these teachers that the delivery of engineering design content in a traditional classroom such as science requires a lot of additional planning, implementation, and assessment.

Because of its interdisciplinary nature, the delivery of engineering education requires teachers to cover a wide range of academic concepts and principles as well as to make connections between these various disciplines while providing relevant reference frames that allow students to see the results of their learning. From this, it was concluded that teachers of core academic subjects are more limited in terms of their capacity to teach engineering design processes due to requirements that force them to "move through the materials." The emphasis on standards is a major reason why teachers such as Malia, Brian, and Franklin expressed they could not invest too much time doing engineering design challenges for each topic area.

Furthermore, as Dyer and colleagues (2006) noted, standards-based reform efforts, such as NCLB, have increased the amount of pressure that educators, such as Malia and Brian, face due to a shift that focuses less on active learning strategies and more on “teaching to the test.” With these shifts, especially in the cases of Malia, Brian, and Franklin (in reference to his physics class only), they felt that a greater level of accountability had limited the degree to which they could incorporate what they learned in the workshop into their instructional practices. Despite these challenges, it was also concluded that these teachers nonetheless persisted in finding ways to weave-in the theoretical framework and methodology of the workshop to enhance the quality of their standards-based instruction.

*Availability of authentic engineering design challenges.* Based on the findings of this study, it was recognized by Malia and Brian that there was a lack of authentic engineering design challenges available for STEM teachers to integrate into their instructional materials. The term “authentic engineering design challenges” denotes the practice of using predictive scientific and mathematical analysis prior to the construction of a physical product or artifact. Specifically, Malia noted how many of the so-called engineering design challenges that are widely available do not use predictive analysis to arrive at a design solution. Instead, many of the projects that she reviewed approach design using a trial and error approach, which is more reflective of the technological design process. Both Malia and Brian were mostly concerned with identifying engineering design challenges that were standards-based. Circling back to our earlier discussion concerning appropriate levels of math, Custer and colleagues (2007) asserted that the integration of appropriate levels of math into engineering and technology-related instructional materials is fundamental to addressing the challenges of unifying existing curricula across the STEM disciplines.

As indicated by Malia's statements, the shift from a curriculum-centered approach to a project-based approach to learning that identifies and conveys a specific set of science and math concepts presents a major challenge for teachers who want to infuse engineering education into their core academic content. Given this perspective, the identification, development, and dissemination of high quality, standards-based materials is indispensable to classroom instruction and professional development for K-12 engineering education (Custer et al., 2007).

Because of these findings, it appeared that standards-based engineering design challenges should facilitate the engagement of students in problem solving to produce an end process, product, or artifact, thus enabling their construction of new and deeper understandings of their core academic subjects, especially as it concerns science and math (Davis, Ginns, & McRobbie, 2002). The creation of engineering design content by teachers who participate in STEM PD may proffer solutions to this need and will be discussed in the following section.

*Creation of engineering design content.* In relation to the concerns raised regarding the availability of authentic engineering design challenges, two of the teachers in this study (A and B) desired to have more training or assistance with creating their own instructional materials. They expressed how they did not have a lot of time to do engineering design challenges because of the amount of material they needed to cover within a school year. Brian explicitly stated that engineering design challenges would not work in his chemistry class unless they were designed so that students could complete the challenges in twenty to thirty minutes. He stated that the real challenge was developing engineering design content that could be completed by students in less than one class period. Malia echoed the same sentiments.

Due to these concerns, it seemed that the creation of engineering design content would be more acceptable to teachers if they were involved in the process of creating their own instructional materials. The challenge therein lied within the creation of brief design-based activities that can be completed in a short amount of time or in a few class periods. These brief design-based activities could ultimately cluster into a final capstone project in which students could apply what they learn over the year to complete a large-scale project at the end of the year. To do this requires having the necessary resources to help STEM teachers facilitate the learning of engineering design concepts and principles.

## Acquisition of Resources

Due to school budget limitations, Malia and Brian had concerns with acquiring the necessary resources for conducting hands-on projects in their classrooms. For instance, Malia explained that she regularly had to use her own money to buy materials and supplies needed for students to create artifacts that demonstrated their knowledge and understanding of academic concepts. The good thing, she said, was that she could write it off on her taxes. Brian also expressed a need for more resources to facilitate learning of chemistry concepts through hands-on projects. Based on this information, it was concluded that budgetary issues prevent teachers from acquiring the needed resources required to perform engineering design challenges (in the case of Malia) and project-based learning activities (in the case of Brian). This relates to the previous discussion that concerned providing teachers with the necessary instructional materials, tools, and equipment needed to sustain PD efforts.  These issues must also be considered in light of having teachers create and deliver their own engineering instructional content.

*Quality of instructional materials available for teaching STEM concepts.* As noted in their interview statements, Brian and Franklin expressed their concerns with the lack of quality of instructional materials related to delivering STEM concepts and principles. This concern related to the design of meaningful learning experiences that helped engage student interests in science and math and, in turn, helped students to see the relevance of their learning. According to Forrester (1992), the quality of teachers is not the root cause of educational deficiencies but the quality of instruction rather stems from the incompatibility of subject material that is being delivered. Moreover, students lack a relevant reference frame for applying what they learn to real-world situations. Without engaging student experiences that link classroom learning to real-world experiences that were relevant and meaningful, Brian and Franklin felt that they would lose the interest of their students. Because we live in a world that is technologically driven, public demands for greater relevance will amplify the need for additional science and math courses that infuse engineering design and problem solving into science and math instruction. This way, students can become engaged in a manner that allows them to see the relevance of their learning (Forrester).

In regards to the NCETE PD workshops, Brian and Franklin expressed how the PD content helped to give them a different perspective of how to teach. After the workshop, they were concerned with “doing it right” so that students would be able to learn the material faster and retain it longer. Taking these viewpoints into consideration reinforces the importance of intersecting subject matter knowledge, content, and pedagogy, as discussed by Ball and colleagues (2007) and Shulman (1987). Intersecting subject matter knowledge, content, and pedagogy, otherwise known as pedagogical content knowledge, allows teachers to deliver instruction flexibly to help a diverse body of students construct knowledge in a manner that connects to real-world situations.

Therefore, it seemed that for STEM PD to be effective, the enhancement of teachers’ pedagogical content knowledge, especially as it concerns a teacher’s ability to deeply understand subject matter content, as well as having the ability to successfully deliver instruction in a way that increases student interest in STEM concepts and principles, is conducive to the infusion of engineering design into high school curricula.

