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Engineering-Oriented Professional Development for Secondary Level Teachers: A Multiple Case Study Analysis

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ENGINEERING-ORIENTED PROFESSIONAL DEVELOPMENT FOR SECONDARY LEVEL TEACHERS: A MULTIPLE CASE STUDY ANALYSIS

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DISSERTATION

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ABSTRACT

This study consisted of multiple case studies of selected professional development programs designed to prepare secondary teachers to deliver engineering-oriented education. The focus was on understanding the professional development design, fundamental content knowledge, essential pedagogies, unique challenges, and effective practices involved in this type of professional development. This was achieved by interviewing the leadership, instructors, and participating teachers; observing the in-person workshops; administering a survey to the teachers; and analyzing the project's documentation. Five professional development programs were examined, including: *Engineering the Future*, *Project Lead the Way*, *Mathematics Across the Middle School MST Curriculum*, *The Infinity Project*, and *INSPIRES*. The findings from the individual case studies were compared and summarized across the five research questions.

To Mom and Dad

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CHAPTER I

THE PROBLEM

Several educational reform periods have occurred during the twentieth century and into the twenty-first, with perhaps the most notable call for reform occurring as a result of the Soviet Union's launching of Sputnik in 1957. This incident "captured national attention and stimulated public pressure to upgrade U.S. science and mathematics education, with particular emphasis on increasing the pool of U.S. scientists and engineers capable of surpassing the Soviet achievement" (Weiss, Knapp, Hollweg, & Burrill, 2002, p. 18). Another landmark event was the publication of *A Nation At Risk* in 1983, which called for higher student expectations. States and professional associations responded by developing new curriculum frameworks, standards, and assessments. By the early 1990s, the National Council Teachers of Mathematics (NCTM, 1991) and the American Association for the Advancement of Science (AAAS, 1993) had developed mathematics and science standards respectively.

Since 2004, a new wave of reports from businesses, associations, and educational entities have called for educational reform. For example, the National Center on Education and the Economy's *Tough Choices or Tough Times* (2007) report argued that the "core problem is that our education and training systems were built for another era" (p. 8) and require a total overhaul. Grubb and Oakes (2007) identified four main themes in these reports including a call for: (a) higher standards and rigor, (b) relevance, (c) equity, and (d) high schools as lively and interesting places for students. Two arguments underpin most of these calls for reform: (a) a national competitive decline and (b) graduates who lack the necessary workforce, civic, and community competencies.

The effects of standards-based reform have been far-reaching into education, specifically impacting teacher professional development. The qualifications and effectiveness of teachers have been regarded as crucial to the success of standards-based reform. Thus teacher professional development has been regarded as the “cornerstone for the implementation of standards-based reform” (Fishman, Marx, Best, & Tal, 2003, p. 643). Little (1993) argued that “one test of teachers’ professional development is its capacity to equip teachers individually and collectively to act as shapers, promoters, and well-informed critics of reform” (p. 130).

In addition to focusing on teacher preparation and development, national reform efforts (i.e., the *No Child Left Behind Act of 2001*, U.S. Department of Education) have also emphasized science, technology, engineering, and mathematics (STEM) education (i.e., *Rising Above the Gathering Storm*, NRC, 2006). With the *Project 2061* (1989), the AAAS recommended that students learn key technological concepts such as design, control, and systems. More recently, in the report entitled *Preparing for the Perfect Storm*, an action plan was developed to address the “T&E in STEM,” stating that it was not enough for students to learn science and mathematics and assume they will have a path to technology and engineering (Coppola & Malyn-Smith, 2006).

Within technology education, there has been a groundswell of support for aligning with the engineering community to achieve many of these goals (Dearing & Daugherty, 2004; Erekson & Custer, 2008; Wicklein, 2006). In particular, engineering design has been targeted as the point of integration (Lewis, 2005). The complexity of engineering and its integration into K-12 education, however, have resulted in a variety of issues requiring sustained empirical research. Although some research has been conducted to better understand how to address these issues (Hill & Anning, 2001; McRobbie, Stein, & Ginns, 2001; Warner & Morford, 2004; Welch, 1999), the need for a stronger research agenda persists (Johnson, Burghardt, & Daugherty, 2008).

Given the larger context of educational reform, the increasing attention on teacher preparation and development, and the emphasis on STEM education, research on teacher professional development is needed. Specifically, the integration of engineering at the secondary level setting has led to the need for, and research on, teacher professional development in engineering-oriented education.

Statement of the Problem

A particularly critical issue involved with the incorporation of engineering is the identification of fundamental content knowledge and sound pedagogies needed to teach engineering-oriented curriculum. In particular, if engineering design is the avenue for integration, teachers must be adequately prepared to incorporate it into their teaching. As Jonassen (2000) pointed out, design problems are usually among the most complex and ill-structured kinds of problems that individuals encounter. Teaching engineering design involves more from the teacher than instruction on following a design process, and how to use or make drawings (Warner, 2003). The problem or “desperate need” (De Miranda, Troxell, Siller, & Iversen, 2008, p. 140) is to understand how to prepare teachers to teach engineering design, specifically through in-service teacher professional development.

In-service professional development covers “a broad range of activities designed to contribute to the learning of teachers, who have completed their initial training” (Craft, 2000, p. 9). Numerous definitions of teacher professional development have been offered

(Bell & Gilbert, 1994; Bredeson, 2003; Clement & Vandenberghe, 2000; Day, 1999; Guskey, 1986). However, a general definition of teacher professional development is described as activities "designed to contribute to the learning of teachers, who have completed their initial training" (Craft, 2000, p. 9). The research has underscored the need for professional development to help teachers understand (a) subject matter, (b) learners and learning, and (c) teaching methods (Loucks-Horsley, 1999).

Serious deficiencies exist, however, in teacher professional development efforts that require reform (Sykes, 1996). Problems include the fact that "teacher learning has traditionally been a patchwork of opportunities—formal and informal, mandatory and voluntary, serendipitous and planned—stitched together into a fragmented and incoherent 'curriculum'" (Wilson & Berne, 1999, p. 173). As far as the research being conducted within teacher professional development, Wilson and Berne's (1999) review of the literature led them to conclude that the there was a lack of research on subject-specific teacher learning, issues of teacher knowledge, and the link between teacher learning to teaching behavior or student achievement. This last observation is supported by others who claim that there remains little research on the effects of professional development on teaching and student outcomes (Evans, 2002; Garet, Porter, Desimone, & Berman, 2001).

There have been some noticeable changes however in the practice of professional development. According to Day and Sachs (2004), "over the last 20 years there has been a shift in the rhetoric of teacher training and development from one in which individual teachers have been able to choose at will from a "smorgasbord" of (mainly) short one-shot workshops and lectures, to one in which lifelong learning is regarded as essential for all as a mandatory part of every teachers' needs" (p. 8). In other words, there "has been a trend towards a broader view of what constitutes as professional development, and towards a greater emphasis on what happens before an in-service training event (needs identification) and afterwards (evaluation and follow-up)" (Craft, 2000, p. 13).

While substantial work has been conducted in mathematics and science education regarding teacher professional development, the efforts in technology and engineering-oriented education are much less mature. Teacher professional development models based on an established foundation of knowledge have been developed within science and mathematics education. For example, Loucks-Horsley (1999) identified four clusters of variables that affect the quality of professional development including: (a) content; (b) process; (c) strategies and structures; and (d) context. Although not as many within mathematics and science, there are a few examples of studies exploring technology professional development (Bybee & Loucks-Horsley, 2000; Compton & Jones, 1998).

However, few, if any, empirical studies have been conducted to examine effective professional development design principles within secondary level engineering education. The professional development demands associated with the emerging alignment with engineering are important to the future of the field. In particular, effective and coherent teacher professional development needs to be developed, researched, and documented. A lack of publication on effective practices, lessons learned, and challenges to professional development in engineering-oriented education at the secondary level made a study investigating mature efforts necessary.

Purpose of the Study

The goal of this study was to explore and describe professional development practices for secondary level engineering-oriented education. This research focused on the design decisions, engineering-specific content knowledge and pedagogies, unique challenges, and determinations of effectiveness. The study consisted of multiple case studies of selected professional development programs designed to prepare secondary teachers to deliver engineering-oriented education. This was achieved by exploring the professional development decisions and practices involved in five projects that incorporated engineering into their programs. The projects included in this study were *Engineering the Future: Science, Technology, and the Design Process*™, *Project Lead the Way*™, *Mathematics Across the Middle School MST Curriculum*, *The Infinity Project*℠, and *INSPIRES*.

The process for selecting the sites for analysis included conducting investigative interviews with key individual informants; reviewing web sites of professional development initiatives; and reviewing abstracts of funded projects and published materials from national clearinghouses. Data collection and analysis consisted of the triangulation of data collected through (a) direct observations of the delivery of professional development activities with practicing teachers, (b) interviews with the projects' leadership, instructors, and teacher participants and (c) a teacher questionnaire.

The research questions that guided the case studies of professional development focused on delivering engineering education were:

1. What are the primary design elements used to deliver engineering-oriented professional development (logistics, format, activities, instructors, and instructional strategies) and why were these elements selected?

2. What fundamental content knowledge is provided in the professional development (e.g., pedagogical content knowledge, core engineering concepts, mathematics/science principles)?

3. What pedagogical principles are determined to be essential for the teachers?

4. What are the particular challenges unique to professional development in engineering-oriented education?

5. How do the programs define and evaluate effectiveness?

The data collected from each project concerning the effective practices, underpinning pedagogical principles, and unique challenges were synthesized and used to develop conclusions and recommendations for secondary level engineering-oriented professional development. This helps to establish a status of the field so as to refine future practices and identify areas for further research.

Significance of the Study

The significance of this study is based on the link between student learning and teaching as articulated by many within standards-based reform. As Supovitz and Turner (2000) argued, the "logic of focusing on professional development as a means of improving student achievement is that high quality professional development will produce superior teaching in classrooms, which will, in turn, translate into higher levels of student achievement" (p. 965). A few studies have been conducted to analyze this connection (Darling-Hammond, 2000; Monk, 1994), however more research is needed.

By exploring and comparing engineering-oriented professional development projects and identifying their effective practices, pedagogies, and strategies, the link to student learning can be better explored in future studies. In addition, an investigation and in-depth comparison of current professional development projects that are attempting to prepare teachers for the complex role of teaching engineering can begin to fill the need of indentifying the fundamental engineering content knowledge and sound pedagogical approaches. It is important to document what has been learned thus far by these projects to refine future professional development and research in this area.

Definitions

Although engineering at the secondary level has not been clearly defined, at the postsecondary level engineering is defined by the Accreditation Board for Engineering and Technology (ABET) as the profession in which knowledge of the mathematical and natural sciences, gained by study, experience, and practice, is applied with judgment to develop ways to use, economically, the materials and forces for the benefit of mankind (Gomez, Oakes, & Leone, 2006). For the purposes of this study, secondary level engineering education was defined to include projects designed to (a) prepare students for postsecondary engineering education or (b) provide a broad base of technological literacy for all students utilizing engineering-oriented concepts and/or activities.

Within engineering-oriented education at the secondary level, the emphasis is on engineering design and technological literacy. Mioduser (1998) offered that consensus has emerged concerning a definition of engineering design, which includes: “the identification of problems and diagnosis of needs, through a series of loops at which solutions are conceived, explored and evaluated until a suitable answer is found and then instantiated.” (p. 177). Technological literacy, on the other hand, is defined by the International Technology Education Association (2000) as the “ability to use, manage, assess, and understand technology” (p. 7).

In addition, the definition of teacher professional development used to guide this study was that it is an “essential mechanism for deepening teachers’ content knowledge and developing their teaching practices” (Desimone, Porter, Garet, Yoon, & Birman, 2002, p. 81). This definition encompasses many different purposes, functions, and types of in-service teacher development; allowing for a broad conception of engineering professional development so as to not exclude relevant projects from analysis.

Assumptions of the Study

The primary assumptions of the study were connected to the study’s design. It was assumed that the criteria used to select the case studies resulted in an adequate sample of efforts to analyze and represent secondary level engineering-oriented professional development. The sites selected for inclusion in this study had to be engineering-oriented, incorporate illuminative professional development design principles, have a level of maturity, utilize a coherent model for professional development, and have gathered some evidence of effectiveness.

It was also assumed that the process for identifying and selecting the sites was appropriate given the lack of publication and the limited range of advertisement of engineering-oriented professional development programs. In addition, it was assumed that the member checking and validation measures described are appropriate to generate accurate and valid case study reports from which to make conclusions and recommendations for future practice and research on secondary level engineering-oriented professional development.

Limitations of the Study

The limitations of this study are consistent with real-world research. With limited documentation on the programs, descriptions were primarily based on data collected from individuals involved in each project. Human recollections are sometimes flawed which may affect the validity of findings. However, the triangulation of data across sources and time reduced this limitation. Data were collected prior to, during, and after the on-site visits, which was compared for consistency. In addition, data were collected from the project's leadership, teachers, and instructors. Data collected during three points and from three populations were also compared to existing documents on the project to help create an accurate picture of the professional development program.

Another possible limitation to the study could have been the selection of the "wrong" or inappropriate case for analysis given the study's research questions. The cases were identified using a list of 15 informants who were selected because of their active engagement and knowledge of engineering professional development. However, there may be projects that were not known to all of the informants or projects that were mentioned but did not meet the selection criteria as intended. The development of an "informant script" and the use of a ranking system where the informants were asked to rank the top three sites that best meet the criteria reduced this possible limitation. It is believed that these possible limitations did not affect the validity or accuracy of the results of this study.

CHAPTER II

REVIEW OF THE LITERATURE

This chapter reviews the pertinent literature related to teacher professional development and positions this study within the larger context of science, technology, engineering, and mathematics education. There are numerous definitions, types, and models of teacher professional development in the literature including staff development, continuing professional development, continuing education, and training. Professional development can encompass the individual development of a teacher, team of teachers, or entire school. There are also numerous functions and purposes of professional development that affect its design and impact, including skills training and professional growth. In addition, professional development is informed by numerous issues related to the professionalization of teaching and teachers' career/life stages, learning theory, school reform, design principles, and best practices.

Profession of Teaching

When discussing teacher professional development, it is important to understand the teaching profession and teachers' career development. The term professional is "essentially describing a set of unique characteristics based on training, knowledge, and skills a person possesses" (Bredeson, 2003, p. 42) that are recognized as existing within a profession. Being a teacher has been translated as the ability to "understand not only the subject matter to be taught, but also how to teach that subject matter, how to modify and adapt instructional practice to individual student needs, and how to diagnose those needs" (Darling-Hammond & Hudson, 1990, p. 241). The training, knowledge, and skills of teaching have contributed to its professionalization but have also contributed to some calls for reform. In addition, the career stages of teaching have also been explored to better understand teachers' developmental needs.

Preparation

In terms of preparation, Andrew (2005) described four pathways for producing teachers in the US. The first pathway is the sanctioning of teachers who have no prior professional training. Home schools, private schools, and some state departments of education allow alternate, emergency, or critical shortage routes for teachers with no professional training. Another pathway to teacher preparation is direct entry through organized programs that are not college or university based. These are typically short term, intensive summer programs run by private businesses, school districts, and non-profit organizations. Formal, college-based programs are the primary route to teacher preparation. These programs emerged in normal schools that evolved into state teachers' colleges then into state liberal arts colleges. Private liberal arts colleges and major research universities offering teacher preparation often in subject field majors is the fourth pathway to teacher preparation.

These multiple and some less well regulated pathways to the teaching profession have created, according to Andrew (2005), "a barrier to the advancement of teaching as a profession" (p. 55) and calls for "a professional development system based on profession-defined teaching standards" (Ingvarson, 1998, p. 128). The National Board for Professional Teaching Standards is an attempt to establish a national professional body for the advanced certification of teachers that provides a system of certification for highly accomplished teachers. According to Ingvarson (1998), the standards have the potential to “revolutionize the professional development system for teachers in the US and place its control in the hands of the profession” (p. 132). The standards outline aspects of accomplished teaching, including an explanation of what teachers need to know, value, and do in order to satisfy the standard at a high level.

Knowledge & Skills

In addition to the preparation of teachers, another distinguishing feature of professions is a defined knowledge base and skill set. Darling-Hammond and Baratz-Snowden (2005), based on a review of research, argued that the common practices of effective teachers draw on three general areas of knowledge. Teachers must have knowledge of learners and how they learn and develop. The subject matter and skills to be taught in light of the social purposes of education is another type of knowledge teachers should have. Finally, teachers should have an understanding of teaching in light of the content and the learners to be taught.

Park and Oliver (2007) also conducted a comprehensive literature review and concluded that “while researchers have differed in their characterization of the relationship between various sub-domains of teacher knowledge, four commonalities have consistently appeared: pedagogical knowledge, subject matter knowledge, pedagogical content knowledge, and knowledge of context” (p. 263). Gordon (2004) expounded on these knowledge bases and included knowledge of the curriculum, of learners and of one’s own educational beliefs.

In particular, pedagogical content knowledge (PCK) has received a great deal of attention from professional development researchers. Shulman (1986) defined PCK as consisting of “ways of representing and formulating the subject that make it comprehensible to others" (p. 9). Based on their review of literature on PCK, Park and Oliver (2007) developed the following definition: "PCK is *teachers' understanding and enhancement* of how to help a group of students understand specific subject matter using multiple instructional strategies, representations, and assessments while working within the contextual, cultural, and social limitations in the learning environment" (p. 263). They further argued that pre- and in-service teacher education programs should provide teachers with the opportunity to develop their ability to examine students' understandings, misconceptions, and learning styles.

Based on a review of literature on the sociology of teacher's work, Bredeson (2003) outlined common features of teachers' professional work. One feature is that teaching is conditional and situational in that there is not one best strategy for every situation but a repertoire of possibilities for effective teaching. The enduring structural features of schooling, such as grade levels and subject specific classrooms, have also impacted teachers' work. In addition, there are norms of privacy and individualism surrounding the teaching profession. Teachers often seek to "maintain their professional and psychological privacy in self-contained classrooms and offices" (Bredeson, 2003, p. 63). The work of teachers is also marked by paradoxes in striving for routine and the need for renewal; the desire for autonomy and the requirements of accountability.

Career Development Stages

After initial training, many teachers continue to have developmental needs related to curriculum and instruction. The "accumulated research on teaching demonstrates that it is a highly complex activity requiring extensive knowledge and a wide repertoire of skills, flexibility, versatility, and commitment" (Darling-Hammond & Hudson, 1990, p.

242). As Knight (2002) stated, “professional development is needed because initial teacher education cannot contain all of the propositional knowledge that is needed and certainly not that procedural, ‘how to’ knowledge which grows in practice” (p. 230). Feinman-Nemser (2001) argued that teachers require “access to serious and sustained learning opportunities at every stage in their career” (p. 1014) if they are to be able to “teach in ways that meet demanding new standards for student learning or to participate in the solution of educational problems” (p. 1014).

Table 1

Career Stages and Development Needs of Teachers

Career Stage	Developmental Needs
Survival	Learn day-to-day operations of classroom and school
Building	Develop confidence in work and multifaceted role of teaching
Striving	Develop professionally and achieve high job satisfaction
Crisis periods	Renewal to counteract teacher burnout
Complacency	React to complacency and low innovation
Career wind down	High status as a teacher without exerting much effort
Career end	Retirement

Note. Adapted from Speck and Knipe, 2005, p. 75.

Many researchers have outlined the career development continuum of teachers to better understand these developmental needs. For example, Speck and Knipe (2005) outlined developmental needs according to the career stages of teachers as shown in Table 1. From the initial survival stage associated with the first few years of a teaching career to the career’s end and preparation for retirement, Speck and Knipe outlined associated needs. Similarly, Gordon (2004) created a graphical display of the professional development continuum as show in Figure 1. Gordon outlined a progression from recruitment into the teaching profession to continuing professional development

Recruitment	Pre-service Preparation	Hiring and Placement	Induction	Continuing Professional Development

Figure 1. Professional Development Continuum

Day (1999) offered a similar continuum, including launching a career, stabilization, new challenges, reaching a professional plateau, and the final phase. Day also pointed out that these types of conceptualizations of teachers' careers, although plausible, are "both over-simplistic and impractical since they are not based on a 'teacher-as-person' perspective but on a systems, managerial perspective of 'teacher-as-employee'" (p. 68). However, these conceptualizations are useful when other factors such as the organizational contexts and cultures in which teachers work, as well as the teachers' learning styles and motivations, are taken into account. Day added that "continuing, career-long professional development is necessary for all teachers in order to keep pace with change and to review and renew their own knowledge, skills and visions for good teaching" (p. 2).

Development of Professional Development

The history of in-service teacher development is linked to the Teacher Institutes of the early 19th century in the U. S. According to Guskey (1986), this history is characterized by "disorder, conflict, and criticism" (p. 5). Responses to this disorder and incoherence have largely been to push professional development in two different directions. According to Little (2004) one direction, "mounted largely by the research community and by teacher-educators themselves, has been to seek professional development that is joined more closely to the genuine demands and resources of teaching practices" (p. 96). For example, Feinman-Nemser (2001) argued that the '"new' paradigm of professional development calls for ongoing study and problem solving among teachers in the service of a dual agenda—promoting more powerful student learning and transforming schools" (p. 1038). The other direction has been pursued by policy makers who seek greater coherence in professional development activity and a closer link to curriculum policy.