In the following paragraphs, challenges associated with infusing engineering design within core academics areas, such as science and math, will be discussed, first, in the context of the earthquake design challenge and, second, as it pertains to doing engineering design challenges in general. The following information may prove useful to the design of future STEM PD programs that prepare teachers to deliver instruction and address the needs of a diverse body of students.

*Curricular Alignment*

Although the main goal of the NCETE workshops was not to infuse the earthquake engineering design challenge into high school curricula, it is informative to examine the attributes of a pre-designed engineering design challenge that potentially determine its likelihood of being integrated into a high school program. Curricular alignment in terms of teaching chemistry, robotics, digital electronics, and physics seems to be the main reason why two out of the four teachers (B and D) did not incorporate the earthquake engineering design challenges into their instructional materials. Victor did not incorporate it because it was simply a project that he was not interested in doing (hence, the creation of his soil hydration lab). Although they seemed to have been impressed with the earthquake engineering design challenge, Brian (who taught chemistry) and Franklin (who taught robotics, electronics, and physics) both felt that it was not conducive to their respective teaching needs. The earthquake engineering design challenge was designed to be integrated into a physics and/or earth science classroom. This seemed to play a major role as it related to the each of the teachers' willingness to incorporate it into their classroom instruction and should be a major consideration for other teachers who are looking to infuse engineering design challenges into their science and math instruction.

Based on the feedback from the teachers in this study, it seemed that the likelihood for integrating an engineering design challenge into high school programs will increase if it: (a) addresses a set of specific educational content standards, (b) includes goals for learning and a proper means of assessing those goals, (c) engages interest and is relevant to students, (d) connects learning to real-world situations, and (e) satisfies the time constraints that teachers are allotted to deliver instruction on a certain set or number of topics. Note that most of the above items listed are linked to curricular alignment. Burghardt and Hacker (2007) asserted that engineering and technology education (ETE) needs to align with core math and science learning objectives. This belief is rooted in the idea that complex topics inherent within ETE require students to have an understanding of how to apply math and science concepts. These same concerns were raised by the teachers in this study as it relates to STEM alignment with educational content standards.

These assertions were further corroborated by Wilson (2007a) who noted,

> The curricula for successful PD should be aligned with the curricula and standards that teachers are working to implement, and a set of national standards helps to articulate the goals of the discipline for both teachers and those who prepare teachers. (p. 1)

In addition to the above, it was surmised that if STEM education PD is to be effective, the identification and development of an established set of content standards is conducive to a strong curriculum that is not only based on a set of abstract principles and techniques. According to Custer and colleagues (2007), there is a lack of standards-based curriculum materials for engineering and technology education PD. In the case of teaching a core academic subject, such as chemistry or physics, it appeared that the infusion of engineering design into high school curricula is very challenging due to the emphasis placed on educational content standards. Table 2 provides a visual representation of the challenges that each teacher in this study faced in terms of implementing the NCETE/CSULA PD content into her/his current instructional program.

Table 2

*Challenges with Implementing PD Content*

| Content | Malia | Brian | Victor | Franklin |
|---|---|---|---|---|
| Assessment | ✓ | | | |
| Team participation | ✓ | | ✓ | |
| Time and standards-based pressures | ✓ | ✓ | ✓ | |
| Availability of authentic E.D.C.'s | ✓ | ✓ | | |
| Integrating appropriate levels of math | ✓ | | | ✓ |
| Creation of engineering design content | ✓ | ✓ | | |
| Resources | ✓ | ✓ | | |
| Quality of Instructional delivery | | ✓ | | ✓ |
| Curricular alignment | ✓ | ✓ | | ✓ |

*Conclusions Related to Theme # 3: Benefits of Incorporating PD content*

The last overarching theme of this study concerns the benefits of incorporating PD content into high school curricula. These thematic findings were viewed in light of both teacher and student benefits. Based on each of the teachers' perceptions, they felt that the NCETE/CSULA PD benefitted their classroom practices because it: (a) facilitated teaching, (b) increased student motivation for STEM learning, (c) kept students engaged, (d) increased student appreciation for science and math, (e) improved student thinking and problem-solving skills, and (f) improved student learning.

*Facilitated teaching.* Based on the data collected in this study, it was inferred that the workshops facilitated each of the teachers' instructional delivery in some form or another. For instance, it was easier for some teachers to implement smaller bits of what they learned from the workshop, while others, such as Malia, made a major overhaul to her instructional materials based on the information and practices that she learned during the workshops. Even Brian, who was the only teacher in this study, who stated that he did not have time to do engineering design challenges in his chemistry class, expressed how using what he learned in the workshops helped to make his teaching easier. It was more feasible for Brian to implement the pedagogical approaches that he learned in the workshop, such as group work, student-centered learning, and other active learning strategies than doing actual engineering design challenges. He stated that this form of teaching promoted critical thinking and helped his students develop analytic skills to solve problems.

In some cases, the teachers used what they learned to improve what they were already doing in terms of STEM education. This seemed to be the case with the two teachers (C and D) who entered the workshop with previous STEM teaching experience. A good example of this was how Victor, the veteran STEM teacher of the group, expressed how the engineering design process model helped to “solidify” his teaching practices. As discussed earlier, he talked about how he took advantage of the time he spent in the workshop to develop a soil hydration lab, which incorporated some of the equipment that was given to him during the workshop.

For all of the teachers except Victor, it was concluded that the seven-step engineering design process model presented in the workshop was beneficial in providing a teaching model that allowed them to couple their students to engineering design content. Overall, it was concluded that the workshops were beneficial in terms of getting each of the teachers to re-evaluate the way that they taught. In addition to teacher benefits, the teachers also discussed the benefits in relationship to student learning outcomes.