Craft (2000) and Day and Sachs (2004) noted some significant changes in the practice of professional development within the past 20 years. These changes include a broader conception of professional development to include lifelong learning opportunities and the development of more comprehensive programs that include needs assessments and evaluation. Many point to educational reform as the primary cause of these changes. As Darling-Hammond and Hudson (1990) stated, there is the growing belief that educational improvement in American schools depends "largely on the caliber of the teaching force" (p. 223).

Standards-Based Reform

The Sputnik launching in 1957 and the publication of *A Nation At Risk* in 1983 have been pointed to as sparking periods of educational reform during the 20th century. With the 21st century concerns about the nation's competitiveness have re-emerged resulting in a new wave of commissioned reports from businesses, associations, and educational entities called for reform (i.e., *Rising Above the Gathering Storm*, 2007; *Tough Choices or Tough Times*, 2007). Underpinning these reports is the call for higher standards for student learning so as to prepare graduates with the necessary workforce, civic, and community competencies.

States and professional associations have responded by developing new curriculum frameworks, standards, and assessments. By the 1990s, the National Council Teachers of Mathematics (NCTM, 1991) and the American Association for the Advancement of Science (AAAS, 1993) had developed mathematics and science standards respectively, in a wave of standards-based reform (explained further below). As Cajas (2002) noted, standards documents can be interpreted as, “political decisions that attempt to represent the values and desires of society in specific areas” (p. 177). These documents reflect the national focus on improving education, particularly mathematics and science education, to increase the nation’s competitiveness.

The effect of standards-based reform on teacher preparation and professional development has been widely noted. As Little (2001) stated, standards-based reform agendas “both focus and justify professional development expenditures, which thus rest not only on the promise of individual teacher growth, but also on a corresponding vision of progression in school improvement” (p. 23). Garet, et al. (2001) argued that the “success of ambitious education reform initiative hinges, in large part, on the qualifications and effectiveness of teachers” (p. 916). Darling-Hammond and McLaughlin (1995) pointed to two key elements of the reform agenda: (a) a focus on learner-centered approaches and (b) a career-long conception of teaching. Both of these elements have impacted conceptualizations of professional development.

In addition to standards, Sparks and Hirsh (1997) pointed to three ideas that have emerged within educational reform that have affected teacher professional development:

(a) results-driven education, (b) systems thinking, and (c) constructivism. Results-driven education is focused on the knowledge and skills developed as a result of schooling, not grades. This approach is impacting professional development by judging successful programs, “not by how many teachers and administrators participate in staff development programs or how they perceive its value, but by whether it alters instructional behavior in a way that benefits students” (Sparks & Hirsh, 1997, p. 5). Systems thinking impacts professional development by incorporating approaches that help develop this type of thinking across all levels of the school organization. Finally, it is believed that constructivist professional development practices best help teachers acquire new knowledge and skills that can be easily integrated into their classrooms.

Definitions

As the practice of professional development has evolved, there have been numerous definitions of the concept offered. For example, Guskey (1986) offered a definition that included a “systematic attempt to bring about change—change in the classroom practices of teachers, change in their beliefs and attitudes, and change in the learning outcomes of students” (p. 5). Bell and Gilbert (1994) viewed teacher development as a purposeful inquiry comprised of three dimensions: (a) professional, (b) personal, and (c) social development.

Day (1999) defined professional development as “the process by which, along and with others, teachers review, renew and extend their commitment as change agents to the moral purposes of teaching; and by which they acquire and develop critically the knowledge, skills and emotional intelligence essential to good professional thinking, planning and practice with children, young people and colleagues through each phase of their teaching lives” (p. 4). Clement and Vandenberghe (2000) argued that professional development is “a continuous process determined by the interplay between the individual and the organization, leading to a combination of craftsmanship and mastery” (p. 87).

Evans (2002) however stated that “even those who are generally considered leading writers in the field do not define precisely what they mean by the term” (p. 124) and that this is a necessity so as to provide conceptual clarity for the study of teacher development and shared understanding. Evans offered the definition of teacher professional development as “the process whereby teachers’ professionality and/or professionalism may be considered to be enhanced” (p. 131). She argued that two constituent elements of teacher development are fundamental to an individual teacher’s development: (a) attitudinal development and (b) functional development. Attitudinal development is where teacher’s attitudes are modified and functional development is the process of improving a teachers’ professional performance.

Purpose and Function

Researchers have offered numerous purposes and functions of professional development. For example, Bolam (1986) identified five primary purposes of professional development along a continuum of needs, from the system to the individual. These main purposes include: (a) staff/group performance, (b) individual job performance, (c) career development, (d) professional knowledge, and (e) personal education. Wideen (1987) outlined two somewhat different purposes: (a) training teachers in skills and (b) continuous personal and professional growth of teachers. Wideen argued that these purposes are not necessarily mutually exclusive, but often inform the design of the professional development program. Guskey (1986) summarized that most teachers engage in development so they can gain “specific, concrete, and practical ideas that directly relate to the day-to-day operation of their classroom” (p. 6).

In terms of the functions professional development fulfills, Day and Sachs (2004) included (a) extension, (b) growth and (c) renewal. However, Blandford (2000) outlined four major functions of professional development including to: (a) enhance individual job performance, (b) rectify ineffective practice, (c) establish groundwork for the implementation of policy, and (d) facilitate change. Craft (2000) added the following functions including promotion, to clarify school policy, and to promote job satisfaction. In addition, Little (2001) found four broad functions of teacher professional development in case studies of schools, including (a) inspiration and goal-setting, (b) knowledge and skill development, (c) inquiry, and (d) the development of collaboration and community.

Related to the purpose and function of teacher professional development is the motivation behind teacher participation. Boardman and Woodruff (2004) outlined key findings from research pertaining to teachers’ motivation and ability to participate in professional development. For example, research indicates that the delivery of new information is less important than the actual content of the professional development. In addition, teachers are able to learn new content in a variety of formats but the new information must be understandable and related directly to classroom practice. Another key finding is that the content of the professional development must meet high standards. In addition, support during implementation increases the likely of using the new information and if the information is presented over time it is better to involve teachers from the same school. These findings are related to general issues outlined in adult learning theory as explored later in this chapter.

Types of Professional Development

In addition to the purpose and function, there have been numerous types of professional development identified in the literature. For example, Bolam (1993) discussed a number of different types of professional development activity including: (a) practitioner development, (b) professional education, (c) professional training, and (d) professional support. Practitioner development is typically school-based and can include observations, induction, and team teaching. Professional education involves higher education coursework. Workshops and conferences emphasizing practical skills are characterized as professional training. Professional support includes career development, mentoring, and promotion incentives. Lieberman (1995) also outlined different types of professional development, including: (a) inside/outside the school, (b) informal/formal, and (c) traditional/reform.

In addition, Day and Sachs (2004) described two broadly conceived types of professional development: (a) a deficit model and (b) an aspirational model. Within a deficit model it is assumed that teachers needed to be provided with knowledge and skills they did not already have. According to Day and Sachs (2004), this model "remains firmly in place" (p. 9). Another model however has been increasingly pursued; the aspirational model. This approach includes an acknowledgement that teachers are already effective, but can improve. This model "builds upon, on the one hand, research findings about effective and improving schools and teachers, and on the other about teachers' identity, commitment, work and lives" (p. 9). Day and Sachs argued that these models do not conflict but can be complementary.

Adult Learning Theory

Underlying the concept of professional development is learning theory. As Wideen, Mayer-Smith, and Moon (1996) argued, “changing one’s teaching is a learning process which involves, in part, building upon and changing prior beliefs and actions about teaching” (p. 188). Darling-Hammond and McLaughlin (1995) concurred, stating that effective professional development involves teachers both as learners and as teachers and allows them to struggle with the uncertainties that accompany each role. Lieberman (1994) added that teaching and learning are no longer “seen as separate functions, but rather as interdependent parts of the whole” (p. 21). In terms of learning theory, there are three related areas important to teacher professional development: (a) andragogy, (b) reflection, (c) learning opportunities, and (d) learning transfer.

Andragogy

Many researchers have cited andragogy (adult learning theory) as important to designing teacher professional development. For example, Blandford (2000) argued that for professional development to be effective “the coordinators should be aware of the needs of teachers as adult learners” (p. 21). Peery (2004) concurred offering that the philosophical underpinnings of andragogy as related to learning new things is particularly important, including that “adults need to know a reason for learning something; they need to learn experientially; they must approach learning as problem solving; and they learn best when the topic is of immediate relevance, meaning it can be applied right away in their personal and/or professional lives” (p. 3).

Gordon (2004) outlined the principles of adult learning that particularly pertain to teacher professional development. For example, adult learning states that motivation to learn is often generated from a need or interest connected to an adults' personal or work lives. This principle informs teacher professional development by supporting the practice of needs assessments and designing programs around those identified needs. In addition, it calls for the need to relate learning activities to teachers' personal and working lives. Adults bring life experiences and prior knowledge to new learning. This indicates the need for allowing teachers to participate in the design of professional development and time to reflect on their experiences and knowledge during the learning experience. Other adult learning principles that impact professional development include that adults learn best when they are actively engaged, they possess varying learning styles, and adults desire self-directed learning opportunities.

Similarly Bredeson (2003) outlined how learning principles should affect professional development. For example, adult learning theory states that different learning goals require different instructional strategies, which implies that professional development should be designed so that learning outcomes are identified before content, delivery, and assessments are designed. In addition, ongoing assessments should be incorporated into professional development because adult learning suggests that understanding learners' prior knowledge, beliefs, experiences, and culture is important. Successful learners understand how they learn, thus critical reflection and meta-cognition should be built into professional development learning activities. Learning also involves transfer, so time and resources should be provided so learners can move ideas into practice and the job of teaching.

Framing teacher professional development within adult learning begs the question of how knowledge for teaching is generated. Wideen et al. (1996) outlined two views of knowledge: (a) producer-user knowledge, and (b) interpretive knowledge. Producer-user knowledge is produced by individuals and is implemented by others. For example, university professors conduct research to generate knowledge that teachers use in the classroom. Interpretive knowledge defines knowledge as being actively constructed within the unstable world of practice. Teachers learn new aspects of teaching as they teach. Wideen et al. (1996) argued that it is the "combination of formal and personal practical knowledge on which teachers base their practice." (, p. 192).

Similarly, Cochran-Smith and Lytle (2001) outlined three avenues of teaching knowledge generation. The first is knowledge-for-practice, which is formal knowledge or theory generated largely by university researchers. Knowledge-in-practice is generated by probing knowledge of expert teachers or being able to design their own learning. The third is knowledge-of-practice, which is generated when teachers treat their classrooms and schools as sites for investigation and learning. Knowledge generation is directly related to opportunities for learning, which is explored in more detail next.

Learning Opportunities

Many researchers have discussed the learning opportunities available to teachers, both structured and unstructured. Craft (2000) discussed the range of opportunities in terms of their length of engagement: (a) long, (b) short, and (c) incidental. Long opportunities range from one to three years and can include university degrees and school improvement plans. In terms of a series of days, short opportunities include working groups, courses, and teacher placements. Incidental opportunities consisting of a day or less include study days, job shadowing, and conferences. Craft also grouped learning opportunities into four categories: (a) learning from concrete experience within the classroom or during professional development experiences, (b) learning through reflection in/on action, (c) learning through experimentation by trying out a new idea assimilating a new idea, and (d) learning through conceptualizing.

Falk (2001) outlined another avenue of teacher learning; learning through assessment. Three types of assessments can impact teacher learning, including (a) teachers' assessments of student learning by observing, documenting, and collecting student work over time, (b) teachers scoring student responses to externally administered standards-based performance tests, and (c) teachers examining and validating their own practice by participating in the National Board of Professional Teaching Standards certification process. Findings from Boardman and Woodruff's (2004) study support this type of approach to teacher learning revealing that statewide assessments significantly impact teaching and teachers' implementation of new instructional practices. However, as discussed by many learning often hinges on reflection.

Reflection

The importance of reflection has been consistently pointed to as key to adult learning and teacher professional development (Burbank & Kauchak, 2003). Reflection is "a vital part of professional development design, informing the work not only after implementation but also during and before" (Loucks-Horsley, Love, Stiles, Mundry, & Hewson, 2003, p. 1). Clarke and Hollingsworth (2002) argued that a focus on reflection signifies the shift in focus from earlier conceptions of professional development to "programs that change teachers to teachers as active learners shaping their professional growth through reflective participation in professional development programs and in practice" (Clarke & Hollingsworth, 2002, p. 948).

Adey (2004) pointed to the concept of the reflective practitioner emerging in numerous professional development studies. A reflective practitioner has “a tacit knowledge base, who continuously builds on that base through ongoing inquiry into practice, constantly rethinking and reevaluating his or her own values and practices in concert with others” (Lieberman, 1994, p. 15). In particular, reflective teachers are able to “examine their classroom practice to determine the gap between the ideal and the real, plan how to bridge the gap, take action, and assess their effort” (Gordon, 2004, p. 204).

Guided reflection within professional development settings can be facilitated through different mechanisms such as diaries or feedback sessions. Lieberman (1994) argued that the focus on teachers as reflective practitioners redefines the concept of teacher professional development from the “old idea of in-service education or staff development since it concerns itself with teachers’ continuous inquiry into practice, viewing teachers as adult learners” (p. 15). Within professional development, guided reflection enables “the process of conceptual change, and conceptual change re-structures the intuitive knowledge upon which teaching practice rests” (Adey, 2004, p. 158). In addition, reflection can promote the transfer to classroom application.

Learning Transfer

Related to teacher learning within professional development, the importance of learning transfer is often discussed in the literature. Learning transfer is “not about carrying the commodity of knowledge from here to there but is about learning to recognize a need for transfer and then to make new understandings with existing knowings and knowledge” (Knight, 2002, p. 234). The emphasis on transfer is related to the impact of the professional development beyond personal growth into classroom practice and student learning. For example, Knight (2002) argued that “something taught in an in-service course has a transfer value and a life expectancy directly proportional to its fit with the community of practice” (p. 232). The link between professional development and application is informed by the design of learning opportunities.

Design Principles

Professional development design elements “are the components that comprise professional development that designers of professional development have immediate control over and can modify in order to increase their impact on teachers’ knowledge, beliefs, and attitudes, and subsequent enactment” (Fishman et al., 2003, p. 646). Speck and Knipe (2005) pointed out that each type of professional development has a distinct “purpose and a level of impact, both of which must be weighed in the overall design for school and student improvement” (p. 70).

Decisions concerning the design of the professional development are related to the desired outcomes identified during the planning process. As Joyce and Showers (2002) stated, design “involves identifying types of outcomes or content to be pursued and selecting training components or strategies likely to bring about success in achieving those outcomes” (p. 70). According to Craft (2000), a key issue for planning professional development is the match between its design and purpose.

Loucks-Horsley et al. (2003) outlined a design framework for professional development in science and mathematics, adding that there is “no ‘paint by numbers kit’ for professional development” (p. 7). They argued that the inputs that designers should consider include the extensive knowledge base that can inform their work, unique contextual features, a wide range of professional development strategies, and critical education reform issues. Designers must commit to a vision and standards; analyze student learning and other data; set goals, plan, and implement; and evaluate the professional development program.

There are numerous design principles identified in the literature. Perhaps the authoritative list is that of the National Staff Development Council (2001), which groups design principles into three categories: (a) context, (b) process, and (c) content. Craft (2000), however, pointed out that there are numerous other angles from which to design professional development including, (a) purposes, (b) location, (c) length, (d) methods, and (e) levels of impact. Fishman et al. (2003) argued that there are four primary elements of professional development design: (a) the content of professional development, (b) the strategies employed, (c) the site for professional development, and (d) the media used.

To help shed more light on this issue Birman, Desimone, Porter, and Garet (2000) surveyed over more than 1,000 teachers who had participated in professional development sponsored in part by the Eisenhower Professional Development Program. They determined that three structural features set the context for this type of professional development including: (a) the form of the activities, reform-based or as traditional; (b) duration or the number of hours and time span; and (c) participation of either groups of teachers or individuals. In addition, they identified three core features, including: (a) content focus, (b) active learning, and (c) coherence with teachers' goals and aligned with state standards and assessments.

Following is a description of some of the major design principles involved in teacher professional development including content, strategies/processes, sites and context, and media. In addition, general outcomes of teacher professional development are also explored.

Content

The content associated with professional development is defined by what designers hope teachers learn from the experience. Fishman et al. (2003) argued that there are two main categories for such content: (a) general teaching knowledge, such as assessment, classroom management, and teaching strategies, and (b) subject matter content, which includes skills related to using technological tools related to that content.

In particular, subject matter content knowledge has been the focus of much of teacher professional development. For example, Monk's (1994) study analyzing the relationship between the subject matter preparation of mathematics and science high school teachers and their students' subsequent academic performance found that teacher content preparation was positively related to how much mathematics and science students learned. In terms of professional development, McLaughlin (2002) stressed that more content knowledge by itself is not necessarily the answer. Teachers "need to know how to engage students in content knowledge, how to allocate time and attention, how to articulate standards appropriate for practice" (McLaughlin, 2002, p. 95).

Strategies/Processes

Strategies are the professional development design elements having to do with the instruction used to teach the teachers. According to Fishman et al. (2003), there is "no canonical list of these strategies, though many authors have presented characterizations of ‘best practice’ strategies” (p. 647). For example, Loucks-Horsley et al. (2003) outlined 18 strategies under six categories that included: (a) aligning and implementing curriculum; (b) collaborative structures; (c) examining teaching and learning; (d) immersion experiences; (e) practicing teaching; and (f) vehicles and mechanisms. In addition, Speck and Knipe (2005) presented a list of professional development types from onetime workshops to summer institutes and outlined their length, level of use, and level of impact. These strategies are presented in Table 2.

Table 2

Professional Development Types, Length, Impact and Use

Type	Length	Level of Use	Level of Impact
Onetime workshop	Episodic	Awareness of new strategy	Little or none
Series of workshop	2-3 days	Awareness, practice	Beginning use
Series of workshop	3-12 months	Awareness, practice beginning implementation	Implementation
Coaching	Ongoing	Ongoing coaching	Continued use
Job embedded	Daily	Research into practice Observation, reflection	Inquiry into practice
Action research	Ongoing	Research in practice	Study of issue
Networks	Periodic	Sharing and reflection	Reinforces work
Conferences	Periodic	Awareness and sharing	Little or none
Summer institutes	Periodic	Awareness, development, practice, reflection	Little or none

Note. Adapted from Speck and Knipe, 2005.

Sites and Context

Another design element professional development providers consider is sites where the learning is to take place. Professional development sites include more traditional locations such as after-school in-service sessions, summer workshops, or graduate-level coursework. Lieberman (1995) located teacher learning in three settings: (a) direct learning as in conferences and workshops, (b) learning in school through peer coaches and mentors, and (c) learning out of school in school-university partnerships or professional development centers.

Related to the site of the professional development, is the issue of the context in which it operates. According to Guskey (1995), the importance of context is often overlooked by professional development designers. Teaching and learning is greatly impacted by highly diverse contexts. As Ancess (2001) found in an analysis of three cases of high-performing high schools; teacher learning does not occur in a vacuum, rather it is inextricably connected to school culture, instructional mission, and organization, as well as teachers' knowledge and the learning and achievement of students. This complexity makes "it difficult, if not impossible, for researchers to come up with universal truths" (Guskey, 1995, p. 117).

Griffen (1987) outlined five contextual features that impact professional development programs: (a) state and national regulatory agencies, (b) ideological climate, (c) available technical knowledge, (d) linkage with other systems, and (e) reputational status of teachers and schools. Loucks-Horsley et al. (2003) also outlined contextual factors including organizational structures and leadership; national, state, and local policies; available resources such as time, money, and available expertise; the history of professional development; and parents and community. They added that, given the unique aspects of context, there are consistent '"tough' nuts that professional developers work to crack as they design and provide learning experiences for teachers" (p. 9). These include time, equity and diversity, professional culture, leadership, capacity building for sustainability, scaling up, and garnering public support.

Media

The media through which professional development is conducted is another design element. Media can include face-to-face interaction, video, audio, computers, and print. The choice of media is dependent on the focus of the professional development in terms of content knowledge; demonstration or modeling of skill; practice of skill under simulated conditions; peer coaching; etc. A specific media that has gained increasing attention is online teacher professional development. Dede (2006) argued that online programs make professional development “available to teachers at their convenience and provide just-in-time assistance” (p. 2).

Outcomes

As Guskey (1986) argued, professional development efforts “*must* consider the order of outcomes most likely to result in desired change and the endurance of that change” (p. 6). He outlined three related outcomes including “change in the classroom practices of teachers, change in their beliefs and attitudes, and change in the learning outcomes of students” (p. 6). Bredeson (2003) outlined a similar list of outcomes related generally to professional development. These included enhanced knowledge and skills, improved practice, and the achievement of goals. Joyce and Showers (2002) articulated potential outcomes including knowledge of educational theories or practices, new curricula, or academic content; the development of new skills; and the transfer of training with consistent and appropriate use of new strategies.

The often pursued outcome of professional development is increased student achievement (Supovitz & Turner, 2000). A few studies have been conducted to analyze this connection. For example, Monk's (1994) study found that teacher content preparation was positively related to how much mathematics and science students learned. This finding was similar to Darling-Hammond's (2000) study where teacher quality characteristics were found to be positively correlated with student outcomes. In these studies, both the kind and extent of professional development mattered for teaching practice and for student achievement.

According to Joyce and Showers (2002), four conditions must be present if professional development is to affect student learning. These conditions include:

1. A community of professionals studying, practicing what they are learning, and sharing the results.

2. Selection of curricular and instructional strategies that have a high probability of affecting student learning for the content of staff development.

3. Change in student learning must be significant enough to be measureable. Teaching practices and the social climate of the school must change to increase student ability.

4. Staff development processes should enable educators to develop the skills needed to implement what they learn.

Evaluation

Another increasingly important design element of professional development programs is the evaluation plan. Evaluation is the determination of value and worth, which "typically involves asking questions, gathering information, drawing conclusions and making a report, containing recommendations for future action" (Craft, 2000, p. 82). Craft (2000) argued that professional development evaluations have been "rather haphazard and not gone beyond measures of particular satisfaction" (p. 85). Adding that the “favored method of evaluation – the end-of-course questionnaire – has often failed to get beyond ‘what did you like and dislike about the day?’” (Craft, 2000, p. 85).

The pressures of funding agencies and their accountability requirements have increased the attention and rigor of evaluation. In addition to funding agencies’ demands, Bredeson (2003) explained that the increasing emphasis on evaluation is due to standards-based reform and the shift in focus on measureable outcomes. As Shaha, Lewis, O’Donnell, and Brown (2004) stated, “in the age of accountability, expenditures must represent *investments* that promise tangible improvements in teacher *and* student performance as verified statistically through data” (p. 1).

Bredeson (2003) pointed out numerous reasons why evaluation is important to professional development. For example, funding institutions of such programs want to see a return on their investment. Researchers have estimated that professional development costs approximately $19 billion annually. Evaluation provides an accounting of impact and a justification of cost. Evaluation provides better information for planning when needs assessments are used to guide decision making. In addition, evaluation can provide better understanding of how people learn, change their practice, and affect student learning. As Fishman et al. (2003) argued, “the most important measure of whether professional development is ‘working’ is whether teacher enactment yields evidence of improved student learning and performance” (p. 655).

In designing evaluations for professional development programs, many researchers have pointed out the need to represent the different stakeholders involved beyond the direct influence on teachers, including students, administrators, and the school culture. In addition, evaluation can be focused on the processes, outcomes, or a combination of these. Craft (2000) categorized the areas of examination involved in evaluation, including (a) preparation, including needs identification; (b) planning the activities, as indicated by the clarity of goals; (c) execution of activities, including the contribution to participants; and (d) impact or the degree of change. Guskey (2000) outlined five critical levels of assessment, which are hierarchically arranged from simple to more complex: (a) teachers’ reactions to the experience; (b) participant learning; (c) organizational support and change; (d) if and how participants use their newly acquired knowledge and skills in practice; and (e) student learning outcomes.

Barriers

Much has been documented concerning the barriers to teacher professional development. For example, Fullan and Stiegelbauer (1991) reviewed the related research and summarized that professional development efforts fail because: (a) of an extensive use of one-shot workshops; (b) topics selected by nonparticipants; (c) lack of follow-up; (d) lack of thorough evaluation; (e) factors within the schools not being addressed; and (f) an absence of a conceptual basis for program planning and implementation. Guskey (1986) theorized that “the majority of programs fail because they do not take into account two critical factors: what motivates teachers to engage in staff development, and the process by which change in teachers typically takes place” (p. 6).

Bredeson (2003) pointed to specific barriers associated with particular professional development dimensions including its design, delivery, content, context, and outcomes, as shown in the Table 3. In addition, Bredeson outlined strategies that can be used to overcome these barriers.

Table 3

Professional Development Dimensions, Barriers, and Strategies

Dimensions	Barriers	Strategies
Design	Individualist Opportunistic Not linked to school goals	Systems thinking Link learning goals and innovations Integrated professional development plan
Delivery	Episodic and fragmented No follow-up Costly Passive participation	Explicit criteria for selecting activities Systematic processes for sharing new knowledge Flexible, creative use of resources
Content	Fragmented and incoherent Quick nuggets of knowledge Insufficient theoretical support	Explicitly link needs and goals of school/individual Follow-up strategies to deepen learning, reflection, and feedback
Context	Inadequate resources Lack of support structures Negative cultures Daily demands of school	Multiple strategies to create time and generate resources Intentional plan to create structures and culture to support learning
Outcomes	Poor assessments of learning Lack of feedback Inadequate cost/benefit analyses	Systematic evaluation of all aspects of professional development Link assessments to plans and goals

Note. Adapted from Bredeson, 2003

Effective Practices

A consensus has emerged within the literature about the characteristics that differentiate effective professional development practices. Bredeson (2003) pointed out that, rather than one best professional development practice, “there is an emerging consensus in the literature suggesting a set of organizing principles and processes that teachers, administrators, and policy makers can use to design their own models for professional learning” (p. 22). Numerous lists have been generated to summarize effective professional development practices with differing degrees of consistency as outlined by Guskey (2003) and Loucks-Horsley, Stiles, and Hewson (1996).

Inventories

Darling-Hammond and McLaughlin (1995) argued that effective professional development engages teachers in concrete tasks of teaching, assessment, observation, and reflection; is grounded in inquiry, reflection, and experimentation; is collaborative; connected to and derived from teachers' work with their students; is sustained, ongoing, intensive, and supported by modeling, coaching, and the collective solving of specific problems of practice; and is connected to other aspects of school change. Based on results from their national survey, Birman et al. (2000) concluded that "professional development should focus on deepening teachers' content knowledge and knowledge of how students learn particular content, on providing opportunities for active learning, and on encouraging coherence in teachers' professional development experiences" (p. 32).

Similarly Desimone et al. (2002) argued that high quality professional development must include "a focus on content and how students learn content; in-depth, active learning opportunities; links to high standards, opportunities for teachers to engage in leadership roles; extended duration; and the collective participation of groups of teacher from the same school, grade, or department" (p. 82). Bredeson (2003) argued that successful professional development design includes active participation by teachers and staff, links to long-range school and district goals, a careful needs assessment, and a plan that expresses core values, purpose, and goals. The content of successful professional development should be relevant to the teachers' work, deepen their knowledge and skills, lead to improved practice, and be connected to other aspects of their work lives.

Loucks-Horsley et al. (2003) outlined elements of effective mathematics and science education professional development. They stated that effective professional development is driven by a well-defined image of effective classroom learning and teaching; builds teachers' content and pedagogical content knowledge; is research based; engages teachers as adult learners; provides opportunities for teachers to collaborate; supports teachers in leadership roles; links with other parts of the education system; is based on student learning data; and is continuously evaluated and improved.

Speck and Knipe (2005) argued that effective professional development is "embedded in the daily work of educators; offers choices and levels of learning; builds on collaborative, shared knowledge, employs effective teaching and assessment strategies; expands teacher knowledge of learning and development; and informs teachers' daily work" (p. 70). In addition, professional development is more effective when it is sustained and intensive, with opportunities for practice, collaborative application through problem solving and action research, coaching, and leadership.

Common Vision?

Loucks-Horsley et al. (1996) reviewed standards documents and related resources and found that they reflected a common vision concerning effective science and mathematics professional development. In particular, the best professional development includes the following seven principles:

1. Driven by a clear, well-defined image of effective learning and teaching.

2. Provide teachers with opportunities to develop knowledge and skills and broaden their teaching approaches.

3. Use instructional methods that promote adult learning and mirror the methods to be used with students.

4. Strengthen the learning community of teachers.

5. Prepare and support teachers to serve in leadership roles.

6. Provide links to other aspects of the educational system.
7. Include continuous assessment.

Guskey (2003) analyzed 13 lists of characteristics of effective professional development from organizations such as the American Federation of Teachers, Association for Supervision and Curriculum Development, Educational Research Service, National Institute for Science Education, National Staff Development Council, and US Department of Education and concluded that these lists varied widely in terms of the characteristics identified. Most of the characteristics identified as effective were often described as ‘yes, but…statements” (p. 750), indicating the complexity of the varied contexts and desired results pursued by different professional development efforts.

Guskey (2003) determined that the most frequently cited characteristic of effective professional development was the enhancement of teachers’ content and pedagogical knowledge. Most of the lists also included the need for prolonged engagement, sufficient resources, the development of collegiality and collaboration, and the inclusion of evaluation procedures. In addition, the research evidence supporting these lists is inconsistent and sometimes contradictory.

Research

Though lists of effective practices have been outlined and different models offered by many within the literature, there has not been an overwhelming empirical connection of these or other components to teacher behavior or student learning. As Fishman et al. (2003) stated, numerous professional development opportunities exist for teachers, particularly within science and mathematics, but there are few empirical research efforts studying these programs. We “continue to know relatively little about what teachers learn from professional development let alone what students learn as a result of changed teaching practices, which is the ultimate measure of standards-based reform efforts" (Fishman et al., 2003, p. 643).

Of those who have engaged in research, Joyce and Showers (2003) grouped the studies into two empirical paradigms: (a) naturalistic studies of teachers and schools, particularly seeking to identify the characteristics of the most effective teachers and schools; and (b) experimental studies where philosophical or psychological positions about the nature of learning have been studied. In addition, Borko (2004) mapped the terrain of research on teacher professional development into three phases; research on: (a) an individual program at a single site; (b) a single program enacted by more than one facilitator at more than one site; and (c) multiple programs, enacted at multiple sites.

Ornstein (1999) provided a historical analysis of research in teacher professional development, stating that in the early stages, up to the mid-1970s, "the theorists were concerned with *teacher processes*—that is, what the teacher was doing while teaching" (p. 17). From the 1970s until about 1990, Ornstein argued researchers shifted their concerns to student outcomes and the assessment of teacher effects. Another shift has recently occurred, where researchers have begun to "analyze the culture, language, and thoughts of teachers, combine (rather than separate) teaching and learning processes, and use qualitative methods to assess what they call *teacher contexts*" (Ornstein, 1999, p. 17). In summary, Ornstein stated that research on teacher professional development was linear and category-based, focused on the process or products of teaching, but has expanded to examine the multifaceted nature and context of teaching.

Wilson and Berne's (1999) review of the literature led them to conclude that the field was "oddly discontinuous" (p. 204). They believed that the research on teacher professional development fell loosely into three "knowledge" categories, whereby researchers talked about: (a) subject matter; (b) students and learning; and (c) teaching. Four observations emerged in their review, including that: (a) the literature had a semi-ahistorical tone; (b) there was a need for subject-specific investigations in teacher learning; (c) future research should focus on issues of teacher knowledge; and (d) few studies link teacher learning to teaching behavior or student achievement. Others have also called for more research connecting the effects of professional development to teaching methods and student outcomes (Evans, 2002; Garet et al., 2001).

Given the documented lack of research and the focus of existing research, many continue to call for more rigorous research on teacher professional development. For example, Evans (2002) argued that the research examining teacher development is dominated by numerous issues, however the concept itself is rarely defined and the methods affecting it are under-examined. As an "emergent area of study, its knowledge base is still underdeveloped and inadequate compared with those of more established areas and, therefore, needs supplementing" (Evans, 20002, p. 128). Fishman et al. (2003) argued that to "create excellent programs of professional development, it is necessary to build an empirical knowledge base that links different forms of professional development to both teacher and student learning outcomes" (p. 643).

Professional Development Models

Based on the identification of effective practices, numerous researchers have identified, developed, or researched different professional development models. For example, Husby (2005) offered a professional growth model that emphasizes individualized, self-directed learning so that teachers can identify areas for improvement and develop plans for professional growth. During group meetings teachers engage in only four activities: (a) completion of a learning plan, (b) mini-lessons to develop self-directedness, (c) independent work on a self-selected project, and (c) individual and group reflections. In addition to specific models offered in the literature, there are three broad types that deserve closer attention: (a) training models, (b) curriculum-linked models, and (c) collaborative models.

Training

Historically, and throughout most of the 20th century, the primary teacher professional development model has been training. However, Tillema and Imants (1995) pointed to a trend in the literature of separating training from professional development, stating that training is "hardly mentioned anymore" (p. 135). Gordon (2004) concurred, stating that when it is discussed "it often is discussed with a negative connotation, even being portrayed as antithetical to authentic professional development (Gordon, 2004, p. 33). Training is often associated with a perspective of teaching as a technical skill and equated with the development of competence in specific behaviors. Gordon (2004) included other common reactions including the belief that animals are trained, not people; that since teaching is such a complex craft, the training model is inadequate; and that teachers should become reflective practitioners, not technicians.

Cochran-Smith and Lytle (2001) argued that “it has been widely acknowledged that professional development needs to be linked to educational reform and needs to focus on culture-building, not skills training” (p. 46). Little (1993) also argued that “the dominant training model of teachers’ professional development—a model focused primarily on expanding an individual repertoire of well-defined and skillful classroom practice—is not adequate to the ambitious visions of teaching and schooling embedded in present reform initiatives” (p. 129). Instead, Little offered four alternatives to the training model: (a) teacher collaboratives and networks, (b) subject matter associations, (c) collaborations targeted at school reform, and (c) special institutes and centers.

Training can include formats such as institutes, clinics, seminars, workshops, courses, academies, and individualized training (Gordon, 2004). Institutes are intensive training in a specific area of study. Clinics focus on specific problems or specific techniques through expert demonstration or coaching. Seminars are small groups working closely with acknowledged experts in their field. Workshops are flexible structures that focus on the discussion, demonstration, and application of skills and strategies. Courses are completed usually in exchange for credit hours from a college and include participation in a specified amount of instructional time, the completion of outside assignments, and a minimum standard of performance. Academies are typically recurring programs, supported by government agencies, professional associations, or other institutions. Individualized training allows for self-paced, guided instruction targeting an individual’s learning needs.

Gordon (2004) argued that the negative portrayals of the training model ignore the ability of this approach to facilitate “empowerment and reflective practice” (p. 34).

Tillema and Imants (1995) argued that for training models to be successful it is important that they are "related experientially to the task environment and that they foster the extension of the teaching repertoire in a stimulating way" (p. 136). In addition for training programs must account for the structure of teachers' knowledge, provide opportunities for learning, and construct and communicate validated knowledge. They added that it is "only with the help of an adequate diagnosis of existing conceptions and beliefs that a training program can successfully connect with the existing knowledge structures or schemata of teacher" (p. 142).

Curriculum-Linked

Another professional development model is "curriculum-linked" professional development, where the focus is "specifically on how to enact pedagogical strategies, use materials, and administer assessments associated with particular curricula" (Penuel, Fishman, Yamaguchi, & Gallagher, 2007, p. 928). In this regard, curriculum is defined as formal curriculum consisting of intentional, carefully planned learning experiences written in documents (Moore, 2005). The emphasis on curriculum within professional development is due, according to Ball and Cohen (1996), to the fact that curriculum implementation is "one of the oldest strategies for attempting to influence classroom instruction" (Ball & Cohen, 1996 p. 6). Fishman et al. (2003) agreed, stating that curriculum holds a central place because curriculum directs teaching in the classroom.

Loucks-Horsley et al. (2003) outlined underlying assumptions of curriculum-linked models. An assumption of this model is that teachers become clearer about the goals for student learning and increase their own understanding of the subject matter by learning to use quality curriculum materials. In addition, the content and pedagogical content knowledge that is directly connected to their curriculum increases the likelihood of teachers learning it and making changes in their classroom teaching. They argued that for curriculum-linked models to "support professional development, plans must be designed that enable teachers to learn about, try, reflect on, and share information about teaching and learning in the context of implementing the curriculum with their colleagues" (Loucks-Horsley et al., 2003, p. 127).

The curriculum-linked model has been criticized by some who argue that this approach "'de-skills' the professional work of teaching and severely limits local discretion over curriculum" (Ball & Cohen, 1996, p. 6). They pointed to trainers who are the publisher's representatives pursuing sales and promotion. In addition, even when the program is more comprehensive, the "materials are seen as offering resources for teachers' work with their own students, and are not designed to entail or encourage teachers' investigations of and work with the material." (Ball & Cohen, p. 8). Curriculum within professional development "could contribute to professional practice if they were created with closer attention to processes of *curriculum enactment*" (Ball & Cohen, p. 7). Thus the model may not faulty but its implementation ignores the transfer of learning back into the classroom.

Collaborative

Collaborative teacher professional development models "provide the mechanism for convening groups for professional learning around goals and procedures that the participants' determine" (Loucks-Horsley et al., 2003, p. 138). The underlying assumptions of these models include that the context within which teachers work provides worthwhile content for their collaboration; collegiality, cooperation, and communication among teachers are valued by the school and extended communities; quality education is a community responsibility requiring collaboration; and learning is a social activity.

These models are often centered on school-university partnerships. School-university partnerships are structured around collaborations between K-12 education systems and teacher education institutions. For example, Miller (2001) stated that school-university partnerships create their own values, rules, and roles to support open interaction. Specifically, professional development schools (PDSs) are educational partnerships that use “resources, power, authority, interests, and people from separate organizations to create a new organizational entity for the purpose of achieving common goals” (Burton, & Greher, 2007, p. 15). Trachtman (2007) pointed to Dewey’s laboratory schools administered by schools and colleges in the early 1900s as the origins of the PDS model. In the 1980s, PDSs re-emerged because they were seen as “the innovation that could effectively link teacher and student learning” (Trachtman, 2007, p. 198).

The PDS model is analogous to teaching hospitals in medicine, in that they provide “professional preparation of candidates, faculty development, clinical research, and enhanced student learning” (Trachtman, 2007, p. 198). Chance (2000) equated PDSs with learning communities, where professors, teachers, administrators, and prospective teachers work together to support the initial and continuing preparation of teachers while focusing on improving teaching and learning in preK-12 classrooms. Four primary goals often surround the mission of PDS, including: “(a) maximizing student learning and achievement through the development and implementation of exemplary practice; (b) engaging in sustained inquiry on practice for the purpose of enhancing exemplary practice and student achievement; (c) engaging in meaningful, ongoing, professional development; and (d) preparing effective new teachers" (Burton & Greher, 2007 p. 15).

Some of the potential pitfalls of school-university partnerships surround "issues of partnership expectations, time on task, negative candidate behavior, negative modeling by partner-school staff, curricular mismatch, and dispositional status" (Ledoux & McHenry, 2008, p. 156). University and school partners often have different expectations concerning the role, responsibility, and outcomes of the partnership. For example, teacher "partners sometimes use teacher candidates as educational entertainment rather than as a source of curricular renewal" (Ledoux & McHenry, 2008, p. 158). University partners sometimes assume the dominant role because the partnership's sole purpose is limited to serving the needs of the student teachers. Tensions due to cultural differences between the institutions can also arise. In addition, "distrust, disrespect, and dissension can undermine the social support requested for productive interaction, discourage open exchange and cooperation, and thwart opportunities for teacher learning and change" (Fisler & Firestone, 2006, p. 1182).

Ledoux and McHenry (2008) argued that careful planning and clear communication can help reduce the likelihood of these pitfalls. As Stephens and Boldt (2004) stated, "each partner needs to try to understand as fully as possible, in the beginning and along the way, that behind the rhetoric of school/university partnerships, there is reality and that behind the reality, there is intimacy" (p. 703). A "collegial and egalitarian relationship between participants is necessary to build a truly effective alliance between a public school and a university" (Lefever-Davis, Johnson, & Pearman, 2007, p. 204). The National Council for Accreditation of Teacher Education (NCATE) developed two sets of standards, *Standards for Professional Development Schools* (2001) and the *Handbook for the Assessment of Professional Development Schools* (2001), to help guide these partnerships and provide accountability for PDSs.

The research indicates that there are numerous benefits to this approach. Pre-service teachers receive more feedback, supervision, and informal guidance when involved in partnership programs. Teacher effectiveness in the classroom is improved and further interaction with the school community is often established. Teachers develop "increasingly sophisticated conceptions about the teaching and learning process" (Burton & Greher, 2007, p. 17). In a study comparing PDS teachers to non-PDS teachers, Castle, Fox, and Souder (2006) found that PDSs are "producing beginning teachers who are more integrated and student centered in their thinking about planning, assessment, instruction, management, and reflection" (p. 78). Although much of this research is focused on pre-service teachers, in-service teachers who participate in PDSs are more likely to improve their own teaching practice as well (Burton & Greher, 2007).

STEM Education

This part of the chapter positions the review of literature within the science, technology, engineering, and mathematics (STEM) disciplines because engineering-oriented content primarily draws from these disciplines. In addition, key national reform efforts (i.e., the No Child Left Behind Act of 2001, U.S. Department of Education, 2002) have emphasized STEM education reform (i.e., *Rising Above the Gathering Storm*, NRC, 2006) and have called for links with engineering education (*Preparing for the Perfect Storm*, 2006). The growing call for collaboration with engineering has led to the identification of critical issues that require sustained research; specifically the need for teacher professional development in engineering-oriented education.