*Increased student motivation for STEM learning.* In regards to student learning outcomes, the teachers mentioned that there was a heightened sense of motivation from some of their students to go beyond what was learned in each of their classes and pursue outside STEM learning opportunities, especially as it concerned engineering design. These opportunities came in the form of summer workshops, afterschool activities/ programs, or matriculating into a college program of study. Specifically, Franklin stated that motivation to engage in a particular type of behavior, such as participating in an extracurricular robotics club, is most prevalent when the source of motivation is manifested from within the individual rather than outside influences. In relation to the connection between motivation and learning, Franklin's statement was corroborated by Bruner (1966) who asserted,

> The will to learn is an intrinsic motive, one that finds both its source and its reward in its own exercise. The will to learn becomes a "problem" only under specialized circumstances like those of a school, where a curriculum is set, students are confined, and a path fixed. The problems exist not so much in learning itself, but in the fact that what the school imposes often fails to enlist the natural energies that sustain spontaneous learning.... (p. 127)

The aforementioned statement by Bruner asserts that a school's learning environment can greatly sway students' level of motivation towards learning and does so in a manner that is multifaceted. For example, the following five strategies for keeping students motivated were extrapolated from the statements of the teachers in this study, and are also inherent in the types of activities promoted by STEM integration:

1. Connect teaching to the interests of students.
2. Help students to develop meaning or understanding.
3. Provide instruction that lowers student's uncertainty towards learning a particular concept.
4. Provide opportunities for students to solve a problem or make informed decisions.
5. Provide opportunities for students to figure something out.

Keller (1983) proposed a similar instructional design model for increasing motivation among students that suggested the following four components of motivation: (a) arouse student interest, (b) make learning relevant, (c) develop expectations for success, and (d) create a sense of satisfaction by providing intrinsic and extrinsic rewards.

*Kept students engaged.* Based on the data collected in this study, it was inferred that the information and practices conveyed through the workshops helped each of the teachers in one form or another implement new types of learning experiences and/or enhance existing learning experiences that kept students motivated and engaged in the process of learning science and math concepts. Malia, Brian, and Franklin mentioned how they were concerned with creating a learning environment that engaged the interest of their students, as well as how they wanted to establish specific goals for student learning. Moreover, it seemed like the ability of engineering and technology education to actively engage students in the process of their own learning demonstrated its potential as a curriculum integrator which, in turn, helped to contextualize learning and motivate students to connect what they learn across a variety of core academic subjects.

*Increased student appreciation for science and math.* It appeared that the PD workshops were instrumental in helping each of the teachers to enhance their instructional materials. Based on the teachers' perceptions, this, in turn, gave students a greater appreciation for what they learned in their science and math classes. Moreover, the teachers appreciated how the workshops imparted a model for teaching that provided greater academic relevance for their students while maintaining the necessary amounts of academic rigor. The idea of a curriculum that adds academic rigor to an extremely relevant set of knowledge was shown to be beneficial to the teachers in this study. As noted by their interview statements, the teachers mentioned when science and math learning is connected to real-world applications, many students seem to develop a greater appreciation for science and math education.

*Improved student thinking and problem-solving skills.* Based on the data collected in this study, it was perceived by the teachers in this study that the STEM PD content had the potential to improve students' critical thinking and problem solving skills. This was apparent in the statements of the teachers as they discussed the importance of getting their students to think deeply and analyze rather than memorize. This form of learning required their students to integrate their prior knowledge with new knowledge as they learned to think deeply about problem-solving scenarios. This construct is especially relevant as problem solving is an integral part of science and math education.

By pointing out the naturalness of problem solving, students were provided with a basic understanding of the variety of potential uses for what they learned in their core academic classes. Overall, the teachers in this study felt that these real-world connections prepared their students to make career decisions, develop teamwork skills, decision making skills, and utilize creative thinking processes as they engaged in problem solving activities. Since the backbone of engineering is science and math, it would behoove STEM educators and stakeholders to examine literature pertaining to science and mathematics PD as it provides models for teaching and learning that can be directly applied to the integration of STEM concepts and principles (Custer et al., 2007).

Improved Student Learning

Based on the data collected in this study, it was concluded that the NCETE/ CSULA PD content helped teachers without strong engineering backgrounds to design learning experiences that improved students' understanding of science and math concepts. It was noted specifically by Malia that student learning improved over the course of the year due to what she implemented from the NCETE PD workshop. Brian also noted how the PD content that he implemented helped his students to learn the material faster and retain the information longer. He attributed this to providing opportunities for students to construct knowledge and understanding on their own through active learning strategies, such as hands-on projects. Both of the teachers expressed how the workshops helped them to re-evaluate the way that they taught and that it "opened their eyes" in terms of getting their students to think versus memorize. Table 3 provides a visual representation of the benefits of implementing the NCETE/CSULA PD content as expressed by each teacher.

Table 3

*Benefit of Implementing PD Content*

| Content | Malia | Brian | Victor | Franklin |
|---|---|---|---|---|
| Made science more fun | ✓ | ✓ | | |
| Improved student thinking (Analyze data deeply) | ✓ | ✓ | | |
| Improved student learning | ✓ | ✓ | | |
| Increased student motivation to do more engineering | ✓ | | ✓ | ✓ |
| Facilitated Teaching | ✓ | ✓ | ✓ | ✓ |
| Kept students engaged | ✓ | ✓ | | ✓ |
| Saved time | | ✓ | | |
| Greater student appreciation for science and/or math | ✓ | ✓ | | ✓ |

## Discussion of Findings Relative to CSULA PD Goals

The purpose of this section is to discuss the findings of this study relative to the desired outcomes as stated by the CSULA PD goals (E. Lipton, personal communication, June, 8, 2008). NCETE learning outcomes that were associated with the CSULA PD goals were as follows: (a) develop teachers' instructional decision making to focus on the analytical nature of design and problem solving needed to deliver technological and engineering concepts; (b) facilitate teacher-initiated change in program design, curricular choices, programmatic and student assessment, and other areas that will impact learning related to STEM (science, technology, engineering, and math); (c) develop teachers' capabilities as learners so that they assume leadership for their PD activities, including recruiting and mentoring their colleagues; (d) create a pool of highly skilled cooperating teachers who will welcome all teachers into their classrooms and mentor the next generation of STEM teachers to effectively teach students of diverse backgrounds; (e) develop engineering analysis and design skills in STEM teachers, including strengthening their mathematics and science knowledge and skills; and (f) develop curriculum integration and collaboration skills in practicing technology teachers so that they can effectively collaborate with science and mathematics teachers. A discussion concerning the effects that the PD had on teacher classroom practices relative to the aforementioned PD goals is the focus of the next section.

### *PD Effects on the Delivery of Engineering and Technological Concepts*

As shown in this study, the goal of developing teachers' instructional decision making to focus on the analytical nature of design and problem solving needed to deliver technological and engineering concepts had the greatest effect on Malia. Conversely, Brian acknowledged that he did not focus on engineering design per se, but incorporated the methodology of doing design challenges that facilitated the teaching of chemistry concepts. Since Victor's and Franklin's area of teaching already focused on the analytical nature of design and problem solving, the workshop made modest contributions to their development in relationship to delivering technological and engineering concepts.