Science Education

As previously discussed, many point to the launching of Sputnik in 1957 as the landmark event spurring educational reform, particularly within science and mathematics education. During the 1960s, the National Science Foundation responded by funding numerous science and mathematics education curriculum and professional development projects. Within science education these projects “emphasized learning scientific inquiry processes or ‘process skills,’ learning valid scientific concepts, and engaging students actively in exploration with materials” (Dana, Campbell, & Lunetta, 1997, p. 421). Science education focused largely on laboratory activities “as a means for learning science in a more meaningful way” (Roth, McGinn, & Bowen, 1996, p. 455). The curricula was based on the assumption that the structure of science was revealed to students when they were engaged through hands-on activities. This notion led to discovery learning initiatives within science education.

The focus on laboratory science, however, “did not appear to develop better understandings” (Roth et al., 1996, p. 455). Research indicated that students learned procedures for following instructions rather than scientific knowledge. By the 1970s, new influences on science education “such as back-to-basics movements; growing concerns about culture, equity, and the special needs of diverse learners (ethnicity, gender, and learning disabilities); and lack of appropriate continuing professional development in science and in science-specific pedagogy—confounded the implementation and development of the innovative science programs” (Dana et al., 1997).

By the 1980s as fears mounted about the nation's competitiveness, focus was again placed on reforming science education, this time around educational standards. In 1989, the American Association for the Advancement of Science, published *Project 2061: Science for All Americans*, calling for changes in science curricula, teaching, and assessment. The National Research Council followed this report with the publication of the *National Science Education Standards* in 1996. The standards outline what students should understand as a result of their science education. Roth et al., (1996) characterized the recommendations embedded in the reform documents, including to: (a) develop understandings of authentic scientific and mathematical practices, (b) pursue the depth of content, (c) emphasize teachers' roles as intellectual coaches, consultants, or moderators, and (d) increase reflection on knowledge construction.

Science Professional Development

With the different waves of educational reform, attention was placed on science teacher preparation and development. As a result of curricular reform in the 1960s, science teachers attended summer institutes, as the "principal mechanism for providing professional development" (Dana et al., 1997, p. 421). However, these efforts largely failed to enable teachers to implement changes. Teachers returned to the realities of their classrooms and "abandoned the 'bags of tricks' from summer institutes and even the new curricula and approaches to teaching science" (Dana et al., 1997, p. 421).

With the publication of reports by the Holmes Group (1986) and the Carnegie Task Force on Teaching as a Profession (1986), attention was once again placed on the complex role of teachers in educational reform. Teaching was seen as more than covering curriculum, but interpreted as the promotion of meaningful understanding in students.

The “knowledge that has emerged from the teaching of science in the twentieth century suggest that teacher education programs must engage teachers in experiences that are grounded in an understanding of science and in a theoretical framework of how learners construct meaningful knowledge” (Dana et al. 1997, p. 423).

For example, Bell and Gilbert’s (1994) review of 15 years of international science learning research led them to conclude that the research has centered on “the notions of children’s science, constructivist views of learning and conceptual development” (p. 483). A primary implication of this research has been on the changed roles and activities of the science teacher. According to Zeidler (2002), “a centerpiece of educational reform (at least within the circles of science teacher education) has been largely a tripartite structure with the anchoring points being teachers’ subject matter knowledge (SMK), pedagogical knowledge (PK), and pedagogical content knowledge (PCK)” (p. 27).

This emphasis on SMK, PK, and PCK, has increased science education researchers’ attention focus on teacher professional development. Professional developers in science education have focused on addressing “the need for science teachers to increase their content knowledge, instructional strategies, and experience using inquiry” (Johnson, 2006, p. 151). Supovitz and Turner (2000) outlined six critical components of high quality science education professional development. These components include: (a) immersion in inquiry, questioning, and experimentation; (b) intensive and sustained experiences; (c) engagement in concrete teaching tasks based on teachers’ experiences with students; (d) focus on subject-matter knowledge and deepening teachers’ content skills; (e) grounding in a common set of professional development standards; and (f) connection to other aspects of school change. In particular, the science education community has focused on the development of student inquiry through teacher professional development.

Mathematics Education

Mathematics education has a similar history as science education with its development linked to national reform movements. Herrera and Owens (2001) pointed to two distinct reform movements within mathematics: (a) the "new mathematics movement", and (b) National Council of Teachers of Mathematics' (NCTM) standards-based reform; with an era of "back to basics" between the two movements. During the 1960s, the new mathematics movement developed in response to the launch of Sputnik and concerns of the nation's technical and mathematical skills. The College Entrance Examination Board appointed a Commission on Mathematics, who developed a nine-point program that "called for preparation in concepts and skills to prepare for calculus and analytic geometry at college entry" (Herrera & Owens, 2001, p. 85). Hallmarks of the new mathematics included the precise language of sets, logic, algebraic structures, and pedagogical approaches of discovery.

Although teachers largely attended training in the "new mathematics," criticism of this new approach grew and in the 1970s the "back to the basics" era began. Instead of the Socratic dialogue of the "new mathematics," teachers were to "guide students through a prescriptive hierarchical curriculum" (Herrera & Owens, 2001, p. 87), focused on computation and algebraic manipulation. According to Herrera and Owens (2001), it was in reaction to the "back to basics" era, that the NCTM standards-based reform movement emerged. Growing concerns of the "back to basics" mathematics centered on the belief that the field of mathematics was not responsive to changes in society. In 1980, NCTM appointed a committee to develop recommendations, resulting in *An Agenda for Action*. Problem solving was set as the curricular focus of mathematics by the committee, which also supported the use of calculators and computers across all grade levels.

During this same time, calls for educational reform were increasing. For example, studies such as the Second International Mathematics Study and the International Assessment of Educational Progress, revealed that the U.S. was “weak in several areas” (Herrera & Owens, 2001, p. 88). The response from NCTM was the publication of the *Curriculum and Evaluation Standards for School Mathematics* (1989) and in 1991 the *Professional Standards for Teaching Mathematics* to address changes in teaching. In 1995 *Assessment Standards for School Mathematics* were also developed. These documents communicated NCTM’s vision of mathematics in K-12 classrooms, which included “a central focus on the conceptual versus the merely procedural” (Herrera & Owens, 2001, p. 89). In 2000, NCTM revised the standards, seeking to simplify and clarify their vision with the *Principles and Standards for School Mathematics*.

In response to these standards documents, much of the literature in mathematics has focused on the conceptual and procedural aspects of mathematics. For example, the Committee on Mathematics Learning Report, *Adding It Up* (2001), recommended that “all five strands of mathematical proficiency (conceptual understanding, procedural fluency, strategic competence, adaptive reasoning, and productive disposition) should guide the teaching and learning of school mathematics” (p. 11). In particular, conceptual knowledge encompasses the “knowledge of the underlying structure of mathematics—the relationships and interconnections of ideas that explain and give meaning to mathematical procedures” (Eisenhart, Borko, Underhill, Brown, Jones, & Agard, 1993, p.

9). Procedural knowledge refers to the computational skills and knowledge of procedures such as knowing how to identify a problem and how to solve it correctly.

As Rittle-Johnson and Alibali (1999) stated, the design of effective instruction depends on the ability to “delineate key mathematical concepts and their associated procedures, identify what children at various ages understand and what they struggle to learn, and examine how instruction influences children’s acquisition of both concepts and procedures” (p. 175). However, Rittle-Johnson, Siegler, and Alibali (2001) stated that much of the literature focuses on the type of knowledge that develops first resulting in either concepts-first or procedures-first theories. They posited that “conceptual and procedural knowledge develop iteratively, with increases in one type of knowledge leading to increases in the other type of knowledge, which trigger new increases in the first” (p. 346).

Mathematics Professional Development

Again as educational reform narrowed the focus on teaching, attention was placed on mathematics teacher preparation and development. For example, during the new mathematics movement, teachers “responded enthusiastically by taking advantage of NSF funded summer-long institutes and training offered by the innovative programs” (Herrera & Owens, 2001, p. 87). However, with the calling for reform both in content and pedagogy, a different view of learning as an active process of constructing knowledge, required different conceptions of teaching mathematics. It was believed that teachers should actively involve students, use concrete materials, include group work, encourage reflection, emphasize context, and facilitate classroom discussion. The task of mathematics teachers became “teaching of mathematics at all levels including its premises, goals and societal environment” (Wittmann, 1995, p. 356).

Peressini, Borko, Romagnano, Knuth, and Willis (2004) argued that calls for reform posed great challenges for the preparation and education of mathematics teachers. Professional development programs are “being called upon to model good mathematics teaching, to help teachers develop their knowledge of the content and discourse of mathematics and of mathematics pedagogy, to offer perspectives on students as learners of mathematics that have a sound research base, and to provide opportunities for teachers to develop their own identities as teachers of mathematics” (Peressini et al., 2004, p. 67). The “principle currencies of the mathematics teacher (if lecturing is rejected as an effective means of promoting concept development) are the posing of problems or tasks and the encouragement of reflection” (Simon, 1995, p. 141).

Technology Education

Technology education’s roots can be located in the manual/industrial arts education movement of the late 1800s, which attempted to connect liberal education to professional training. During the late 1800s, a massive increase in the number of public school students forced schools to adapt the curriculum to meet the needs of children of the working class and manual or industrial arts emerged as an avenue to meet those needs. The curriculum in its early stages reflected the time period with its primary focus on tool usage and design within the graphic, mechanical, plastic, textile, and bookmaking arts (Kirkwood, Foster, & Bartow, 1994).

Throughout the greater part of the 20th century, schools offered a variety of classes that fell under the umbrella of manual/industrial arts or vocational education. By the 1950s, vocational education was an established aspect of the curriculum. However, by the 1980s these programs began to suffer a decline due to incoherence in the field and changing demands of high school graduation requirements (Hansen & Reynolds, 2003). In an attempt to reach a consensus on the direction of the field, the *Jackson's Mill Industrial Arts Curriculum Theory* was developed (Wright, 1992). In addition, the *Standards for Industrial Arts Programs* (*SAIP*), which were revised by the American Industrial Arts Association in 1985 resulting in the *Standards for Technology Education Programs* (Dugger, 2002).

By the late 1990s and into the present, the field had largely transitioned into technology education. The expanded mission of the field was articulated in the *Technology for All Americans Project* (ITEA, 1996). This project was funded by the National Science Foundation and the National Aeronautics and Space Administration in 1994 with the first of three phases focused on articulating a rationale for technology education. The phases resulted in: (a) *Technology for All Americans: A Rationale and Structure for the Study of Technology* (1994-1996), (b) *Standards for Technological Literacy: Content for the Study of Technology* (*STL*), and (c) Companion Standards.

The current definition of technology education shifts the focus of the discipline to the education and preparation of all students for a technological world through the development of technological literacy. With the development of the *STL*, the International Technology Education Association outlined what students should know and be able to do related to technology. The primary goal of technology education was stated to be technological literacy, which is the "ability to use, manage, assess, and understand technology" (ITEA, 2000, p. 7).

Technology Professional Development

Research on technology teacher professional development has been less well explored when compared to science and mathematics. There have been few studies examining the effects of professional development on teacher's knowledge or methods and ultimately student learning. However, there are a few examples of studies exploring technology education professional development. For example, Compton and Jones (1998) studied two technology education teacher professional development programs finding that "in order for teachers to become successful technology classroom practitioners, their professional development programmes should focus on identifying, understanding the influences on, and further developing their own conceptualizations of technology education, teacher pedagogy and technological practice" (p. 153). Within specifically vocational education, Eisenman, Hill, Bailey, and Dickison (2003) researched the School-to-Work Professional Development Institute, finding that the teachers believed "boundary crossing-experiences opened new opportunities for their students" (p. 93).

In a commentary on technology professional development, Bybee and Loucks-Horsley (2000) articulated four key components necessary for effectiveness: (a) teachers need to learn about and develop skills related to technology; (b) teachers need opportunities to learn about how to teach technology; (c) teachers need tools and motivation to continue their own learning; and (d) long-term professional development is required to support the kinds of changes required for the STL to be successful. Bybee (2001), in addition to outlining 15 professional development strategies, put forth design principles for effective professional development of technology teachers, including: (a) student learning should be at the core; (b) technology education pedagogical content knowledge should be developed; (c) student learning principles should guide teacher learning; (d) learners' current understandings should be acknowledged; and (e) professional development must align with and support system-based changes.

Pre-College Engineering Education

Within the past decade, many K-12 education researchers, particularly technology education researchers, have proposed a closer collaboration with engineering. Dearing and Daugherty (2004), for example, concluded that engineering and technology education overlap in the areas of problem solving, communication, working within constraints and parameters, brainstorming, appropriate technology, and the impacts of technological growth. Wicklein (2006) argued that engineering is understood more broadly than technology education, elevating the status of the field. Erekson and Custer (2008) also identified reasons for the inclusion of engineering, including the: (a) facilitation of technological literacy, (b) provision of a mathematics and science learning context, and (c) enhancement of an engineering pathway.

Many have zeroed in on engineering design as the point of integration. For example, Lewis (2005) argued that engineering design is the "single most important content area set forth in the standards" (37). Engineering design can be viewed as a form of problem solving, "where there is the requirement that, in addition to solving the problem, the solution be creative" (Middleton, 2005, 65). Design problems, however, are usually among the most complex and ill-structured kinds of problems that individuals encounter (Jonassen, 2000). Design problem solving "fosters the kind of cognition that combines declarative knowledge, the *what*, with procedural knowledge, the *how*" (Welch & Lim, 2000, p. 34).

Amongst engineers and other professional designers, “a certain degree of consensus exists regarding the overall definition and stages of the design process: identification of problems and diagnosis of needs, through a series of loops at which solutions are conceived, explored and evaluated until a suitable answer is found and then instantiated” (Mioduser, 1998, p. 177). However, beyond that general consensus the process is open and flexible, allowing space for a variety of possible problem definitions and solution paths. Expert designers often cycle through the design process, “expanding creative thinking, generating ideas, analyzing them and making a selection” (Court, 1998, p. 145), in an iterative, not predetermined manner.

Within the classroom, Burghardt and Hacker (2004), in a synthesis of the related literature, found that “pedagogically solid design projects involve authentic, hands-on tasks; use familiar and easy-to-work materials; possess clearly defined outcomes that allow for multiple solutions; promote student-centered, collaborative work and higher order thinking; allow for multiple design iterations to improve the product; and have clear links to a limited number of science and engineering concepts” (p. 6). Lewis (2005) also characterized two approaches to engineering design: (a) conceptual and (b) analytic. Conceptual design is the point where engineering science, practical knowledge, production knowledge and methods, and commercial aspects are brought together to solve a problem. Analytic design, however, relies upon mathematics and scientific principles to make decisions and is more problematic for technology education.

This move toward engineering, however, has not been without detractors. Williams (2000), for example, argued that because technology is “such a broad area that a focus on any one process will not provide students with a broad concept of the nature of technology" (p. 57). Instead, Williams advocated for teaching a range of processes in addition to design, including problem solving, a systems approach, invention, and manufacturing. In addition, Mawson (2003) called design a "dominant discursive regime within technology education" (p. 119) and advocated for a focus on "innovative, risk-taking, reflective" (p. 125) problem solving.

A point of contention surrounding the incorporation of engineering design is the "inauthentic" approach of teaching technological problem solving and design. Many instructors have taught problem solving and design with a prescriptive, step-by-step model or a trial-and-error approach. Wicklein and Thompson (2008) stated that this approach has common features including: (a) the identification of a problem, (b) the development of a proposal, (c) the creation of a model or product, and (d) the evaluation of the model or product. Engineers, however, design in an iterative, non-predetermined manner and typically "*predict the behavior* of the design and the *success of a solution* before it is implemented" (Wicklein & Thompson, p. 57). In addition, design is context-specific, in that it is "shaped by the tools and resources available and adapts to the specific, and changing, situation" (McCormick, Murphy, & Hennessy, 1994, p. 6), further complicating its implementation into the K-12 classroom.

As these issues continue to be raised, technology education has increasingly embraced an engineering-oriented perspective with the hope that engineering will "not narrow the choices" (Salinger, 2005, p. 3) for K-12 education, but broaden them. For example, different initiatives such as curriculum development projects (i.e., *Engineering byDesign*™ and *Project Lead The Way*™) and National Science Foundation funded projects such as the National Center for Engineering and Technology Education

(NCETE) have been developed to infuse engineering into primary and secondary education. One key goal of the Technology Teacher Education component of NCETE is to impact the focus and content of the technology education field at the secondary level (Hailey, Erekson, Becker, & Thomas, 2005). As these projects move forward, it is important to understand the connection between problem solving, an established component of technology education, and engineering design.

Teacher Development in Engineering

As K-12 educators move to embrace engineering design, teachers are faced with the challenge of how to teach it appropriately. As McCormick et al., (1994) stated, teaching is an extremely complex and demanding role "even when the teachers understand and are committed to the design process" (p. 31). Teaching design involves "much more than instruction on the manipulative skills of using tools or making drawings, more than instruction on the intellectual knowledge of how a task can be done" (Warner, 2003, p. 7). Perhaps the first step is to define the "appropriate" approach to engineering design, so as to structure teacher preparation (Lewis, 2005). For example, if technology education is to embrace analytic design and "interpret the standards to be an authentic depiction of design as it is conceived and practiced by engineers" (Lewis, 2005, p. 40), then teachers would need to be prepared accordingly. The same can be said if mathematics and science teachers are to embrace engineering content.

The challenge is to identify the fundamental content knowledge and sound pedagogical approaches to aid in the teaching of authentic engineering design. According to McRobbie et al. (2001), in order to "develop worthwhile teacher education courses in design and technology, it is necessary to find out more about the design processes of preservice and in-service teachers and enable them to identify more clearly the students' design understanding and capabilities" (93). Teachers need to be equipped with the knowledge to select problems "within students' capabilities but which enable them to develop and apply their knowledge further" (McCormick et al., 1994, p. 8). Thus research into the most "appropriate" type of design, the conceptual and procedural knowledge underpinning design, and the most appropriate pedagogies for teaching that type of design is needed.

As research progresses so as to better understand teacher and student learning, teacher development can be enhanced. While substantial work has been conducted in mathematics and science education regarding teacher professional development, the efforts in the technology education field, and programs focused on engineering content, have been less intensive and are much less mature. A lack of publication on effective practices, lessons learned, and challenges to secondary level engineering-oriented professional development makes a study investigating mature efforts in the field necessary. A multiple case study of engineering-oriented professional development examining their effective design principles and outcomes will establish a status of the field and help refine future practices and identify areas for further research. It is important to understand where we are so that we can determine where it is we want to go (Strauss & Corbin, 1998).

CHAPTER III

METHOD

This study consisted of a multiple descriptive case study design analyzing five engineering-oriented professional development projects. A case study "connotes a spatially delimited phenomenon (a unit) observed at a single point in time or over some period of time" (Gerring, 2007, p. 19). Case studies allow "one to peer into the box of causality to locate the intermediate factors lying between some structural cause and its purported effect" (Gerring, 2007, p. 45). In addition, case studies protect the right of the researcher to "follow the compelling question, the nagging puzzle, that presents itself once in the setting" (Marshall & Rossman, 1989, p. 81). Multiple case studies allow comparative analysis so that similar cases can be compared and contrasted (Stake, 2006).

This research design was appropriate for this study because of the nature of the research questions and the purpose of the study. The focus was on describing the design decisions, fundamental content knowledge, essential pedagogies, unique challenges, and effective practices involved in the professional development of teachers for secondary level engineering education. In order to adequately describe these issues and explore the complexities involved in this particular type of professional development, a multiple case study design was best suited. As Stake (1995) argued, case study research is about "particularization, not generalization" (p. 8). By coming to know each project through an in-depth analysis, this study was able to answer the research questions, as well as draw significant comparisons across cases.

In addition to answering the research questions, the cases revealed the range of possible properties, dimensions, and relationships involved in this type of teacher professional development. In other words, the "evidence of the complexities of what the program is and is not" (Stake, 2006, p. 84) was sought. The multiple case study analysis also resulted in a summary of common categories, themes, and patterns apparent across the projects, as well as distinct and illuminative approaches that may inform future professional development projects. This synthesis was compared to the existing research to draw important conclusions and recommendations for future research and practice.

Marshall and Rossman (1989) noted the importance of addressing key, theoretically-based practical issues when designing and conducting case study research. These include making decisions about the selection of cases, data collection methods, and data analysis procedures, all of which are discussed in detail next.

Case Selection

Under the guidelines of IRB approval, a discriminate sampling technique was used to select the cases for analysis in this study. As Hamel, Dufour, and Fortin (1993) pointed out, the case selected for analysis does not need to represent the population because of frequency of some phenomenon, but should be representative "in terms of an initial sociological theory" (Hamel et al., 1993, p. 44). In addition, the ideal case is where: (a) entry is possible; (b) there is a high probability that the processes, people, and structures related to the research questions will be present; (c) the researcher can maintain a proper presence; and (d) data quality and credibility can be reasonably assured (Marshall & Rossman, 1989). In addition, the selected cases should also maximize the opportunities for comparative analysis (Stake, 2006).

The cases selected had to consist of professional development programs that focused on engineering-oriented education at the secondary level. For the purposes of this study, engineering-oriented education was defined broadly to include projects designed to (a) prepare students for postsecondary engineering education or (b) provide a broad base of technological literacy for all students utilizing engineering-oriented content.

The cases selected for inclusion into this study were *Engineering the Future: Science, Technology, and the Design Process*™, *Project Lead the Way*™, *Mathematics Across the Middle School MST Curriculum*, *The Infinity Project*sm, and *INSPIRES Curriculum*. These cases included funded curriculum development projects that have established a reputation for delivering innovative engineering-oriented professional development. The projects ranged from relatively small, focused initiatives to extensive, multifaceted implementation efforts. In some cases, the implementation of the program was extensive, involving teachers from numerous sites on a national scale. In other cases, the implementation was much more restricted in scope, concentrated at a single location.

Selection Criteria

In order to help guide the selection of professional development projects for inclusion in the study, criteria were developed to help guide the case study selection process described next. The selection criteria included:

1. *Engineering-Oriented Content*: The cases had to contain elements that are interesting, applicable, and useful for engineering-oriented professional development at the 9-12 level.

2. *Illuminative Professional Development Design Practices*: The initiatives needed to contain an effort to include “best practices” (e.g., standards based, pedagogically sound, context driven, authentic, and assessment based) and creative design practices that can illuminate and inform future professional development in this area.

3. *Maturity*: Priority was given to mature initiatives with an established track record for delivering professional development over a sustained period of time (at least two years).

4. *Coherent Model*: Priority was given to projects that were grounded in a coherent and documented model for professional development.

Process for Case Selection

The process for identifying the engineering-oriented professional development projects for case study analysis included conducting investigative interviews with key individual informants (e.g., current and former National Science Foundation program officers, the leadership of professional organizations, and professional development experts). An initial list of informants was generated by identifying leaders of recently funded K-12 engineering-oriented projects by conducting online searches of abstracts and by asking acquaintances of the researcher who are actively involved in technology or engineering education to identify individuals who have had extensive involvement and developed national reputations in engineering-oriented teacher professional development. This approach resulted in the identification of 15 informants who generated a list of engineering-oriented professional development efforts.

A script was used to interview the informants to ensure a consistent process (see Appendix A). In addition to asking for a list of sites that meet the criteria specified, the informants were asked to rank the top three sites that best fit all of the criteria and should be included in the study. Web searches were also conducted of professional organizations, science and technology museums, and government agencies, as well as abstracts of funded projects and published materials from national clearinghouses (e.g., NSF), to identify additional professional development projects.

After interviewing the informants and conducting the web searches, the project names, the number of times mentioned, and the rankings for each were compiled into a list. The projects were then rated based on the number of times mentioned by the informants and by the rankings provided. Prior to contacting the project leadership, an extensive review of the projects' websites and any resulting publications was conducted to ensure that the projects did in fact meet the criteria for inclusion in the study. Those projects selected for inclusion in the study were mentioned by multiple informants, as well as ranked highly. A total of five projects were selected for inclusion in the study. This resulted in an analysis of different approaches to engineering-oriented professional development and allowed for in-depth comparisons across the projects.

Procedures

After the cases were selected, an email was sent to the project leadership informing them of the research project and requesting a phone conversation to further explain the project and their potential role. During the phone conversation, the research questions, case selection process, and data collection procedures were briefly explained. A request for their participation in the study was garnered, along with dates and venues for the project's professional development activities. Once access was granted, a preliminary interview with the leadership was conducted and the on-site visit scheduled.

Data Collection

The data collection plan is "a road map, an overall plan for engaging phenomenon of interest in systematic inquiry" (Marshall & Rossman, 1989, p. 76). For the purposes of this study, the data collection plan for each case study consisted of the following phases: (a) pre-visit data collection and analysis, (b) on-site data collection, and (c) post-visit data analysis. To ensure that each research question was addressed through the different forms of data collection, Table 4 was developed to show how each research question corresponded to the different case study phases.

Table 4

Data Collection Plan

Research Question	Case Study Phases		
	Pre-Visit	On-Site	Post-Visit
1	Project leadership interviews	Observations Teacher questionnaires Teacher focus groups Instructor interviews	Member checking Expert review
2	Project documents	Observations Project leader interviews	Member checking Expert review
3	Project leader interviews Project documents	Observations Teacher questionnaires Teacher focus groups Instructor interviews	Member checking Expert review
4	Project documents	Observations Teacher questionnaires Teacher focus groups Instructor interviews	Member checking Expert review
5	Project leader interviews	Observations Teacher questionnaires Teacher focus groups Instructor interviews	Member checking Expert review

Each of these phases is discussed in more detail below, however the main components are outlined here. The pre-visit data collection and analysis involved a telephone interview of the project leadership and a review of project documents (funding proposals, curriculum, and annual report information). The on-site data collection was comprised of the following: (a) observations, (b) teacher questionnaire, (c) teacher focus groups, (c) instructor interviews, and (d) follow-up interview with the project leadership. The post-visit phase included the development of each case study report, member checking, and a comparison across cases. Each of the instruments was intended to address one or more of the research questions as indicated in Table 4.

Instrumentation

Multiple instruments were used to collect data to develop each case study. The Project Leadership Interview Questionnaire was developed based on the need to understand the history and design of the professional development project (see Appendix B). These questions were developed by the researcher and grouped into the following categories: (a) the project's history/origins, (b) participants, and (c) structure and delivery. As Joyce and Showers (2002) stated, designing professional development "involves identifying types of outcomes or content to be pursued and selecting training components or strategies likely to bring about success in achieving those outcomes" (p. 70). The Project Leadership Interview Questionnaire was intended to uncover these design components prior to the on-site visit.

The construct validity of the questionnaire was established to ensure that the instrument, in fact, uncovered these components and correctly operationalized the concepts being studied (Gall, Gall, & Borg, 2003). The co-observer and expert panel comprised of two engineering experts and two technology education experts, were asked to review the instrument and provide feedback. As explained in more detail later, the researcher was accompanied by Dr. Rodney L. Custer on the site visits of each project. In addition, as described further below, an expert panel of engineering and technology education experts was convened to inform the data collection process and to validate the study's findings. Based on their feedback, the questionnaire was modified to include questions about the major need being addressed by the project (question 3), to further probe how the professional development component emerged (question 5), and to inquire about the “typical” participant (question 10).

As a guide to conduct the observations of the professional development in action, the Professional Development Observation Form was created (see Appendix C). The form was adapted by the researcher based on Stake’s (1995) “Issue-Based Observation Form for Case Studies in Science Education” (p. 50). The form not only has space to capture relevant information such as the date and time, but also “draws attention to the issues of immediate concern” (Stake, 1995, p. 50), such as the content, pedagogies, and/or pedagogical content knowledge being targeted by a particular lesson or activity.

The Instructor Interview Questionnaire was developed based on the need to better understand the professional development project from the instructor’s perspective (see Appendix D). These questions were developed by the researcher and guided by the need to learn about the materials, the delivery of the professional development, and the training of the instructors. This questionnaire was also intended to shed more light onto the (a) content; (b) process; (c) strategies and structures; and (d) context of the professional development (Loucks-Horsley, 1999). These four clusters of variables have been identified as affecting the quality or nature of professional development.

The construct validity of the Instructor Interview Questionnaire was also established by the co-observer and expert panel. Based on their feedback, two of the original questions were modified to better inquire about the delivery of the instruction (question 4) and the areas of the professional development that could be improved (question 6). In addition, two questions were removed asking about the origins of the project that were better asked of the project’s leadership prior to the on-site visit.

The Teacher Survey Questionnaire was developed based on the need to better understand the teacher participants who chose to attend the professional development (see Appendix E). These questions were developed to learn about the characteristics of the teachers, their motivations to attend, and what they have learned. As Bybee and Loucks-Horsley (2000) argued, teachers need both the tools and the motivation to continue their own learning. Knowledge resources alone do not necessarily translate into improved practice. Teachers should also know "how to engage students in content knowledge, how to allocate time and attention, how to articulate standards appropriate for practice" (McLaughlin, 2002, p. 95). The Teacher Survey Questionnaire was designed to collect information from the teachers as to how the professional development has or will impact their practice.

The Teacher Survey Questionnaire was also reviewed by the co-observer and expert panel to establish construct validity. Based on their feedback, questions were added to the instrument to obtain demographic information about the teacher participants (questions 1 and 2). In addition, the format of questions 1 through 5 was changed to allow respondents to quickly check their responses, instead of write their answers. In addition, the wording of question 11 was modified to better ask respondents about the engineering concepts they deemed particularly important.

The Focus Group Interview Script was developed based on the need to gain a more in-depth understanding of the professional development project from the teacher participant's perspective, in addition to the teacher survey questionnaire (see Appendix F). These questions were developed by the researcher and guided by the desire to learn about their understandings of the focus and content and the potential effects of the professional development. Penuel et al. (2007) argued that "teachers need professional development that is interactive with their teaching practice, allowing for multiple cycles of presentation and assimilation of, and reflection on, knowledge" (p. 929). This interview was designed to gather information from the teachers as to how they perceived the professional development's design and the knowledge they gained.

The Focus Group Interview Script's construct validity was established by the co-observer and expert panel's review as well. The bulleted items at the beginning of the script were added to prompt the completion of the consent letter and to communicate to the participants the structure of the interview as divided into three sections: (a) the content of the professional development, (b) the impact on their teaching, and (c) implementation barriers. In addition, question 3 was added to probe the teachers about their understanding of the engineering concepts. Question 7 was also added to ask about specific techniques they learned to teach engineering content.

Data Collection Phases

In addition to the data collection plan, a table outlining the case study data collection phases and the stages of professional development (design and planning, implementation, and evaluation/follow-up) was developed to help ensure that the entire scope of each project is captured in the data (as shown in Table 5). As Stake (1995) pointed out, by triangulating the data sources through multiple stages the researcher is able "to see if the phenomenon or case remains the same at other times, in other spaces, or as persons interact differently" (p. 112).

Table 5

Data Collection to Understand the Stages of Professional Development

Data Collection	Stages of Professional Development		
	Design and Planning	Implementation	Evaluation/Follow-up
Pre-Visit	X	X	X
On-Site		X	X
Post-Visit		X	

The pre-visit data collection provided an initial understanding of the project's design planning, elements of its implementation, and how the project is evaluated. This phase consisted of two elements: (a) structured telephone interviews with the project's leaders, and (b) an analysis of the project's documents. The structured telephone interviews with the project's leaders were conducted to collect factual data about the project to help provide the "back story" and inform the on-site data collection. An hour long interview was scheduled via email correspondence with the project leadership. The Project Leadership Interview Questionnaire (see Appendix B) was used to guide the interview. Answers were audio recorded with the permission of the participants. The audio files were transcribed by a professional transcriptionist with the instructions to transcribe the files verbatim, indicating speakers, and including punctuation.

During the telephone interview, the project leaders were asked to supply its original proposal (if it was a funded project), evaluator reports (internal and/or external), the project's curriculum, annual report information, and any other related documentation of the project. These documents were reviewed to better understand the project's development, philosophy, and approach to professional development. The answers to the following questions were sought in the documentation provided by the project:

1. *Inception and Development*: What factors contributed to the creation, development, and diffusion of the professional development efforts? What were the goals and objectives of the initiative and how were these formulated?

2. *Participants*: How are/were the participants selected? Is there prerequisite knowledge/experience needed for a teacher to participate? Who is the "typical" participant?

3. *Effective Design Practices*: What are the practices, themes, and ideas concerning the design of the professional development that have emerged from the initiative?

4. *Pedagogical Principles*: What are the fundamental principles of teaching and learning that under-pin the design and implementation of the professional development effort? What is the identified pedagogic knowledge and pedagogical content knowledge identified by the project as being important for engineering-oriented education?

5. *Models*: What are models that have and are being deployed/adapted/promoted by the professional developers? In what ways has the project planned for flexibility and adaptation of the model as the project has evolved?

6. *Evaluation*: What processes and metrics have been used to evaluate the effectiveness of the professional development and what are the salient outcomes of the evaluation process? What procedures have been implemented to ensure that the results of formative assessments are used to inform the ongoing professional development process?

The data gathered from the project leader's interviews and the project's documentation were synthesized and developed into the foundation of the case study report prior to the on-site visit. This provided the necessary detailed background information about the project so the researcher and co-observer were informed and prepared for the on-site visit. In addition, overlapping data analysis with data collection "not only gives the researcher a head start in analysis but, more importantly, allows researchers to take advantage of flexible data collection" (Eisenhardt, 1989, p. 539).

The rationale for conducting on-site visits was to (a) obtain first-hand reports from the programs' participants, (b) directly observe the professional development activities and interact with program leaders and participants, and (c) document and validate information obtained from the pre-site interviews. In order to ensure the triangulation of data, the on-site data collection for this study consisted of the following three methods: (a) participant observations, (b) survey questionnaire, and (c) interviews. The on-site data collection was conducted over the span of two days.

The researcher was accompanied by Dr. Rodney L. Custer on these site visits to provide another "set of eyes" as a co-observer. Eisenhardt (1989) outlined two key advantages for the use of multiple investigators for data collection. Insights from more than one investigator "add to the richness of the data, and their different perspectives increase the likelihood of capitalizing on any novel insights which may be in the data" (p. 538). The second key advantage is that the "convergence of observations from multiple investigators enhances the confidence in the findings" (p. 538). Convergent perceptions further ground the findings of the study, while conflicting perceptions keep the researcher from drawing premature conclusions.

The first day consisted primarily of observations of the professional development guided by the Professional Development Observation Form (see Appendix C). Observations, as a research method, entail "the systematic description of events, behaviors, and artifacts in the social setting chosen for study" (Marshall & Rossman, 1989, p. 79). The researcher learns about behaviors and the meanings attached to those behaviors by observing the phenomenon in action. Participant observation demands the first-hand involvement and immersion in the setting allowing the researcher to hear, see, and experience the setting as the participants do. The researcher and co-observer independently documented the day's activities with field notes including the interactions between presenters and participants. Upon conclusion of the first day, the researcher and co-observer compiled their field notes and discussed the day's events.

In addition, at the end of the first day the Teacher Survey Questionnaire (see Appendix E) was administered to all of the teachers. During the second day of the on-site visit, the questionnaire was collected. Questionnaires are a supplemental data collection technique in qualitative research; used to learn about the distribution of a characteristic or set of characteristics, a set of attitudes, or beliefs (Marshall & Rossman, 1989). For the purposes of this study, the teacher questionnaire was used to better understand the characteristics of the teachers, their motivation for attending the professional development program, and the teachers' backgrounds. The same questionnaire was administered at all of the sites, providing data for comparison across all five cases.

On the second day of the on-site visit, focus group interviews of the teachers, interviews with the professional development instructors, and, if necessary, a follow-up interview with the project leadership were conducted and captured using field notes. In-depth qualitative interviews are more like conversations and are a useful way of getting a wide variety of information from multiple subjects. In addition, interviews allow for immediate follow-up and clarification.

Focus groups are a type of interview that occurs with multiple participants at the same time. These interviews were guided by the Focus Group Interview Script (see Appendix F). When possible, the teacher focus groups were comprised of existing small groups of teachers (approximately 3 – 4 teachers), who had been assigned or elected to work together for group projects. By using existing groups, disruptions from the day's activities were kept at a minimum. Otherwise, with the assistance of the instructors, groups of teachers were pulled together during breaks and asked to participate in the interview. As many of the teachers as possible were asked to participate in a focus group. The focus group interviews were audio recorded with the permission of the participants. The audio files were transcribed by a professional transcriptionist with the instructions to transcribe the files verbatim, indicating speakers, and including punctuation.

The interviews with the instructors were intended to provide information about the materials, the delivery of the professional development, and their training. In addition, it is important to include the multiple perspectives involved in the project (Stake, 1995) and the instructor is a prominent aspect of the delivery of the professional development. These interviews were guided by the Instructor Interview Questionnaire (see Appendix D). By the end of the second day, if unanswered or additional questions remained, informal interviews of the project's leadership occurred. Both the instructor interviews and any follow-up leadership interviews were audio recorded with the permission of the participants. The audio files were transcribed by the transcriptionist with the instructions to transcribe the files verbatim, indicating speakers, and including punctuation.

Data Analysis

At the end of each on-site day the researcher and co-observer shared individual observations and field notes of the two days. Upon returning from the on-site visit, the researcher submitted the audio files to the transcriptionist. The transcripts from all of the interviews were analyzed closely to find information and interesting quotations that answered or shed light on the study's research questions. This information was highlighted and grouped into a document that contained headings related directly to the research questions: (a) primary mechanisms, (b) effectiveness, (c) fundamental content knowledge, (d) essential pedagogical strategies, and (e) persistent barriers and challenges.

The background report prepared from the pre-visit data and the analysis of the transcripts were compiled into case write-ups. As Eisenhardt (1989) stated, these "write-ups are often simply pure descriptions" (p. 540) and allow the researcher to "become intimately familiar with each case as a stand-alone entity" (Eisenhardt, 1989, p. 540). At this point member checking was conducted to ensure the accuracy of the case study write-ups. Member checking is a process where individuals involved in the case are "requested to examine rough drafts of writing where the actions or words of the actor are featured" (Stake, 1995, p. 115) to examine the writing's "accuracy and palatability" (p. 115). The project leaders were asked to examine their project's case study report and provide feedback on any inaccuracies related to the project's history and development.

After member checking of the case write-ups was conducted, full descriptive case studies were prepared for each case study. The case studies integrated the background report, the analysis of the transcripts, and a descriptive narrative of each on-site visit into a complete report. This approached allowed the researcher to gain a rich familiarity with each case, resulting in the emergence of unique patterns within each case before pushing "to generalize patterns across cases" (p. 540). With case study research, the goal is not to develop "exhaustive and mutually exclusive categories of the statistician, but instead to identify the salient, grounded categories of meaning held by participants in the setting" (Marshall & Rossman, 1989, p. 116).

Summary

The individual case write-ups were further analyzed to develop a summary of the five reports across the study's research questions. The analytic procedures used to analyze the case studies included the following five steps: (a) organizing the data, (b) generating categories, themes, and patterns, (c) testing the emergent hypotheses against the data, (d) searching for alternative explanations for the data, and (e) writing the report (Marshall & Rossman, 1989).

To further advance the research and practice of engineering-oriented professional development, the case studies were synthesized by conducting a cross-case search for patterns amongst the study's findings. The approach used in this study to conduct the cross-case analysis was to "select categories or dimensions, and then to look for within-group similarities coupled with intergroup differences" (Eisenhardt, 1989, p. 540). These similarities and differences are discussed across the five research questions.

Validation

Validation of the case study synthesis is an important step "to determine how well that abstraction fits with the raw data and also to determine whether anything salient was omitted from the theoretical scheme" (Strauss & Corbin, 1998, p. 159). Thus "fitness" or how well the analysis corresponds to the data is an important aspect of validation (Soulliere, Britt, & Maines, 2001). In addition, validation is concerned with "whether the relevant community of scientists evaluates reported findings as sufficiently trustworthy to rely on them for their own work" (Mishler, 1990, p. 417).

For the purposes of this study, an expert panel of engineering and technology education experts was convened to validate the findings of the case study reports. The expert panel was comprised of three experts (two engineering education experts and one technology education expert), who have extensive involvement in teacher professional development. These individuals are "seasoned professionals" identified by the researcher through their involvement in the National Center for Engineering Education or in the 2007 National Science Foundation funded Engineering and Technology Symposium.

The expert panel provided experienced engineering and technology education perspectives to ensure valid findings. The researcher met with the expert panel via teleconference on two separate occasions to review the findings of the case studies, as well as provide a "context-based explication" (Mishler, 1990, p. 423) of how the interpretations were grounded in the data. The expert panel was provided a copy of the case reports prior to the meetings. Their reactions and critiques were captured by the researcher and used to further refine the study's findings.

CHAPTER IV

FINDINGS

The goal of this study was to describe professional development practices for engineering-oriented secondary education. The focus was on better understanding the professional development design decisions, fundamental content knowledge, essential pedagogies, unique challenges, and effective practices in this type of professional development. Five professional development programs designed to prepare teachers to deliver engineering education at the secondary level were examined, including: *Engineering the Future: Science, Technology, and the Design Process*™, *Project Lead the Way*™, *Mathematics Across the Middle School MST Curriculum*, *The Infinity Project*[sm], and *INSPIRES*.

The five case studies, based on the data collected from each site through interviews, observations, and surveys, are presented in the order they were visited. The case studies are structured around a description of the on-site visit focusing on the project's professional development design, format, activities, participant feedback and evaluation. The findings from the individual case studies are then compared and summarized across the five research questions. As Stake (2006) pointed out, what multiple case studies "have most to offer is a collection of situated case activities in a binding of larger research questions" (p. 90).

Engineering the Future

We arrived at the museum early on a bright, sunny Thursday morning during the summer of 2008 to spend two days observing *Engineering the Future: Science,* *Technology, and the Design Process*™ (EtF) professional development. The museum had just opened its doors for the day, with staff still arriving to work, and visitors beginning to line up at the ticket counter. Located on a river dam, the museum allows visitors to see breath-taking views of the river and the cityscape through its many large windows. As we chatted about some of the exhibits within the main entrance, we were soon greeted by the instructor, who was also one of the project's leaders, and escorted to the workshop.

Along the way, the instructor explained that the workshop was located in the newly remodeled National Center for Technological Literacy (NCTL) wing of the museum. NCTL projects such as EtF are housed in this modern, "green" space. Spurred by a desire to develop an engineering course that delivers technological literacy for all high school students, NCTL began the EtF project in 2003. Grant funding was obtained from numerous institutions to develop a full-year course designed for students in their first or second year of high school. The course was field tested from 2004 until it was published in 2007.