*PD Effect on teacher change.* The facilitation of teacher initiated change in program design, curricular choices, programmatic and student assessment, and other areas that impacted learning related to technology and engineering was shown to have the greatest effect on Malia. Although Brian's instructional practices did not reflect learning related to engineering and technology specifically, it was shown that he did initiate changes relative to his instructional delivery especially as it pertained to curricular choices such as shifting from a traditional lecture/lab teaching environment to the inclusion of active learning approaches to teaching chemistry. Since Victor and Franklin had already been engaged in teaching engineering design concepts to their students, the facilitation of teacher initiated change in program design, curricular choices, programmatic and student assessment, and other areas that impacted learning related to engineering and technology were minimal except in relation to the development of Victor's soil hydration lab. For Franklin, most of the change in program design, curricular choices, programmatic and student assessment, plus other areas that impacted learning related to technology and engineering was not a result of the workshops. Instead, these changes were the result of the predesigned, pre-engineering curriculum package that his school adopted to deliver STEM instruction.

In regards to the workshop's effect on learning, Franklin stated that the workshops inspired him in terms of how he could more effectively integrate science, technology, engineering, and math concepts in a manner that better engaged the interests of his students. In terms of curricular choices, he mentioned how the workshops helped him to include appropriate levels of science and math. Franklin said that when his students used science and math "to inform their process they would get better results," meaning that students who applied science and math versus a trial and error approach to design had greater success with their design projects.

*PD Effects on teacher leadership, mentorship, curriculum integration, and collaboration.* The scope of this study was limited to the effect that the PD had on individual teacher classroom practices. Therefore, the effect that the PD workshops had on the teachers' capabilities as learners so that they assume leadership for their PD activities, including recruiting, mentoring, and collaborating with their colleagues, was irrelevant to this study. Since each of the teachers in this study already had backgrounds in math and/or science (Note: Franklin had an industrial education background as well), the effect that the workshop had on the development of curriculum integration and collaboration skills in practicing technology teachers so that they could effectively collaborate with science and mathematics teachers was also immaterial.

*PD effects on enhancing math and science teaching skills.* Although it was not the scope of this study to determine the effects of PD on enhancing math and science skills, each of the teachers in this study expressed that they were comfortable with the math and science presented in the workshops (because of their academic teaching backgrounds). According to their interview statements, the math and science portions were more of a review for them. Therefore evidence to support an enhancement of math and science teaching skills was not relevant in this study. Although it was not conclusive as to how much the workshop helped to strengthen their science and math knowledge and skills, each of the teachers expressed an appreciation for how the workshop demonstrated how STEM concepts and principles could be integrated into each of their areas if teaching.

*Discussion of Findings Relative to Spring and Summer PD Goals*

In addition to the aforementioned goals, the workshops were successful at meeting the following spring workshop goals (E. Lipton, personal communication, September 9, 2008): (a) setting the scene, (b) creating a cohort, (c) describing the engineering profession, (d) diagnosing abilities, (e) providing foundational instruction, and (f) establishing a methodology (engineering design). The summer workshop goals were also met as follows: (a) Introducing an earthquake engineering design challenge, (b) practicing how to solve design problems, (c) learning how to infuse engineering design into high school programs, (d) studying curriculum models, and (e) learning how to assess engineering design. Based on certain limitations of the PD workshops, recommendations will be discussed in the following sections as they are relative to the improvement of future PD efforts.

## Recommendations for STEM PD Developers

Based on certain strengths and limitations of the NCETE PD workshops, recommendations pertinent to these issues will be made. These recommendations can be used by STEM PD designers to inform the organization and structure of future PD efforts.

*Recommendation #1: Provide an Introduction to the Fields of Technology Education and Engineering Education*

In this study, it was noted that for teachers to embody and gain perspective for

STEM education, it is important to provide information that gives teachers a better understanding of the fields of technology and engineering education. This background information could include a brief historical and philosophical overview as well as current issues and trends in the fields. Oftentimes, technology education is confused as educational technology or working with computers. People are more familiar with the purposes of learning science and math but do not understand the rationale for engineering and technology education.

### *Recommendation #2: Develop STEM PD Workshops Based on Sound Theoretical Framework and Methodology*

In this study, it was observed that the theoretical framework and methodology of the workshop had a lasting effect on teaching practices. As evidenced from participants, the NCETE STEM PD Workshops coordinators at CSULA were consistent with these efforts in that they provided a well-articulated theoretical framework that provided a rationale for teaching engineering as well as a methodology for teaching that served as a launching pad for introducing a greater degree of relevancy to core academic subjects. Therefore, it is recommended that PD should continue to include a sound theoretical framework and methodology to give participants a solid foundation for infusing engineering based content into their instructional materials. As stated earlier, without a strong rationale and/or justification for doing engineering in the classroom, teachers and schools may be less likely to buy-in to STEM PD efforts.

*Recommendation #3: Develop STEM PD Workshops That Include an Exemplar Engineering Design Challenge*

It was noted that although only one of the teachers in this study (Malia) incorporated the earthquake engineering design challenge as part of her instructional material, there was a consensus among the teachers that the earthquake engineering design project served as an exemplar teaching model that demonstrated that the integration of science, technology, engineering, and math concepts was practicable. Therefore, it is recommended that STEM PD should continue to include an exemplar engineering design teaching model so that teacher participants have a model for how to implement and perform engineering within the classroom. Specific examples of how teachers implement and manage engineering design challenges in the class will be helpful in assisting teachers, especially those new to the field.

*Recommendation #4: STEM PD Workshops Should Provide Training on Assessing and Evaluating Teamwork*

It was shown that some of the teachers in this study expressed a concern with student participation as it concerns team projects. One of the major concerns was discerning which students were contributing to the team and which ones were not. When doing group projects, it is important that teachers develop a system that assesses the contributions of each member of the group rather than grading the group as a whole (Davis, 1993). This way, students who do not contribute to the group do not unfairly reap the rewards of those who in fact made contributions otherwise known as social loafing.

Group work is time consuming and may involve covering less topics but research reveals that group work helps students to develop an enhanced ability to solve problems and indicate better grasp of the material (Cooper, 1990). Despite these benefits, teachers contend with a variety of issues when students are engaged in group work such as those previously discussed by Malia, such as creating projects that fit the students' skills and abilities, and assigning group tasks that allow for an equal distribution of work or input. Therefore, it is recommended that STEM professional developers continue to include training on how to manage group dynamics as it concerns team projects because working within a team environment is reflective of real-world practices and is a skill that transcends engineering disciplines. Moreover, "The engineering profession recognizes that engineers need to work in teams, communicate with multiple audiences, and immerse themselves in public policy debates and will need to do so more effectively in the future" (National Academy of Engineering [NAE], 2004, p. 43).