EtF was designed to meet technology education standards; foster inquiry, critical thinking, and hands-on problem solving; and utilize a variety of assessments. A central goal of the EtF course is to "communicate how everyone is influenced by technology, and in turn influences future technological development by the choices they make as workers, consumers, and citizens" (Sneider & Brenninkmeyer, 2007, p. 6). The Teacher Guide (2008) includes the goals of the course related to students' learning: (a) technology; (b) the engineering design process; (c) complementary relationships among science, technology, and engineering; (d) how technological advances affect society; and (e) fundamental concepts of energy.

In addition, professional development programs emerged from the field testing of the curriculum. Pilot test teachers were brought into the museum for a few days and provided an orientation. This “accidentally set the model for the next summer, when also our focus was not PD, but field testing.” During the summer of 2007 the project went “really fully in the professional development mode.” In addition to half-day “awareness” workshops, the project created three to five day professional development formats. An online component was also developed and pilot tested to address the constraints of limited resources. According to EtF’s website, their professional development has reached over 160 teachers and 7,500 students in 16 states.

Professional Development Design

Currently the professional development is comprised of two primary designs: (a) in-person workshops and (b) online courses. The “overall aim of our teacher education programs—whether in-person, online for credit, or via the web, is to empower teachers to take charge of their own learning by assessing their own needs and selecting a means for preparing to teach that satisfies the requirements of their district, that meets the needs of their students, and that fits within the constraints of their daily lives” (Sneider & Brenninkmeyer, 2007, p. 10). The in-person workshops are structured around a combination of mini-lectures, hands-on activities, and reflections. Specifically, the workshops: (a) provide an overview of the course, (b) support collaboration between science and technology teachers, (c) encourage veteran EtF teachers to mentor new teachers, (d) emphasize the value of EtF, (e) identify student learning outcomes, and (f) allow teachers to share their experiences teaching EtF.

Online support and an online course for college credit have been developed through funding by grants from Cisco Systems and Lockheed Martin. One of the project leaders stated that they found that “we had to give ammunition and tools to the teachers and we could do it electronically after the workshop this way.” The online support for teachers includes news, file storage, discussion boards, a calendar, resources, and videos. In addition, an online course was developed as a separate professional development design. The online course enables the project to introduce and implement the curriculum nationally without the expense of traveling and conducting in-person workshops. The format of the online course is guided by a syllabus, which outlines readings, videos, assignments, and a threaded asynchronous discussion.

The Workshop

As we made our way along the museum hallways, the project leader provided more detail about the particular workshop we were about to observe. Since this was the second day of the four day workshop, we were given an update on the first day’s activities. He explained that the teachers were provided an overview of the course and completed a few of the activities from the first project. With some chagrin, he added that there were only three teachers participating in the workshop. They had expected twice that number, but had three teachers who did not show up. He attributed the low attendance to the workshop prerequisite requiring teachers to have attended a half-day workshop. This prerequisite was imposed because grant funds were used to provide food, parking, and mileage reimbursement for the workshop.

We arrived to the workshop, which was held in a large insular room designed to accommodate such events. One large row, two tables deep, was set-up in a U-shape in the center of the room. The teachers were spread out among these tables. A long row of tables, two tables deep, were set up along the back of the room containing EtF materials. The instructor operated from a desk at the front of the room. A television and DVD player on a stand sat next to the instructor's desk. Behind the back row of tables was a large screen that displayed the instructor's computer monitor, which he projected from an LCD projector on his desk. Along the outer walls were cabinets, a sink, and countertops. At the back of the room two large doors opened to a large storage closet containing materials and kits for NCTL projects. This was the first workshop the instructor had led in this space and indicated his disapproval for the design and limited space of the room.

Upon arrival, we were introduced to two of the three teachers, who had already arrived and were enjoying the many different breakfast items. After the third teacher arrived, the instructor formally convened the group, introduced us, and allowed us to explain the research study. At this time we obtained the participants informed consent to participate and allow us to observe the workshop. We sat at the U-shaped row of tables with the teachers and observed the day's activities.

Format

The format of the workshop was outlined in a daily agenda, which was distributed during the morning of each day and adhered to closely. The agenda outlined the activities by segments of time (typically an hour), with bulleted action items under each activity. The instructor pointed out that "the agenda is really trying to be a mix of not sitting and talking too long, and pointing out what we considered to be the five E's." He added that we "engage them, ask them to explain something, explore it, elaborate on it, evaluate, you know talk about assessment and talk about what they would do differently." On the back side of each agenda were the Massachusetts Technology/Engineering Standards addressed with that day's project.

The Massachusetts engineering and technology curriculum standards were used to develop the EtF course, including the essential questions, assessments, and activities. A textbook, engineer's notebook, and teacher guide comprise the EtF course, which is recommended for 9th grade students as a science credit. The EtF course is divided into four projects. Each project takes about eight weeks to complete. In addition, an "overall 'storyline' was used to provide 'coherence and flow'" (Sneider & Brenninkmeyer, 2007, p. 6). Each chapter in the textbook is written in the first person from the perspective of one of 32 practicing engineers, technicians, and students. The engineer's notebook contains activities in teamwork, the engineering design process, structural design, discovery in hydraulics, pneumatics, thermal energy and propulsion, and electrical circuits. The teacher guide provides lesson plans, assessment instruments, lists of materials and vendors, and background information.

Activities

Each of the four days of the workshop was devoted to one of the four projects in the course. After an introduction via the DVD teacher tips or an online resource, the teachers completed the activities, which were typically the "quick builds" within the major projects of the course. Most of the activities we observed used easily accessible materials (cardboard, paper, tape) and required minimal equipment and tools to complete. This aligns with the project leaders' philosophy believing that "students can practice the engineering design process without requiring schools to spend tens of thousands of dollars on equipment and supplies" (Sneider & Brenninkmeyer, 2007, p. 6-7).

During our visit, we observed the “quick builds” from Projects 2 and 3. The morning of Day 2 was devoted to the tower building activity in *Project 2: Designing Building of the Future*. From his desk at the front of the room, the instructor outlined the activity and showed a video clip from the EtF DVD, which outlined relevant terms (i.e., compression, tension, and sheer) for the project. Teachers were asked to build a tower from paper, paper clips, and tape to meet specific height, weight, and cost specifications. Working independently, the teachers assembled and tested their towers. They were also asked to describe why their structures failed using the terminology introduced in the video. The instructor ended the activity with a brief discussion about assessment.

After a short break, the instructor outlined the second activity of the day, materials testing from Project 2, where teachers prepared their own concrete mix. The teachers chose the aggregate to mix into the concrete in order to make the strongest mixture. Once the teachers had prepared their concrete, one of the teachers, who had taught the course the previous year, provided an overview of the next project in the course. The project demonstrated energy flow in buildings by having students create thermal boxes with different insulation materials to determine R-values. The instructor explained the color coding chart used in this and other EtF activities. As a conclusion to this day, the instructor distributed a copy of the project concept map and briefly discussed how it could be used as a form of assessment.

On the second day of our visit we were greeted by the sounds of a metal toy boat powered by a candle “putt putting” around a large tub of water. Day 3 of the workshop was devoted to activities from *Project 3: Improve a Patented Boat Design.* Using the think-pair-share instructional strategy, the teachers were asked to think about how the boat worked and write a sentence or two on a note card. They were then asked to pair up with another teacher and compare their note cards. They shared by reporting out to the group. The instructor then showed various resources online connected to this project. This led into the next activity, where the teachers followed step-by-step instructions to create their own toy boats. The instructor guided each step of the process emphasizing how to best manipulate the materials. The instructor also demonstrated another activity from Project 3, making a hull press that demonstrated the differences between hydraulic and pneumatic power.

Participant Feedback

One of the teachers who participated in the workshop was a high school teacher and the other two were middle school teachers. Two of the three teachers participated in the focus group interview and the same two returned the teacher participant survey. One taught technology education and industrial technology courses and the other indicated that he taught physics and life science. When asked why they attended the workshop, one of the teachers who had implemented the curriculum the year before, stated that he wanted to “grow this course.” When asked what they thought was the content of the professional development, both agreed that “the process of doing the projects, more specifically looking at each project and how they’re executed.” Neither teacher indicated challenges to implementing what they were learning. For example, one of the teachers commented that he had the support of his administrators and that the state standardized test in technology education/engineering “has validated the value of my course.”

The curriculum outlines qualifications for teachers, including the ability to lead discussions, support team work, and help students through the design process. During field testing, EtF worked with about half technology teachers and half science teachers. One of the project leaders stated that they found that “the science teachers involved, were people that like doing things with their hands” and the technology teachers were typically those that “were friendly to the idea that there needed to be a synergy between” science and technology. Currently the teachers participating in EtF professional development are a mixed group looking for a curriculum to serve different purposes from high school, middle school, community college, home schooling, after school and other informal education settings. One of the leaders stated that they are trying “to be more conscious of that, that we aren’t just addressing a uniform group of people that wants to implement the curriculum.” They try to have some teachers in attendance who have implemented the curriculum so the other teachers can “pick their brains.”

As stated, one of the project leaders was the instructor for the workshop. He had been a community college administrator and principal investigator on NSF grants prior to working on the EtF project. Instructors for the project are key individuals in the curriculum development phase or are trained by “accompanying us to half day workshops that we’ve done, and actually getting to present some pieces of them, and reading the materials and doing the activities.” The instructor indicated that the focus of the workshop was on preparing teachers so that “they go away with some confidence that they understand what the whole year is like, and what the key activities within each project are like.” In terms of engineering content, the instructor stated that “the process and the content are all married together to us; we’re not separating them out, saying this is content, this is process.” As far as barriers faced with this type of professional development, the instructor referenced a limited and dwindling staff and the need to constantly pursue grant funding to keep the project up and running.

Evaluation

As we observed, each day began with a review of the teachers' feedback from the previous day through plus-delta cards. The evaluation of the professional development includes daily plus-delta activities and a summative feedback form. Participants are asked to write down what they liked (plus) and what they would like to change (delta) at the conclusion of each day. Teachers are also asked to complete a form asking their opinions on how worthwhile different elements of the workshop were or were not. Sneider and Brenninkmeyer (2007) outlined lessons learned from the plus-delta activities and feedback forms. They concluded that teachers appreciated hands-on activities because they "provide practical experience in what is expected of students, help teachers prepare for potential pitfalls, and better understand how the activities support student learning of key concepts and skills" (p. 8). Teachers also liked networking with other teachers, preferred flexible implementation approaches, and desired stipends to participate.

Summary

Based on the pre-visit interview with the project leadership and the on-site visit, it is clear that the EtF professional development is directly linked to the curriculum. The focus of the workshop was on exposing teachers to the curriculum through hands-on activities. Instruction on these activities was often guided, following a step-by-step process outlined in the curriculum. Practical implementation issues were often outlined including how best to obtain and store supplies, assess student learning, and access website resources. As a wrap-up to the activities, teachers were often led through a very brief reflection on how they would connect the particular activity to their classrooms or possible extensions they could do beyond the activity.

The content and pedagogical approaches identified in the professional development were also directly linked to the curriculum and the activities selected for the teachers to complete. The content was centered on technology (materials, brake press, manufacturing processes) and physics (strength, energy, power). For example, the content associated with the first activity we observed focused on strength and developing the language of failure analysis. The engineering design process was intended to provide the content base for the engineering aspect of the course and the professional development. And although specific pedagogical principles were not explicitly discussed, the instructor often pointed out how teachers could deliver the activities in their own classrooms.

Project Lead the Way

We made our way to the computer science building on the engineering quad of a large Midwestern research university to attend a *Project Lead the Way*™ (PLTW) Summer Training Institute (STI). Winding our way through a modern state-of-the-art building that contained computing tools built into the structure itself, we were greeted by the state's affiliate director for PLTW. The affiliate director introduced us to the instructors, including two practicing classroom teachers (master teachers) and a university mechanical engineering professor (affiliate professor). She showed us the materials on the STI, including a large binder and folders on the project. The teachers had progressed through many pages of the binder as we were about to observe days 4 and 5 of a two week training institute on the Introduction to Engineering Design™ (IED) course.

PLTW is a 501(c) (3) not-for-profit corporation that, according to its website, “works with schools to implement an instructional program to prepare students to be successful in post secondary engineering and engineering technology programs.” PLTW is the organization that provides leadership and financial support, teacher training and curriculum development, and consultant services (Blais & Adelson, 1998). The organizational structure of PLTW is based on forming partnerships between: (a) the PLTW Corporation, (b) school districts, (c) colleges and universities, and (d) industry.

The mission of the project is to create partnerships with schools to prepare an increasing and more diverse group of students to be successful in science, engineering, and engineering technology programs. PLTW seeks to expose middle and high school students to real engineering through their curriculum. According to the PLTW website, the courses are “modeled after introductory engineering courses taught at the university level” so students “gain first hand experience in different facets of engineering and discover where their strengths lie.”

PLTW was established in the 1980s through funding from the Charitable Venture Foundation. A school district director of occupational education field-tested what would eventually become PLTW (Cech, 2008). By 1998, 12 New York state high schools had tested the curriculum. A year later, PLTW field tested a four unit Middle School Program in three middle schools. According to a project leader, as of September 2008, PLTW has over 270,000 students, located at over 2,936 school sites in 50 states and Washington D.C., being taught by over 8,000 teachers, who were trained at 36 university sites.

Although conceived as a curriculum project, early in its development, the project’s leadership recognized the need for professional development. As one of the project leaders stated, “professional development is really where curriculum comes to life.” The first professional development model included providing schools grants so teachers could attend a university or community college to audit courses. Recognizing that this model prevented consistency, PLTW’s leadership developed a different approach. PLTW’s two week (80 contact hours) STIs were developed, which are comprised of “full time classes with homework, projects and exams” (Reid & Feldhaus, 2007, p. 9). STIs are conducted at an affiliate training center. Universities are granted affiliate training center status by completing a certification process and obtaining approval from PLTW.

Professional Development Design

There are three elements of PLTW’s professional development design: (a) self-assessment and pre-core training, (b) core training in the form of summer training institutes, and (c) continuous training. The online self assessment is comprised of a skills self-test and questionnaire to determine a teacher’s readiness for core training and to “assure that all teachers arrive for the summer institute training ready to prepare for their September teaching assignment” (Reid & Feldhaus, 2007, p. 9). According to the project leader, the pre-assessment tests the teachers in three basic areas: mathematics, science, and computer literacy. He added that teachers “can’t register for training until they pass the assessment with at least a 70 percent.” The “intent” however is for teachers to determine their knowledge level in these three areas and provide teachers with resources that they can study prior to training.

The core training is comprised of the two week STI course. According to the project leader, STIs are designed to have teachers “participate in many of the activities, projects, and problems that they're expected to teach, so that they can see how it is delivered by the instructors." Teachers "must successfully complete this course prior to teaching a PLTW course" (Reid & Feldhaus, p. 9). If they do not pass the STI training, PLTW notifies their principal and they develop a plan to help the teacher complete the training. Once teachers pass the summer institute training they are ready to teach, however continuous training is provided in the form of university based level II training and a virtual academy. The level II training is intended to keep teachers apprised of significant changes to the curriculum. The virtual academy is a teacher-based, online site where teachers can download lessons to refresh their learning.

The Summer Training Institute

On the morning of our first onsite visit, the classroom was a buzz of activity, as the teachers were arriving, setting up their laptops they were instructed to bring to the STI with the appropriate software, and diving into their binders that guided the STI's activities. The master teachers were actively moving about the room answering questions and preparing for the day's activities. The classroom, arranged into four rows of large tables, was filling with the 16 teachers who were participating in this STI. A large screen was pulled down at the front of the room with one of the master teacher's computer screen projecting a computer aided drafting image. We settled into our seats at the back of the room to observe the *The Introduction to Engineering Design*™ STI.

Right at 8 o'clock, the master teachers and affiliate director called the group to attention. The affiliate director introduced us to the teachers and asked us to provide a few details on the study. At this time we obtained the participants informed consent to participate in the study and allow us to observe the institute. One of the master teachers then took over by reviewing the previous day's activities and answering a question that was raised by a teacher who arrived early that morning. The master teachers were seated at the front of the room and the affiliate professor and affiliate director were seated at the back of the room.

According to a project leader, PLTW has "about 300 master teachers and affiliate professors that we work with to actually do the teaching during the summer months." Master teachers must have at least two years of experience, be selected through an application process, and complete training before they can instruct an STI. Master teachers lead the workshop. The master teachers at the STI observed for this case study stated that their intent was also to model good pedagogy; not reflect openly on pedagogy during the STI. The primary instructional strategies used to deliver the content and activities were lecture, demonstration, hands-on activities, and cooperative learning. The role of the affiliate professor varies some at each affiliate training center. At the STI we observed, the affiliate professor's role appeared to be to serve as a resource for engineering expertise and to provide assistance during some of the activities.

Format

The format of the STI for each PLTW course is specified in a "scope and sequence" document. The master teachers are heavily involved in developing the scope and sequence that will be used at all STIs across the country. The scope and sequence outlines the activities and materials, which are derived from the curriculum. As a project leader stated, teachers "experience very much what the students will experience once they're back in the classroom." The leader added that the STIs provide "the ten thousand foot level of what the course looks like, meaning the teachers do those activities, projects, and problems during that two week cycle that they're going to be teaching during the course of the next school year."

There are STIs for each of the PLTW's courses within their middle school and high school program. The middle school program called *Gateway to Technology* contains six 9-week courses. The high school program called *Pathway to Engineering* is divided into three tiers: (a) foundation courses; (b) specialization courses; and (c) capstone courses. The *Introduction to Engineering Design*™ (IED) course is one of PLTW's foundation courses, along with *Principles of Engineering*™ and *Digital Electronics*™. According to the PLTW website, the IED course "uses a design development process while enriching problem solving skills; students create and analyze models using specialized computer software."

Activities

The primary activities observed during the two day observations of the IED STI were computer automated drawing (CAD) activities from the second lesson within the course. According to PLTW's website, and as evidenced by the site visit, the curriculum uses a combination of activities-based, project-based, and problem-based learning, with some lecture and demonstration. The first morning began with a lecture and demonstration given by one of the master teachers on how to construct view orientations, center line representations, and dimensioning using the CAD software. Alternating between the whiteboard and projected desktop, the master teacher provided detailed instructions on how to use the software tool.

After about an hour of instruction and demonstration, the master teacher allowed time for the teachers to use these skills on their own. He then assigned an exercise in the curriculum that used these specific skills; drawing a toy train engine. The exercise outlined a step-by-step process for drawing the toy train engine. The teachers were actively engaged in completing this assignment, working with each other and asking the master teachers questions as they arose. Teachers were seated purposively next to each other based on the pre-assessment, which gauged experience level with CAD. More CAD-experienced teachers were seated next to less experienced teachers so they could help each other through the STI.

After lunch, the affiliate professor guided the teachers on a tour of the water/air laboratory on campus. He explained the facility and the different labs engineering students worked on as they learned different principles of engineering. Once the tour was completed, we returned to the classroom and the teachers worked on completing their train car exercise. An interesting issue arose as a group of teachers were working on assembling the different components of their toy train car. They encountered a problem and, along with the master teachers, engaged in intensive trouble-shooting to identify the problem and design a solution. Although this was not intended, the master teachers and teachers were actively engaged in pursuing a solution, which was shared with the class.

The second morning began with a video conference with another PLTW training institute's master teacher. This master teacher talked about the virtual design problem in the IED course, where PLTW teachers are asked to pair up and have students work long distance in teams on a project. The master teacher explained the design problem and the logistics of arranging long distance teams. In addition, he explained some of the technological and administrative challenges for this problem, as well as stressing the importance of this type of project and its relation to real world engineering. Teachers at our site were given the opportunity to ask the master teacher questions about this activity.

During the afternoon, teachers were asked to form teams and design a train car to be linked with the train engine some where still in the process of completing. The faculty associate explained a design decision making matrix that the teachers were asked to use to select their design on a quantitative basis. They were given different parameters, including size and material, and as a class they developed the evaluation criteria on the matrix. The master teacher asked the teams to brainstorm and document several design ideas in their engineering notebooks and then use the matrix to rank four designs from which they were to select their best design. The rest of the day was devoted to the teachers working on designing and drawing their train car.

Based on the observations of the two days of this particular STI, there were three distinct types of activities and stages to the instructional design. These stages included: (a) a demonstration of a set of CAD techniques, (b) using the learned CAD techniques to draw an object following specific instructions (the toy train engine), and (c) designing and drawing another object to fit specific constraints (the train car). As the master teacher explained to the teachers, “you’ve been given canned activities, seen a variety of tools, now become a design team.”

Participant Feedback

In order for teachers to teach PLTW, their school superintendent must complete an agreement of quality standards and agree to send teachers to a STI. When asked about qualifications, the project leader stated that, in addition to being a certified teacher, they “ought to be a career and technical person” because “they have a knowledge base around equipment, and labs and all those kind of things." The leader indicated that currently 70 percent of the teachers who teach PLTW courses are technology education certified. The remaining 30 percent are mathematics and science teachers, as well as a few business teachers. In addition, the project leader stated that approximately 15-18 percent of the teachers were former engineers. The leader also indicated that "around 7,000 teachers that are teaching the program, probably a good 65 percent are white male."