### *Recommendation #5: Developers of STEM PD Should Consider How Pressures Associated with Standards-Based Educational Reform Efforts May Impact the Delivery of Engineering Design Content*

It was noted that issues concerning the amount of time typically needed to perform engineering design challenges was impacted by standards-based educational reform pressures exerted by school districts. Although the teachers in this study expressed a desire to incorporate more of what they learned in the workshops, these standards-based pressures impeded two of the teachers in this study (A and B) from implementing more of what they learned from the NCETE workshops. They said that they did not have enough time to infuse engineering design challenges for every topic that they needed to cover. Garet, Porter, Desimone, Birman, and Yoon (2001) asserted that PD should be a "coherent part of a wider set of opportunities for teacher learning and development" (p. 927). A sound approach to PD links teachers' goals and activities, is consistent with state and district standards and assessment, and promotes communication among teachers engaged in similar reform efforts (Garet et al.). Therefore, it is recommended that designers of STEM PD continue to consider that standards-based pressures may challenge teachers' ability to include engineering design challenges into many of the topics that they are required to teach in their classes.

### *Recommendation #6: Train Teachers How to Create Their Own Engineering Design Challenges*

It was made aware that two of the teachers (A and B) in this study desired more training on how to create their own engineering design challenges that can be used to incorporate a variety of content into the teaching and learning environment. In this study, the effect that the workshop had on the teacher's thinking inspired them to develop their own standards-based design challenges that aligned with their respective areas of teaching, namely, physics (Malia) and chemistry (Brian). As a corollary, Wilson (2007b) stated that professional development needs to employ teacher knowledge as an integral component of the PD design, as well as, bridge the gap between research and practice. As mentioned previously, Malia and Brian expressed that they did not have a lot of time to spend on one project but required smaller, less time intensive projects so that they could cover the instructional materials needed to prepare their students for standardized testing. Although Malia and Brian took the initiative to develop their own engineering design challenges based on the information and practices they learned in the workshops, they still expressed a need for more training in this area. Therefore, it is recommended that designers of STEM PD provide training to teachers on how to develop their own standards-based, engineering design challenges. Furthermore, this training should provide teachers with information on how to develop short term (e.g., a few days) to long term (e.g., 3 weeks or more) design challenges.

*Recommendation # 7: Train Teachers How to Incorporate Grade-Level Appropriate Science and Math Concepts*

It was shown that in addition to the concerns with learning how to create their own content appropriate design challenges, teachers were also concerned with the grade level appropriateness of these challenges. Specifically, Malia and Franklin were concerned about incorporating appropriate grade levels of math so that students could perform their analysis prior to the construction of a physical product or artifact. Due to the procedural nature of math and science instruction, the ability to apply math and science concepts oftentimes entails a higher level of understanding than is presented in mathematics and/or science classes (Burghardt & Hacker, 2007). Since science and math are both integral components of STEM education, research concerning math and science education PD provides a solid basis for the design, organization, and delivery of engineering and technology PD (Custer et al., 2007). Therefore, it is recommended that designers of STEM PD include training for teachers on how to integrate appropriate levels of science and math into engineering design challenges. It is recommended that designers review science and math content standards that provide grade appropriate learning experiences.

In addition, designers may consider developing “help sheets” that provides mathematical shortcuts for students to use.  For example, a preprogrammed spreadsheet could be developed which contain formulas that allow students to input data and receive an output/answer without having to perform complex mathematical operations.

*Recommendation # 8: Workshops Should Involve Experienced Teachers and School Administrators*

For STEM PD to translate into teaching practices, an understanding of what transpires in a high school classroom is indispensable to effective teacher training. Experienced teachers have a wealth of knowledge concerning how students learn, know how to use effective teaching strategies, and have knowledge about school culture and student expectations that are very valuable to PD (Wilson, 2007b). Therefore, it is recommended that experienced STEM high school teachers be included in the preparation of teachers who will teach STEM concepts and principles. Using the expertise provided by someone who knows firsthand the challenges that teachers face and how to deal with classroom management issues will help teachers to better contextualize how STEM learning will take place in a high school setting.  In addition, the inclusion of school administrators as part of PD efforts would provide increased support and a better understanding of teacher needs in regards to STEM learning.

*Recommendation #9:  Design PD Workshops to Match Various Levels of Teacher Learning*

It was shown that just as students enter a classroom with various levels of achievement, teachers can also come to the classroom with varying knowledge levels, especially in areas related to math and science concepts. For teachers to deliver engineering design concepts, they must be well grounded in science and math concepts. Teachers who are deficient in these areas create a drag on the rest of the teachers because they require greater amounts of assistance thus slowing down the progress of the PD effort. This issue is very problematic in the sense that it creates a sense of anxiety, frustration, and impatience among the more advanced teachers (Brian, personal communication, September 17, 2008). Therefore it is recommended that designers of STEM PD screen or pretest teachers prior to enrolling them into the PD program. Moreover, by doing this, teachers who require additional academic intervention can be clustered together with less advanced teachers while more advanced teachers can be grouped with other advanced teachers to maximize their PD learning experience. These actions have the potential to incite greater collaboration between PD participants wherein a greater exchange of ideas may be facilitated.

*Recommendation # 10: Professionalism*

Overall, the importance of having a high degree of professionalism when conducting a PD program seemed to be an important factor amongst each of the teachers in this study. Items such as serving quality food, teacher compensation in the form of stipends, a willingness to listen to teacher ideas and recommendations, good organization, a show of respect for what teachers do, and providing the necessary support for teachers to sustain what they learn, all reflect a high degree of professionalism. Actions such as these impart a feeling of acceptance, worth, and appreciation for teachers participating in PD. Therefore, it is recommended that designers of STEM PD deliver quality PD by creating an environment that is hospitable to teachers and makes them feel important.

## Recommendations for Future Study

The following recommendations are based on the findings and conclusions presented in this study.

1. Conduct a research study that uses the NCETE/CSULA PD model (see Appendix D) to investigate the effects of including teachers with experience with STEM integration as teacher educators and/or teacher educator preparers. This research study should also focus on the impacts on teachers' abilities to assume leadership roles and, in effect, propagate STEM integration and education among their peers. The inclusion of school administrators should be highly considered. The inclusion of school administrators should be examined to determine how administrative support impacts successful teaching practices.

2. Conduct a research study that uses the NCETE/CSULA PD model (see Appendix D) to investigate ways in which STEM educators can cooperatively work together to develop an interdisciplinary set of engineering design challenges that could be implemented in a small learning community.

3. Conduct a research study that uses the NCETE/CSULA PD model (see Appendix D) to identify the best methods on how to develop culturally relevant engineering design challenges that can be used to incite greater interests in the STEM disciplines from underrepresented populations.

4. Conduct a research study that uses the above culturally relevant engineering

design challenges to investigate the effect of the above PD on underrepresented student attitudes and perception towards STEM education.

5. Conduct a research study that uses the NCETE/CSULA PD model (see Appendix D) to identify a set of best practices on how to create engineering design content that are standards-based and specific to a variety of core academic needs. This research study should also focus on the design of short term, engineering design challenges that can be completed in less than one class period (approximately 30 minutes or less). Additional research should focus on how to cluster these short term engineering design projects into a final, end-of-the-year capstone project.

Note: Students should be included in all of the above research to gain perspective into how these projects will be managed in the classroom. This will address issues concerning team participation and group dynamics and will help in the pilot testing prior to integration into the classroom. In addition to the above, an evaluation of cognitive, psychomotor, and affective qualities that engineering design challenges have on students should be conducted. This data can be used to determine the effect that the infusion of engineering design into high school curricula has on student learning outcomes or achievement scores.

6. Conduct a research study that uses the NCETE/CSULA PD model (see Appendix D) to identify a framework of how to best develop assessment instruments (rubrics) specific to STEM education for evaluating the unique and creative qualitative aspects of engineering design projects.

7. Conduct a meta-analysis of effective practices in regards to what other

countries are doing in regards to STEM PD and use effective PD models as a reference for designing U.S. STEM PD.

## Final Conclusion

With dramatic academic declines in math and science achievement scores over the years, together with waning competitiveness in U.S. technology, educators are shouldering the responsibility to reinvent US education and are seeking new ways to engage student interests in science and math. As touched upon in the introduction to this study, until science and math are delivered in ways that connects students to real-world applications, for some students, there will remain a lack of interest and a sense of irrelevancy for what students learn in their science and math classes. Education represents one of the most important endeavors towards economic prosperity. Without an educated, highly skilled populace to support economic development, other efforts to stimulate the economy, such as the creation of green jobs or improving the quality of the US's infrastructure, will be rendered futile. Moreover, not only will our children be competing with other Americans for work but will also have to compete with their counterparts from around the world. In the final analysis, STEM education is not merely about creating a pipeline for future engineers but is about enhancing the quality of student thinking about the world around them.

With recent pushes to infuse engineering design within science, math, and technology education, the preparation of teachers with the ability to integrate STEM concepts becomes vital to these efforts. Given that teachers have a direct link to student learning, it is important to invest the necessary time and resources to help teachers provide the best quality education possible. Achievement of this goal can be realized through quality teacher preparation and/or PD programs.

In order for teachers to have an impact on how students learn and apply engineering and technological concepts and principles, teachers should possess a profound understanding of the content or subject matter they teach. General professional literature in conjunction with science and math PD research provides a good starting point with which ETE to align.

As TTE partners advance their work in preparing engineering and technology educators, evaluations of these efforts will shed light on what STEM education teachers need to know, the best way to prepare them, and the best way to deliver instruction in STEM fields at the high school level. By incorporating elements of effective PD from math and science literature, including materials from other reputable TTE institutions, observations of NCETE activities can be used as a platform for the creation of an NCETE endorsed method of delivering PD to high school teachers. These approaches can also be replicated at other institutions that offer programs in STEM and/or technology teacher education.

It is imperative to NCETE's mission to conduct on-going research to evaluate the effects that it is having on STEM teacher classroom practices because the inclusion of engineering content into science, technology and math education relies on existing teachers in the field. Many 9-12 STEM teachers do not have the necessary knowledge and skills to infuse engineering design into their classroom practices and require added support and preparation. PD is instrumental to these efforts and NCETE has sought alternative approaches to delivery rather than relying on a one-time workshops model for teachers to acquire the necessary knowledge and skills needed.

As the data in this study showed, each teacher was unique in regards to their educational backgrounds and experiential knowledge. This means that a one-size-fits-all model for STEM PD will not be conducive to preparing a variety of teachers from multiple backgrounds with the needed knowledge, skills, and abilities to deliver engineering design and problem solving concepts to their students. It would behoove STEM education stakeholders to conduct more research and invest greater resources into discovering the most effective ways to deliver STEM PD. In addition to conducting research in US schools, designers of STEM PD should research what other countries are doing in this regard.

On a final note, change begins within the individual. PD should be viewed as a catalyst for educational reform and improvement but insufficient as a mechanism for change in and of itself. STEM PD must articulate a clear vision for teacher and student goals or most likely it will be considered a waste of time. Teachers must be made aware of how STEM PD connects with their subject area and individual interests. The integration of STEM disciplines requires critical thinking, creativity, a sound understanding of subject matter, and how to best deliver instruction in a manner that is pedagogical effective. Overall, STEM integration requires that one be willing to try new approaches to teaching and assessment. Evidently, along with the commitment to change come many challenges such as standards-based pressures, assessment, and resistance to change, and teacher reeducation. The challenges facing the infusion of engineering design into high school curricula may seem daunting but as the famous African American scholar and abolitionist, Frederick Douglass stated, “There is no progress without struggle.” Are our children not worth the struggle?

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# APPENDICES

# Appendix A

## Invitation to Participate

Dear Members of Cohorts One and Two:

I am writing this request to ask you to give assistance to a very special person and a friend of the Department of Technology. His name is Zanj Avery. Zanj is now working with NCETE, conducting research on our teacher development program. He is currently a “fellow” with NCETE, and is in the final stages of his Ph.D. program at Utah State. Prior to attending Utah State, Zanj earned his bachelor’s and master’s degrees at Cal State L.A. He has observed our workshops at various times, so you may have met him.

Zanj’s dissertation is a follow-up study of the teachers that participated in our cohorts one and two. That’s where you come in. He would need to contact you and interview you. I hope you will consent to help him by granting an interview.

I also want to make clear that the goal is not to “impress” anyone. We want an honest, genuine account of what happened once the workshops ended. In other words, if the answer is “not much”, then that is the answer we seek. We are also willing to pay a $100 stipend to compensate you for your time.