Of the 12 teachers who completed the survey at the STI observed for this case study, 11 were male and one was female. The age of the teachers ranged from a teacher in his twenties to teachers in their fifties. The experience of the teachers also varied from a new teacher to teachers with over 21 years or more experience. All but one of the teachers taught technology education, industrial technology, or pre-engineering. This teacher taught algebra and geometry. The teachers indicated on the survey that they were highly motivated to attend the STI. Although one teacher stated that there was "a significant amount of compression of information" and another added that they were "trying to learn a whole year's worth of curriculum in a two week timeframe," the teachers felt prepared to implement the course.

In terms of effectiveness, two of the teachers stated that the hands-on aspect of the STI was particularly effective, allowing the teachers to work together. Teachers also commented on the credibility and personality of the master teachers as being particularly effective. As one teacher stated, "the fact that this professional development is presented by people that actually do it, and teach it" is important. Two other teachers commented more broadly that PLTW helps them to increase the credibility of what they teach. For example, one teacher stated that PLTW is "taking that stigma of oh, they're in an applied class in the applied technology department, it’s more of a college bound class, it’s a higher level of learning and being able to apply the skills.”

In terms of challenges, many of the teachers’ comments focused on factors related to students. For example, five of the teachers identified challenges related to prerequisite knowledge, in particular with mathematics and reading comprehension. One teacher stated that his students’ low level of mathematics abilities is “going to be a very big challenge.” Two of the teachers indicated that their students’ lack of motivation would be a particular challenge. Five of the teachers reported on the survey that learning the software and the technological skills and requirements to implement the curriculum were challenges. Another teacher stated that money and time were persistent challenges.

When the teachers were asked about the content of the STI in the focus groups, a few commented on the engineering aspect of the workshop. A majority of these responses focused on the “softer” skills of engineering (i.e., team work, communication, documentation, and aesthetics). On the survey, five of the teachers responded that design was an engineering concept that struck them as important. Two other teachers indicated that modeling was an important engineering concept. One teacher zeroed in on constraints as something he learned during the workshop related to engineering.

The master teachers, the faculty associate, and the state affiliate director agreed that the primary content of the workshop was focused on the engineering design process. When asked about the focus of the STI on CAD as it relates to engineering, the instructors stated that, given the importance of CAD as a communication tool in engineering design, they think it is crucial to provide this kind of in-depth exposure to teachers and students.

Evaluation

In terms of evaluation, PLTW has "recognized the importance of outside qualitative and quantitative assessment of its programs" (PLTW, Winter 2008). The project leader stated that the evaluation component of the STI is primarily focused on the instructors. The teacher participants complete an online evaluation and the PLTW leadership uses these to determine if they want to continue using the same instructors. The instructors can also access these evaluations to help them improve their instruction. The universities are also asked to conduct evaluations on the facilities used for the STI. The affiliate directors structure their STIs "from deciding which classes will be offered to where teachers will sleep" (PLTW, Fall 2005).

Another key component of PTLW's professional development related to evaluation is accountability. For example, the first page of the scope and sequence indicated the participants' requirements including the maintenance of a portfolio of exercises, activities, and projects. The teachers were asked to sign the first page of the document. In addition, throughout the workshop, master teachers were required to sign off on the successful completion of specified activities. Teachers are provided a certificate of completion indicating that they have met all of the requirements for the STI and that they can teach the course. When asked about this aspect of the STI, one teacher stated that "I actually want to do these assignments, because once I get over that frustration and it clicks, it actually becomes fun."

Summary

PLTW's systematic approach to achieving its mission through an engineering-oriented curriculum is apparent in its approach to professional development. The design of the professional development reveals an extensive program with three distinct phases (pre-core, core, and continuous training) centered on preparing teachers to teach the PLTW curriculum. The scope and sequence of the STIs are structured around developing teachers' knowledge and skills in delivering the curriculum. The location of the STIs and the combination of master teachers and engineering faculty also reveals attention toward PLTW's mission of linking K-12 to post-secondary engineering.

Based on the pre-visit interview with a project leader and the on-site visit of the IED STI, the content and pedagogical approaches were directly link to the curriculum, in particular to activities within the IED course. The content was focused on computer aided drafting. The hands-on activities progressed from a guided activity to draw an object (a train engine) to an open-ended design problem (design a train car to attach to the train engine). The overall approach appeared to be to scaffold design on top of specific tool use development. In other words, instruction was provided on specific tools using a demonstration/lecture technique, and then teachers moved on to more open-ended design projects after the "basics" were learned.

Mathematics Across the Middle School MST Curriculum Project

After navigating the unfamiliar streets of Long Island, New York, we arrived at the *Mathematics Across the Middle School MST Curriculum Project* (MSTP) professional development workshop for the first of our two day visit (days 5 and 6 of an 8 day workshop) as the teachers and project leaders were enjoying breakfast. The workshop was held at a local middle school. We entered a large space with subdivided sections for classrooms. Six classrooms shared the space and were divided by partitions that did not go all the way to ceiling. One wonders how teachers could teach when all of the rooms are filled with noisy middle school students.

We joined the group in one of the classrooms. Sitting at desks made for smaller bodies, the group was eating and chatting. Even if the teachers did not know each other before the workshop, it appeared that they had gotten to know each other over the past five days. We sat with the project leaders and started discussing the project. It was clear that the project leaders had worked together for a long time. They seemed to be able to anticipate what the other was thinking, at times argumentative, but always showing a tremendous respect for each other. One of the project leaders called the group's attention and introduced us. We described our research project to the group and obtained the participants' informed consent to participate in the study.

MSTP is a five-year, 12 million dollar National Science Foundation Mathematics and Science Partnership (MSP) professional development project. According to Burghardt and Hacker (2008), the "thesis of the project is simple: with more instructional time devoted to mathematics, and with mathematics taught with current pedagogical principles, student learning should improve" (p. 2). The partnership consists of Hofstra University, State University of New York at Stony Brook, the New York State Education Department, and 10 school districts, which has engaged university educators and middle school mathematics, science, and technology teachers and administrators. As a result of the partnership project, a professional development guide modeled after the project will be published.

The primary focus of MSTP is mathematics infusion into science and technology education. According to the project's funding proposal, MSTP sought to "enhance teachers' abilities to help students construct important conceptual understandings in mathematics; develop the conventionally acceptable skills, vocabulary, and notation associated with the concepts; and acquire the disposition to continue study" (p. 10). Burghardt and Hacker argued that knowing mathematics means knowing: (a) mathematics content, (b) what mathematics students require, (c) what mathematics can be contextualized, and (c) how to teach it. The criteria Burghardt and Hacker outlined for infusing mathematics include: (a) that content must be important, present difficulty for students, and facilitate science/technology learning objectives, (b) targeting mathematics that the mathematics instructor will address prior to mathematics-infused lesson, and (c) using reform-based mathematics pedagogy.

Professional Development Design

There have been three distinct phases and associated professional development designs with the MSTP project. The first phase was the development of Collaborative School Support Teams (CSSTs), which consisted of two university STEM experts, five school district personnel, and a human service professional. This professional development design used a train-the-trainer approach where the MSTP project provided training to the CSST members, who then trained teachers within their districts. Teachers were placed on grade-level STEM teams with colleagues from their school and engaged in learning mathematics content and pedagogy, as well as experiencing and developing multidisciplinary projects. Through the use of CSSTs, "each school district could shape how it provided professional development and how it built an MSTP community" (Burghardt & Hacker, 2007, p. 1).

The second phase of the MSTP project evolved into an A/B mathematics infusion workshop model. The CSSTs conducted summer workshops where teachers would "meet twice (A workshop and B workshop) and between the workshops they implement a mathematics infused lesson" (Burghardt & Hacker, 2007, p. 3). Science and technology teachers were able to work with mathematics teachers and university faculty to design, implement, and revise mathematics infused lessons. During the 2006-2007 school year, MSTP worked with over 300 middle school teachers from 10 districts and 20 higher education faculty using the "A/B" workshop model.

The third distinct phase, which we observed for this case study, was comprised of an experimental control group research study designed to measure the impact of a mathematics infused technology and science lesson on student achievement in mathematics. The study integrates aspects of the previous phases of the project and examines their effectiveness. According to one of the project leaders, the focus of this phase is on looking at "the ease of transferability to interested districts, who haven't been aware of mathematics infusion," as well as "the efficacy of mathematics infusion."

The Workshop

There were two MSTP workshops running concurrently, one targeting science teachers and one targeting technology teachers. Each group operated independently from the other, with one of the two project leaders facilitating each group. We observed the technology teacher group because of its focus on design. After the teachers were dismissed from the classroom, where the entire group met in the morning, we followed the technology teacher group to a large computer laboratory, with four long rows of tables with desktop computers ready for use. The teachers went right to work completing the previous day's activities.

In addition to one of the project's leaders, the technology education group was led by a lead teacher who had implemented the architecturally-based bedroom design lesson multiple times within his own classroom. In addition, a recognized mathematics education expert provided instruction and support related to the mathematics of the lesson for both the technology and science groups. She stated that she helped to infuse "the proper mathematics at the proper place" by letting the "context drive the mathematics." Throughout each phase of the project, the project leaders have relied on outside STEM consultants to help provide the professional development.

Format

The format of the workshop was largely guided by a bedroom design lesson, where students are asked to design a room within given specifications and constraints (i.e., the window area must be equal at least 20% of the floor, the minimum size of the room is 120 sq. ft., and the budget is $27,500). This mathematics infused lesson was the basis for the research study. The workshop was intended to inform the teachers of the research study and provide them with the experience of working through the lesson and the opportunity to make revisions. The teachers would be implementing the lesson during the next school year and for the purposes of the study needed to teach it the same way.

There are three primary aspects of the bedroom design lesson: (a) mathematics infusion, (b) informed design, and (c) "hybrid" modeling. The first few days were devoted to learning about the research study and its focus on mathematics infusion. The mathematics instruction targeted the appropriate grade level mathematics "endemic" to the technology education activity. This was delivered primarily by the mathematics consultant and was focused on integrating mathematics into the context of the bedroom design problem. In teams, the teachers then engaged in the bedroom design lesson.

The bedroom design lesson was developed using an informed design instructional strategy. The "key factor that differentiates informed design from other design processes is how the Research and Investigation phase is approached" (Burghardt & Hacker, 2008, p. 7), with knowledge and skill builders (KSBs). KSBs scaffold learning by engaging students in "short, focused activities designed to help students identify the variables that affect the performance of the design" (Burghardt & Hacker, 2008, p. 7). For the bedroom design lesson, the KSBs were related to mathematical concepts such as geometric shapes, ratio, proportion, and creating and folding nets. The teachers learned the KSBs and then developed their individual and team virtual and physical models ("hybrid" modeling) of their bedroom design.

Activities

A key activity of the previous phases of the MSTP project's professional development has been a curriculum revision and alignment process. Workshop participants would "meet in large groups, in 'birds of a feather' groups (e.g., all mathematics, all social workers), and in school-based groups" to revise and align their lessons to state standards and assessments. The activities engaged in during the workshop observed for this case study were centered on the bedroom design lesson that the teachers would be implementing for the study. When asked why this lesson was selected, the leadership responded that they care "more about the process than the product" and this activity is the "carrot" to learn the KSBs and make "mathematics visible."

During the morning of our first day the teachers were actively engaged in completing their bedroom design using Google Sketch Up (an online computer aided drafting tool). After creating their own designs, the teachers were grouped into teams where they had selected a design and were making improvements. We found a table and chairs at the back of the computer laboratory near a team that had completed their design. We asked the three teachers about their design and about the first few days of the workshop. The teachers were animated about their participation in the workshop and very willing to answer all of our questions. They knew each other prior to attending the workshop and were having a good time working together.

After about an hour, the lead teacher asked a representative from each team to present their group’s design and explain their decision making process. Once the teams had presented their designs the lead teacher instructed the teams on how to make print-outs for wallpaper, flooring, etc. to use in their physical model. After a break, the teachers reconvened in another room with a large conference table to work on constructing a physical model using various materials including cardboard and paper. Teams went to work with little instruction on how to construct their models. The rest of the afternoon was devoted to completing these models.

After the teachers had left for the day, the leadership team, comprised of the lead teacher, the two project leaders, and the mathematics consultant, met to talk about the day’s activities and plan the agenda for the next day. They discussed the issue of time and making sure they accomplished what was necessary for the research study. In addition, a particular point of conversation was whether or not the physical model, in conjunction with the virtual model, was important to the lesson. They decided to start the next day with a discussion about this issue.

The next morning began with this discussion led by the project leader. He grouped the discussion into three categories: (a) advantages of developing a virtual model; (b) advantages of developing physical models; (c) the value added with physical model after developing a virtual model; and (d) how their teaching will be impacted as a result of participating in the professional development. The teachers actively participated in discussing these issues, largely advocating for the advantages of both virtual and physical modeling. The mathematics consultant recorded the teachers' feedback on a computer projected on a screen. The teachers spent the rest of the day divided into groups to make revisions to the lesson plan.

Participant Feedback

The teachers who participated in the workshop observed for this case study responded to an advertisement and were selected through an application process. Of the 11 teachers who completed the survey at the workshop observed for this case study, all were male technology education, industrial technology, and/or pre-engineering teachers. One of the teachers also indicated that he taught science and research. All but two of the teachers were 6^{th}-8^{th} grade teachers, the other two were high school teachers. In addition to 6^{th}-8^{th} grade, one teacher indicated he taught kindergarten through 5^{th} grade.

In responding to the survey, the teachers indicated a high level of motivation to attend the professional development. The teachers also felt prepared to implement the content associated with the professional development. In regards to engineering, five of the teachers responded that scaling and two responded that modeling were particularly important. In addition, one teacher indicated that the informed design process, another stated designing within constraints, and a third teacher stated research and planning within design were particularly important engineering concepts. The application of mathematics within a project was also mentioned by two teachers on the survey and by teachers in the focus group interviews as important. For example, one teacher stated that he learned the appropriate grade level mathematics to infuse into his classes.

When asked what, if any, changes the teachers would need to make to implement what they learned in the professional development, seven teachers indicated that they would not need to make changes. As one teacher stated in the focus group, “a lot of stuff we’ve already been doing, but now we’re recognizing it.” Two of the teachers indicated on the survey and some within the focus groups that they would have to increase the mathematics in their teaching. One teacher commented in the focus group that “it’s more than me showing a formula, how to plug the numbers in, that’s it anyone can do that. Now I’m going to go back and go, what’s the meaning of that formula?”

During one particular focus group interview, a group of teachers discussed some of the unique pedagogical strategies they learned to deliver mathematics. One commented that charting was a strategy they learned and that it “was extremely beneficial to chart it and leave displayed so they can visualize what’s going on.” Another teacher stated that he learned mathematics vocabulary that was reflected in the standards and state assessments. This was the first time one teacher had examined the state mathematics standards and he had been teaching for 17 years. Another teacher commented that developing lesson plans using the format provided by the project was something he learned. He stated that “now it’s kind of you know, directing me all right, let’s take that five to ten minutes, give you a formal mathematics lesson, infuse it with the technology, and bring mathematics in and show them the real world application of it."

When asked about what aspects of the professional development they experienced had been particularly effective, one teacher responded that "it's very valuable to go in and have a group of professionals come in with all the extra resources, to go in and individually dissect a unit." Another agreed that there is not enough time in the school year to invest in lesson planning and the workshop provided this opportunity, as well as a "think tank of technology education teachers." The mathematics consultant was also seen as an effective aspect of the professional development. Related to this issue, one teacher commented that the focus on mathematics infusion is "validating our profession as a technology teacher, by collaborating with the mathematics and infusing it into our curriculum." Two other teachers commented that the hands-on aspect was effective. And another thought the online environment to share resources would be effective because they could "post immediately and find out what worked, what didn't work."

When the teachers were asked on the survey about some of the biggest barriers to implementing what they learned, answers varied from time to student motivation. Five of the teachers indicated that teaching the mathematics would be a particular challenge. Two other teachers were concerned about their level of computer literacy and access to computer labs within their classrooms. As one teacher stated in the focus group, "we all go back to our schools, and our schools are very different from one school to another." Some of the obstacles Burghardt and Hacker (2008) identified particular to mathematics infusion included: (a) teacher inexperience, attitudes, and beliefs, (b) lack of subject matter knowledge, and (c) the need for preparation to infuse mathematics.

Evaluation

Although it is not clear what type of evaluation was incorporated into this or other MSTP professional development workshops, based on their experiences, Burghardt and Hacker (2007) have concluded that there are three essential elements for STEM professional development: "(1) guided lesson plan design, implementation, feedback, and revision; (2) academic year implementation; and (3) peer review and learning communities" (p. 4). These elements allow teachers to "examine their own practice, participate in professional development related to mathematics content and pedagogical enhancements, and then engage in development of mathematics infused curriculum" (Burghardt & Hacker, 2008, p. 3).

Summary

Initiated as a partnership-driven professional development project, *MSTP* refined its approach to professional development as it progressed. Beginning with a train-the-trainer model and evolving into an A/B workshop model and finally seeking to establish empirical evidence of the efficacy of this approach with a research study, this project has sought to develop science and technology teachers' abilities to infuse mathematics into their teaching. Specifically with technology teachers, the project has used design as an approach to accomplish this goal. Developing an informed design process, where mathematics and other related content are infused as knowledge skill builders, provides a guide for teachers who do not necessarily have a mathematics background.

Based on discussions with the project's leaders and observations of the workshop, the project appears to be oriented toward general literacy for all students in the MST disciplines. The content and pedagogical approaches were directly linked to the goal of infusing mathematics into science and technology. The mathematics consultant sought to model how to build mathematics into a technology lesson, in this case a design-oriented lesson. In addition, the project sought to incorporate a “hybrid” modeling approach to the design lesson, preparing teachers to use an online computer aided drafting tool, and reflecting on the benefits of this approach.

The Infinity Project

Arriving early to attend the last two days of a five day *The Infinity Project*[sm] *Professional Development Institute*, we made our way to a private university in Dallas, Texas. The institute was held in the environmental, civil, and mechanical engineering building on campus and the master instructor for the institute met us at the door of a large computer laboratory. After quick introductions, the project coordinator and a project leader entered the room and greeted us. We settled into our chairs on one side of the room to await the beginning of the day and to be introduced to the teachers, many of whom were actively working on their computers. The master instructor called the group’s attention and the project leader, who was also an Associate Dean, introduced us to the group. At this time we explained the research study and obtained the participants informed consent to participate in the study.

The Infinity Project[sm] was founded in 1999 as a partnership between Southern Methodist University (SMU) and Texas Instruments. The project was initiated as a curriculum development project to “respond to the national challenge of exciting and preparing young students for advanced education in engineering, technology, mathematics, and science.” The objectives of the project include: (a) to develop understanding of the engineering design process; (b) to develop understanding and skills in the use a variety of technological devices; and (c) to explore the connections between humans and technology. One of the project's leaders added that the project was designed to "dispel stereotypes about engineering, and to also just encourage kids at a young age to take more mathematics and science courses, so an engineering career in college and beyond would be a reality for them."

According to the project leadership there are three keys to *The Infinity Project*^{sm}: (a) a "wonderful curriculum," (b) a "first class professional development institute," and (c) an "excellent easy-to-use inexpensive technology." At the time of the site visit, schools in 34 states had become certified to teach the curriculum and the program was expanding internationally into Australia, Ireland, Israel, Lebanon, Mexico, and Portugal. According to the project's leadership, their success is attributable to a low cost curriculum that works with an existing teacher base with significant classroom support.

The classroom support is provided through the project's professional development institutes, which are week long (40 hour) sessions hosted by SMU or other university partners. Institutes include hands-on instruction by master instructors in the use of the hardware, software, and textbook features of the curriculum. According to the project's leadership, the professional development is designed "to provide the teachers with the support material they need to be able to be successful in the classroom." In addition, classroom support is offered through a website that enables teachers to access a blog to share ideas and find downloads and news. One of the project leaders stated that they "want the teachers to feel that they have a long term connection to the program here."

Professional Development Design

The design of the professional development is centered on preparing teachers to teach *The Infinity Project's*^{sm} curriculum. One of the project leaders stated that the weeklong institute is designed to "give the teachers the opportunity to go through the curriculum itself and then the actual lab experiments that have been designed, and where they actually learn how to use the hardware, become familiar with software and go through and review the lab experiments as well." Another project leader added that, "about half of the institute is spent on the curriculum itself reviewing the concepts, and then the other half is actually in the lab."

The Infinity Project^{sm} curriculum includes a year long high school (sophomore through senior level), early engineering course titled *Engineering Our Digital Future*, and an adapted version of this course called *The Infinity Project for Computer Applications* for the 9th and 10th grades. The course provides mathematics, science, or career and technical education elective credit. The instructional materials include a textbook, student lab materials, an instructor's guide, daily lesson plans, and chapter presentation slides. In addition, a technology kit is another component of the curriculum; turning a "PC into 'Engineering Design Platform'" with LabVIEW software. An "Introduction to LabVIEW for *The Infinity Project*^{sm}" offers instructions and support for this aspect of the curriculum.