Can we count on your help?

# Appendix B

## Interview Guide

*Interview script*

I would like to thank you for your time to ask you about your personal experience with the NCETE PD project. You have already signed the consent form to participate in this study, but I would like to remind you that your participation is entirely voluntary and that you may withdraw from the study at any time, without any adverse consequences. Do you have any questions about the consent form? I would like your permission to record our interview, so that a written transcript of our conversation can be generated. At any time during the interview you may request that the recording be stopped. Then with your permission, I would like to begin recording our interview.

The following are seven open-ended qualitative research questions, along with follow-up questions that will be used to probe for missing data.

*Background*

1. What do you remember in general from your NCETE PD workshops experience of two years ago?
2. What parts of these workshops made the strongest impression on you? In what ways?

*PD Effects on Content and Pedagogy*

3. How have you incorporated the information and practices you learned in the PD workshops into your own teaching?
   - If you can, please discuss specific examples related to your

teaching (e.g., methods), to student learning experiences (e.g., worksheets and activities), and evaluation.

4. What were some of the challenges you faced as you tried to incorporate what you learned in the PD workshops into your classroom?

   - Were you able to eventually overcome these challenges? If so how?

5. What were some of the benefits associated with implementing what you learned in the PD workshops into your classes?

   - Do you believe that what you learned in the workshops and incorporated into your classes has helped improve student's understanding of the field of engineering and engineering design in general?
   - How do you see students applying what they have learned in your class to their everyday lives?

*Lessons Learned*

6. What do you think you have learned most from your NCETE PD experience?

   - How has it changed your overall thinking?
   - How has it changed your thinking related to incorporating engineer design into the curriculum?

7. What recommendations would you make to improve the NCETE PD workshops the next time it's offered?

- Pleases consider location, timing, content covered, and activities.

*Demographics (Note: This will be supplemental to the actual interview. These questions will be asked prior to the interview via e-mail and/or introductory phone conversation)*

a) What class did you implement the curriculum in?

b) Grade level(s)?

c) When did you start?

# Appendix C

## Seven-Step Engineering Design Evaluation Model

Seven-Step Engineering Design Evaluation Model

Purpose: To determine how teachers have infused the seven-step engineering design process model into their classroom and/or laboratory projects.

Directions: Based on your review of the collection of teacher and student documentations, please use the following checklist to evaluate how closely the subject materials reflect the below seven-step engineering design model. As you make your evaluation please keep the following questions in mind:

- ☐ Were the documents logical and reflective of the engineering design process?
- ☐ Did the documents contain some sort of predictive step used and uses relevant and appropriate math?
- ☐ Did the documents contain predictions that are verified by an experimental component?
- ☐ Were the required resources well defined and realistic and appropriate for a high school classroom?

Teacher pseudonym______________________________________________________

Course(s) taught: ______________________________________________________

Engineering Design Process Model (Check all that apply).

- ☐ Identify the Need
- ☐ Define the Problem/Specifications
- ☐ Gather Information
- ☐ Develop and Evaluate Alternative Solutions
- ☐ Select the Optimal Solution
- ☐ Refine and Implement the Solution
- ☐ Test and Verify the Solution

Notes:

Appendix D

NCETE/CSULA PD Model

*Engineering Design in the High School Classroom*
**A Professional Development Model**
**The National Center for Engineering and Technology Education**
**California State University, Los Angeles**

## I. Program Publicity and Candidate Solicitation

- Contact STEM supervisors
- Supervisors recommend candidates
- Screen candidates
- Send invitation letter

## II. Candidate Selection Criteria

The NCETE PD teacher:

- Has at least three years of experience.
- Has a clear teaching license/credential.
- Must pledge to attempt to implement what is learned in professional development.
- Must be willing to travel to the PD site.
- Must be willing to participate in online activities that will supplement face-to-face PD.
- Must be willing to communicate regularly through email.
- Will be given preference if he or she shows evidence that he or she plans to work with mathematics and science teachers in their respective schools in some way that will enhance the implementation process or be involved in a small learning community.
- And;

Will provide the following –

- Provide forms from NCETE
- Resume stating your experiences including industry, business, and teaching.
- Letter of Intent stating that you want to participate in all 100

hours of inservice.

- Letter of support from the principal that states –the principal recommends the teacher
- the school system supports the teacher’s participation in the inservice
- will allow the NCETE to observe the teacher’s classes when he or she tries to implement what was learned so long as the NCETE files the necessary paperwork to gain formal approval with the school system
- Demographic page stating your Name, Race, Gender, Type of Teaching License, Number of Years Teaching, Teaching Assignment, College Degree Earned, Years of Experience, Other subjects taught, (grade and curriculum), Approximate number of free lunch students in your school and its racial demographics, School Name, School Location, School and Home Contact Information (including email).

**III. Candidate Selection**

- Select 12 teachers at each site
- Should math and science diagnostic be administered before hand or on site?
- Contacting supervisor and principal upon selection
- Send permission letter form

**IV. Candidate Pre-Orientation**

Long letter with Goals and what to expect and what teachers are committing to, etc.

**V. Math and Science Diagnostic Pretests**

- Basic math assessment instrument (UCLA)
- Basic science assessment instrument
- Assess math/science skills
- Develop individualized remediation plans (administered during Foundation Program)

## VI. Foundation Program (Spring) (48 of 100 hours)

- Nature of engineering design
- Cooperative learning strategies:
  - Managing cooperative learning
  - Lego hotel
- What engineers do:
  - The engineering design process
  - Strategies for working each step in the process
  - Engineering notebook
  - Engineering electronic portfolio
- Engineer guest speakers
- Work on Math and Science Diagnostic Results
- Engineering design activity (Sand Trench)
- Reflection
- Performance assessment techniques
- One minute papers after each physical meeting (formative PD program evaluation)
- Summative PD program evaluation for spring

## VII. Professional Development Program (Summer) (40 of 100 hours)

- Engineering design activity (prepared by PD Team)
- Field trip to seismic lab at Cal Tech
- Analysis of results
- Planning and Implementation for the school year
- Summative PD program evaluation for summer

## VIII. Classroom Visitation Program (Follow-up) (8+ of 100 hours)

- Center professors offer help to each teacher to assist with implementation by being with the teacher at school as a consultant on planning, delivering, and assessing students.
- Teachers visit each other’s classes
- Observation dependent variables: engineering design content is being taught; effective pedagogy

## IX. Cohort Meetings (4+ of 100 hours)

- Extent to which PD addressed the overall goals
- Extent to which planning time and having follow-up in the classroom helped.
- Extent to which knowledge and attitudes changed.
- Changes in student learning.
- Lab management and cooperative learning reflections
- Content mastery reflections

## X. Program Evaluation

- Student achievement
- Participant satisfaction
- Videotape classrooms
- Observe classrooms
- Peer evaluation
- Dependent variables: engineering design content is being taught; effective pedagogy

# CURRICULUM VITAE

## ZANJ K. AVERY

### CAREER OBJECTIVE

Seeking to work within a collegial educational environment wherein my combined skills as a manufacturing engineer, technologist, researcher, STEM educator, and good interpersonal communication skills can add value and quality to student learning. Particular areas of interest include research involving the infusion of engineering and technology-based content within K-12 education. Goals include working with educational programs that aim to close California's academic achievement gap while increasing the number of underrepresented populations in STEM-related career fields.

### EDUCATION

Ph.D., Engineering and Technology Education, Utah State University. Fall, 2009.

Concentration: Science, Technology, Engineering, and Math (STEM) Education. Research interests: academic motivation, self-beliefs, self-regulation, self-efficacy, PD, and metacognition.

Dissertation: *Effects of PD on Infusing Engineering Based Content into STEM high school programs.* Committee: Edward. M. Reeve (Co-Chair), Sherry Marx (Co-Chair), Don Maurizio, Kurt Becker, Gary Stewardson.

M. A., Industrial and Technical Studies, CSU, Los Angeles, CA. 2004

Thesis: *The Development of a Technology Education Module Concerning Circular Motion.* Area of specialization: Middle and secondary level science and technology education.

Bachelor of Science, Industrial Technology, CSU, Los Angeles, CA. 2000

Area of specialization: Design, manufacturing systems and engineering technology.

Associate of Science, Machine Shop-CNC, L.A. Trade Technical College, 1998. Area of specialization: Computer Numerical Control (CNC), Statistical Process Control (SPC), Geometric dimensions and tolerance (GD&T), machine tools, material processes mechanical design, and metal fabrication.

## PUBLICATIONS

Avery, Z. & Denson, C. African American high school student's perceptions of engineering and technology education. Journal of African American Studies.

## PRESENTATIONS

Avery, Z.K., & Cox, K. (2007) 70th Annual International Technology Education Association Conference, Salt Lake City, Utah. Presentation entitled: *Using Backwards Design to Develop STEM Standards-based Instruction.*

Avery, Z. & Denson, C. & Hill, R. (2007) 69th Annual International Technology Education Association Conference, San Antonio, TX. Presentation entitled: African-American students: Perceptions of technical careers.

## ADDITIONAL RESEARCH EXPERIENCE

Co-Principal Investigator, *Using visual learning techniques to teach engineering fundamentals*. Qualitative Methods II, Principal Investigator, Dr. Sherry Marx. March-May 2007.

## HONORS AND AWARDS

Donald Maley Spirit of Excellence "Outstanding Graduate Student Citation", ITEA Conference, Louisville, Kentucky, 2009.

Martin Luther King Junior Scholarship, Utah State University, 2005-2006. $10,000

Chancellor's Doctoral Incentive Program, California State University, Los Angeles, 2006-2008, $30,000

National Center for Engineering and Technology Education Fellowship, 2005-2008.

Utah State University, Tuition scholarship, 2005-2008.

Golden Key Honor Society, 1999

Dean's List, CSULA, 1998

Dean's List, LATTC, 1996

## PROFESSIONAL EXPERIENCE

STEM Education Consultant, August 2009 – Present

Century Community Charter School

Description: Developed standard-based learning units and provided professional development to teachers to enhance quality of science and math instructional delivery.

Adjunct Faculty, 2007-present

California State University, Los Angeles

Description: Developed curriculum content to enhance first year (freshman) engineering student learning experiences. Provided instruction for a variety of first year (freshman) engineering courses (See “Professional Teaching Experience” list).

Manufacturing Engineer, 2001-2003

Parker Aerospace (Air and Fuel Division)

Description: Designed assembly tooling and testing fixtures for critical flight control systems. Worked with integrated product development (IPD) and lean manufacturing teams to streamline production of aerospace flight control valves.

Assistant Park Services Attendant, 1991-1999

City of Los Angeles Recreation and Parks

Description: Managed ground operations at a pay-tennis recreational facility. Other duties include working with the public, computer work, accounting, and troubleshooting technical problems such as lighting and computer issues.

## PROFESSIONAL AFFILIATIONS/MEMBERSHIPS

National Center for Engineering and Technology Education: 2005-present
International Technology Education Association: 2005-present
CTTE Twenty-first Century Leader Associates: 2009-10

## PROFESSIONAL TEACHING EXPERIENCE

Instructor, Physics Applications in Engineering Design (ENG 154), California State University, Los Angeles. Fall 2009

Instructor, Introduction to Engineering (ENG 150), California State University, Los Angeles. Fall 2009

Instructor, Math/Robotics Integration (ENG 154), California State University, Los Angeles. Summer 2009

Instructor, Algebra 91 and 102. California State University, Los Angeles. Summer 2009

Instructor, Cartoon Animation in Engineering (ENG 154), California State University, Los Angeles. Spring 2009

Instructor, Robotics and Invention (ENG 154), California State University, Los Angeles. Winter 2009

Instructor, Introduction to Engineering (ENG 150), California State University, Los Angeles. Fall 2008.

Instructor, Introduction to Engineering (ENG 100), California State University, Los Angeles. Fall 2007.

Instructor, Material Processing and Tooling Systems (ETE 1080), Utah State University. Fall 2006-Spring 2007.

Co-instructor, Material Processing and Tooling Systems (ETE 1030), Utah State University. Spring 2006.

RESEARCH GRANTS

Avery, Z. (2008). *Effects of PD on Infusing Engineering-Design into High School Curricula. $2000*

Avery, Z. & Denson, C. (2006). *Perceptions of African American High School Students Towards Engineering and Technology Education*. $2500

RESEARCH SKILLS

Qualitative and Quantitative Research Methods

PROFESSIONAL SKILLS

Development of standards-based, engineering design challenges
Engineering and technological design processes
Manufacturing systems and material processing
Engineering with Excel
Solid Modeling
CAD/CAM
SPSS statistical analysis software
Microsoft Office (Word, Excel, PowerPoint)