The Institute

After the project leader introduced us to the teachers, she addressed the group, providing a brief history of the project. She also stressed the need for students to have had calculus and physics in high school to be successful and persist in engineering programs. The connection was made between *The Infinity Project's*^{sm} curriculum and the larger goal of better preparing high school students for post-secondary engineering. She also urged the teachers involved in the program to educate their students about what it takes and is like to be an engineer. After fielding a couple questions from the teachers, she thanked them for their participation and offered the assistance of the project and university to help the teachers be successful.

The next hour was devoted to open lab time for the teachers to receive individualized help from the master instructor. Chapters 1 through 4 and their corresponding labs had been the focus of the previous three days of the institute and teachers were at different points in these labs. Some of the teachers worked at their own pace on labs and others worked together. We took the opportunity to walk around the room and ask teachers questions. We discovered that two pairs of teachers came to the institute together from the same school. One of these pairs, a science teacher and a technology education teacher, was planning on team teaching the course in the fall and were working on one computer together. *The Infinity Project*^{sm} encourages schools to send teams of two teachers to who work together throughout the institute.

Format

Open lab time was built into the format of the institute, which was structured around the textbook's chapters. The institute was guided by an agenda that outlined the schedule for the week. The project leadership developed the agenda, which was reviewed by the master instructors prior to each summer's institutes. Master instructors are teachers identified by the project's leadership when they come to an institute for training. They are invited to become master instructors by attending two additional weeks of training. At the time of the site visit, there were about 10 master instructors for *The Infinity Project*^{sm}. The master instructor for the institute we observed had previously been a chemist and an engineer for fifteen years before becoming a chemistry teacher.

In addition to the agenda, the teachers are provided a binder of materials, which they use to work their way through the content and labs during the week. Prior to attending the institute, participants are sent a memo outlining the important mathematics concepts in the curriculum and asking them to complete a 3-hour LabVIEW tutorial. The primary focus of the institute is on learning how to use the LabVIEW software, which is a virtual instrument with controls (inputs) and indicators (outputs) that can be manipulated on the computer . In addition, the block diagram or accompanying program can be viewed to see how devices are "wired" together.

Activities

The primary activities observed during the two days were PowerPoint presentations and self-guided laboratory time. The PowerPoint presentations and related instructional materials were prepared by the project's leadership and used at the discretion of the master instructors. The master instructor in charge of the institute we observed concluded that he spent about 70% of the institute on "the mechanics of the software, and then 30% on the concepts." The PowerPoint presentations were designed specifically for the professional development, but according to the master instructor, portions could be modified and used in the classroom as well. During the two day visit for this case study, chapters 4 – 8 were reviewed.

After the open lab time during the first morning of our visit, the master instructor directed the teachers to a more traditional lecture-style classroom next to the computer lab, with rows of tables and chairs facing the front of the room. A PowerPoint presentation was projected on a large screen. The master instructor quickly reviewed the content for *Chapter 4: Mathematics You Can See*. A discussion emerged about the relevance and capability of teaching a particular aspect of the software: block diagrams. A couple of the teachers requested more detailed instruction on LabVIEW so that they could understand its full capability better. They wanted to know more beyond the "canned labs" so they were prepared to help students who wanted to know more.

The rest of the morning and most of the afternoon of the first day of our visit were devoted to self-guided lab time to work through Chapter 4. During the last few hours of the day the teachers attended a gender equity workshop conducted by an outside consultant brought in by the project. The second day of our on-site visit followed the same format with open lab time in the morning for about an hour and then a quick review of the content associated with Chapters 5 – 7. During this review, teachers asked questions related to the content of these chapters. For example, one teacher asked about how red eye elimination works with digital imaging and another teacher asked about Blue Ray DVD technology.

Although not a major focus of the professional development, the curriculum has an overt focus on technologically-based concepts, with an emphasis on mathematics. It appears that the decision to focus less time on concepts and pedagogical strategies was an intentional decision. The master teacher stated that the teachers "know these concepts." This may be attributable to the majority of the teachers having an engineering background. As one teacher stated, "having gone through the whole engineering curriculum, and actually worked as an engineer for awhile, you know, I see where all this mathematics is going." In addition, the master instructor did not appear to be modeling/training teachers in essential classroom pedagogy because of the speed of delivery of the content of the chapters. This time appeared to be an opportunity for teachers to become aware of the content of the chapters, not learn new content or new strategies to teach the content.

Participant Feedback

*The Infinity Project*sm conducts outbound marketing to recruit teachers and teachers and/or school administrators also find out about the project on their own. Schools become "Infinity Schools" by completing an online application and then are contacted by a project staff member, who interviews the administrator. Accepted schools acquire the necessary classroom technology and textbooks and send teachers to a professional development institute. Originally, physics and calculus teachers were the primary audiences of the project. However, according to the project leadership, mathematics, science, and technology teachers are equally represented in teaching the curriculum; with a "50/50 gender mix."

Of the 26 individuals who attended the institute observed for this case study, 15 were male and 11 were female secondary level teachers. The years of teaching experience varied amongst the teachers from three with 1-2 years of experience and five with 21 years or more. The subjects the teachers taught also varied, with 14 teaching mathematics (Algebra, Calculus, and Geometry), nine teaching science (physics and chemistry), and 13 teaching technology (technology education, pre-engineering, computer science) or a mixture of these. All of the teachers indicated a high level of motivation to attend the professional development and felt prepared to implement the curriculum. The teachers also indicated that their students would be motivated to learn the content and that their administrators would be supportive of the implementation of this curriculum.

When asked about particularly effective strategies employed during the professional development, many of the teachers responded that the hands-on component of learning the software was the most effective. As one stated, getting "involved in the labs and using or accessing or manipulating the software behind the labs" was why he wanted to attend the institute. Other teachers also responded that the collaboration with other teachers was particularly effective. In addition, the time to devote to experiencing the curriculum was valued by the teachers. As one stated, "I want to get down to business here, because when I get home I'm not going to have that time to mull through it." The use of the blog was valued by one of the teachers who indicated that during the institute they are able to put "faces to names" and then correspond with each other through the blog during the school year.

When asked on the survey what engineering concepts struck the teachers as particularly important many focused on the digital technology aspect of the curriculum. Specific concepts such as digital imaging, digital sound processing, and computer animation were listed. In addition, the real world application of mathematics was cited with the specific example given of trigonometry functions. Another teacher indicated that he learned logical processes to solving problems and four teachers indicated they learned more about engineering design process. One teacher responded that he felt the concepts were more technologically oriented, not engineering based. Another echoed this by stating that the curriculum teaches "more about what is behind technology and technology objects they use everyday."

One of the teachers indicated that she believed the pedagogy employed in this curriculum was more oriented toward pedagogy in science. She stated that “you do some lecture, you do some lab that demonstrates that.” Another teacher responded that the basic components of the pedagogy he observed were; “lecture, discussion, do the labs.” Another responded that he thought the curriculum was designed to be flexible and adapt to each teacher’s style of teaching. He stated that “every one of us is going to walk out of here and design our own little version of this course.” The institute enabled them to “see what’s coming, and know what’s happening” in order to better accomplish this.

Many teachers responded to the survey that they anticipated a challenge related to obtaining access to computers, installing software, and managing the technology, while preparing for and teaching the curriculum. Another particular challenge articulated by quite a few teachers was related to their feelings of preparedness. Although most of the teachers did not expect the instructor to guide them through all of the content and labs step-by-step, many of the teachers stated that they would have preferred a more structured experience. As one stated, “I need some more nuts and bolts.” Another teacher commented that he would need more time to “get reacquainted with the formulas and the concepts behind them.” Yet another stated that he wished the master instructor pointed to “things to take away from the chapter, look for these when you’re doing the lab you know kind of focus it in a little bit for us.”

Evaluation

The evaluation component of the project included a pre-test/post-test assessment. Teachers are asked to complete the assessment before they attend the institute and then at the end of the institute they are asked to complete the same assessment to see how well they have “mastered the concepts throughout the week.” In addition, the teachers are asked to complete an evaluation of the institute. According to the project leadership, twice a year the project staff touches base with the teachers and sends “out an assessment from their perspective as far as teaching, how well the training was for them, how they’re doing in the classroom.”

Summary

The Infinity Project’s[sm] summer institutes are structured around providing an overview of the content within each chapter and providing time for teachers to learn how to use the LabVIEW software. Based on the pre-visit interview and the on-site visit, the instructional design of the institute modeled a typical post-secondary engineering education approach. The master instructor presented the broadly structured conceptual information without a lot of guided instruction on using the software. The teachers then worked through the labs at their own pace, where they developed more fully the use of the software and were able to apply the concepts. As the master instructor stated, the approach is for the teachers to “get in there, get their feet wet.” The focus, however, was on increasing the teachers’ comfort level with the hands-on portion of the institute; not to become an expert “by no means.”

Although the design of the professional development appeared to account for the type of teachers attending the institute, there were some particular challenges noted by the leadership. One of the challenges that the project leaders identified was the mathematics deficiencies in some of the teachers. As one stated, “mathematics may be less fresh in their mind. And so that’s something we’re struggling with as we move forward, and try to get more teachers from career and technology involved.” One way that the project has sought to remedy this challenge is by requesting that teams attend the institute, with one of the teachers having a mathematics background. In addition, teachers are sent a memo prior to attending the institute outlining the mathematics concepts involved in the curriculum so they can review those that are less fresh in their minds. Another remediation undertaken by the project was to have one of the master instructors create a mathematics "refresher" for teachers that will be available online.

INSPIRES

The two day *INSPIRES* workshop was held in an eastern state on a large university campus in the information technology/engineering building. After finding my way to the large lecture hall, I was greeted by the project leaders who were busy setting up a PowerPoint presentation and laying out breakfast items. They handed me a name tag and a folder containing the workshop materials and I made my way to a seat near the back of the room. We were soon joined by the graduate student research assistant who worked on the project, as the twelve teachers began to arrive.

The morning began with one of the project's leaders presenting a PowerPoint outlining the project's history and goals. She explained that *INSPIRES* was an NSF-funded curriculum development project with the purpose of "Increasing Student Participation, Interest, and Recruitment in Engineering and Science." According to Ross and Bayles (2007) *INSPIRES*, began with a simple question by two engineering faculty "What do we wish our students were learning in high school to better prepare them for engineering study?" (p. 1). They concluded that many freshmen do not understand what engineers do; and while "they have significant background in mathematics and science, they often fail to see the relationships between the two and do not understand how either is related to the solution of engineering problems;" (Ross & Bayles, 2007, p. 2) and that "many students buy into the image of the stereotypical engineer" (p. 2).

The *INSPIRES* curriculum was developed to address those needs by targeting "core engineering skills and concepts that should be addressed at the high school level in order to better prepare students to pursue engineering and technology related careers" (Ross & Bayles, 2007, p. 1). The curriculum was also designed to "encourage interest and participation in engineering and technology by all groups, including women and minorities" (Ross & Bayles, 2007, p. 4). In addition, the curriculum is designed to enable teachers to integrate different modules or elements of modules into their classrooms; not be a stand-alone course.

In order to make the curriculum accessible, the project's leaders began conducting workshops. One of the project's leaders summed up the workshops as "really as much as anything, as much a part of our dissemination piece, of trying to get materials out there and used in the classrooms." The other project leader added that the primary goal is "to get teachers in to tell them about the materials, to train them how to use the materials." Another goal of the workshops is related to the evaluation of the project so as to "maximize the integrity of implementation from classroom to classroom such that data may be compared among trials in various schools" (Ross & Bayles, 2007, p. 4).

Professional Development Design

Currently the professional development component is comprised of a two-day workshop devoted to an individual *INSPIRES* module led by the project's leaders. The leaders are engineering faculty with a combined "12 years of industrial experience and 24 years of experience teaching engineering at the undergraduate and graduate levels" (Ross & Bayles, 2007, p. 11). In addition, one of the project's leaders has been organizing professional development workshops for middle-school and high-school mathematics, science and technology/pre-engineering teachers and guidance counselors for about twenty years. A graduate student research assistant on the project was also available to assist in the delivery of the professional development.

At the time of the on-site visit for this case study, the *INSPIRES* curriculum series was in development. The curriculum will consist of five stand-alone modules, which are centered on specific engineering design challenges. These modules include: *Engineering in Health Care: A Hemodialysis Case Study*, *Engineering in Flight: A Hot Air Balloon Case Study*, *Engineering Energy Solutions: A Renewable Energy System Case Study*, *Engineering and the Environment*, and *Engineering in Communications and Information Technology*. The observations conducted for this case study were completed at a workshop focused on the *Engineering Energy Solutions: A Renewable Energy System Case Study* module.

The content areas were selected to "stimulate student interest in engineering and technology and to provide a real-world context" (Ross & Bayles, 2007, p. 4). Each module targets the *Standards for Technology Literacy* (ITEA; Standards 8, 9, and 11), in addition to various national science and mathematics standards. With the assistance of technology teachers and engineering experts, the project leaders developed the modules around engineering design challenges, which are tested with freshmen engineering classes, who test the activities prior to testing in the high school environment. The challenges are intended to "allow student creativity in finding a design solution that meets all design criteria and constraints" (Ross & Bayles, 2007, p. 4).

The Workshop

After the project leader outlined the *INSPIRES* project, she introduced me and another UMBC professor to the group. At this time I explained the research project and obtained the participants' informed consent to participate in the study. Afterward, the professor, who worked in science teacher professional development, explained that he was brought into the project to help inform future professional development efforts associated with *INSPIRES*. The teachers were asked to complete two surveys, including one this professor administered and a pre-test given at all *INSPIRES* workshops. Once teachers had completed these items, the group moved to a computer laboratory across the hall to log into the project's online environment.

Format

The format for the workshop was outlined in an agenda distributed at the beginning of the first day. The workshop primarily consisted of the general overview of the project and then experiencing the curriculum "in the order and format that it is to be implemented in the classroom" (Ross & Bayles, 2007, p. 4). One of the project leaders stated that they "try to get them to experience the curriculum as a student for a couple of days." The project leaders model what they hope the teachers will in turn do with their students and focus on implementation throughout the workshop. As one of the project leaders stated, the "vast majority of it is really hands-on with them working with the curriculum; and then sort of follow-up discussions of how that went and how that would work in terms of implementing it in their classrooms."

Moving between three different classrooms, a lecture hall, a computer laboratory, and a laboratory classroom, the teachers are asked to complete the module from the pre-assessment and pre-module design challenge to the post-assessment and post-module design challenge project. The challenges are “intended to introduce the design process and assess the capabilities of the students before and after the *INSPIRES* curriculum” (Au, Bayles, & Ross, 2008, p. 2). The teachers also work through the web-based tutorials and interactive simulations that are included in the module. The project’s leaders believe that this format has “proven effective since it provides an example to the teachers of how the curriculum should be presented” (Ross & Bayles, 2007, p. 5).

The only element that is not completed during the workshop, but is discussed, is the large scale design problem. The project leaders argued that design is “the central core concept that distinguishes engineering from any other field of study” (Ross & Bayles, 2007, p. 2). Design helps students better understand “how engineering applies to everyday problems and how it affects their lives on a daily basis” (Ross & Bayles, 2007, p. 2). In addition, the project leaders argued that design develops skills such as working effectively in teams, communicating technical ideas, and synthesizing mathematics and science. The project leaders “strongly believe that it is more important at the high school level to develop specific skill sets than it is to introduce a particular set of topics” (Ross & Bayles, 2007, p. 2). A project leader stated that it is “really all about the process and all about the transferable skills, and much, much less about specific domain knowledge.”

Activities

After the teachers successfully logged into the *INSPIRES* website and completed the pre-assessment, the group moved to the laboratory classroom that contained four lab tables at about waist height, cabinets surrounding the walls, and a large sink; the perfect environment to construct projects and experiment with materials. Teams of four teachers were formed by counting off and given a hand-out outlining their challenge. Using only the resources provided (2 liter plastic bottle, wooden dowel rod, index cards, fishing line, masking tape, and scissors), the teams were asked to design and construct an apparatus that used hydro-power to raise a weight in the shortest time possible. With little instruction from the project leader and only a few questions answered, the teams were given 30 minutes to design their solutions. The project leader stated that the goal of the challenge was to “pre-assess student use of the engineering design process and develop an appreciation of the engineering design process.”

After lunch we met in the lecture hall and one of the project leaders presented a PowerPoint on the content of the module. For the particular module explored during the workshop, the key concepts were related to energy (i.e., work, power, voltage, etc.). The project leader who presented this information stated that the goal of the lecture was to have students think about the key concepts and to set the guidelines for the large scale design challenge. In addition to the lecture, a demonstration-based activity was discussed. The demonstrations included devices intended to demonstrate specific energy concepts. After a break, the teachers reconvened in the laboratory classroom and were given the opportunity to experience the hands-on demonstration projects. The day ended in the computer laboratory where the teachers worked on completing the online tutorial.

The second day of the workshop began in the lecture hall with an overview of the other *INSPIRES* modules and some of the issues in the current module. An interesting element of this particular project is that it is still in its development phase. The module explored in the workshop was not fully complete and teachers were asked to provide feedback throughout the two days. While working through the online tutorials many teachers found mistakes in the materials and the project leadership and graduate student research assistant documented these. This contributed to a professional development experience where teacher feedback and critique was welcomed by the project's leaders. As one teacher stated, "the ability to instantly update, you know, we're telling them, this, this, this" was an important aspect of the workshop.

The rest of the second day focused on completing the online simulation, an overview of the large scale design challenge, and the post-design challenge and assessment. The project leader showed the teachers video clips of design solutions from her freshmen engineering class. The emphasis on the final design challenge was once again placed on the design process and developing student creativity. After the teachers completed the post-design challenge and assessment in the laboratory classroom, the project leaders led lengthy discussion answering teachers' questions. Two issues stood out during the wrap-up discussion; teachers requested: (a) help with the calculations, and (b) a list of key terms, including force and gravity.

Participant Feedback

The project sends out direct mailings to teachers, technology education coordinators, and county coordinators of education in the region to recruit participants. The mailings include a letter describing the project, a description of the current module that will be the focus of the professional development, and an invitation to apply to participate in the workshop. The only requirement for participation is that the teachers have an interest in implementing the curriculum into their classrooms. The application asks the teachers to relay their interest in the curriculum and asks about their facilities.

Most of the previous participants have been technology education teachers with a few science teachers attending. Of the 12 high school teachers who attended the workshop observed for this case study, all but one of the teachers in attendance taught technology education or pre-engineering. Two of these teachers taught additional subjects; computer science and physics. In addition, a life science teacher participated in the workshop. Six of the teachers were female and six were male. The years of teaching experience varied with one having 3-5 years of experience and four teachers having over 21 years. Four of the teachers had attended an *INSPIRES* workshop in the past and had taught one of the other modules.

The teachers indicated a high level of motivation to attend the workshop. One teacher explained her motivation for attending by stating that "quite bluntly any time that I see in place curriculum that I might be able to draw from without having to do it myself, I take advantage of at least spending the time to look at it." In addition, the support and access to materials were noted as particular motivators. If the teachers agree to enable access to their student's assessments, they receive all of the equipment and materials to teach the modules for free. As one teacher stated, the fact they are "sending out kits for us to use as well; that's just such a super support part of the program."

In terms of the engineering concepts that struck the teachers as being particularly important, most indicated those related to energy (productivity, efficiency, generation, consumption). A few of these teachers pointed to particular activities in the curriculum. For example, one responded that gear-pulley ratios were particularly important because "ratio helps with so many of the projects." Some of the teachers indicated that the design process struck them as being particularly important. One of the teachers explained that the design process was important because "students need to understand the basis of design engineering." Another added that with the "engineering design process, there's no unique solutions, so creativity and infusion of science and mathematics and technology" are important.

When asked about what was particularly effective about the workshop, two of the teachers commented that the opportunity to experience the online aspect of the module was particularly effective. Another teacher stated, "I liked being able to go through those demos and get other teacher's input." The hands-on projects were also noted as being effective. As one stated, you get the "opportunity to actually touch and feel some of the projects." Another added that getting the chance to "actually work through it as though I am the student is most effective." The credibility of the instructors was also commented on by many of the teachers, who stated that their engineering expertise was important. For example, one of the teachers stated "here's some people, they're engineers from a reputable university; so let me go find out some information about it."

The teachers pointed to a variety of challenges involved in implementing the curriculum on the survey and in the focus groups. Some of these concerns focused on their preparation to implement the curriculum. One teacher reflected that he thought "they're assuming a lot" and offered that they should "break it down a little bit, just to go over it for us." Another agreed adding they should "get a little bit more to the basics." Others were concerned about the time to prepare. For example, one of the teachers commented that "quite honestly I haven't got up into the material enough to really feel like I'm refreshed skill wise, but I at least see the need now and I know that's one of the things I'm going to have to do." Another added that "if I was going to do it this year, I think I'd definitely have to take a leap of faith." And one teacher wondered "when, where, and how to incorporate" the curriculum into her curriculum.

In addition to these challenges, the project's leadership noted numerous challenges. They have found that many technology teachers "herald from vocational backgrounds and simply lack the fundamental skills necessary to easily implement our curriculum (or any other pre-engineering curriculum)" (Ross & Bayles, 2007, p. 9). Related to this, they have found it to be a challenge to ensure that teachers implement the curriculum as intended. They have recognized a trend of teachers downplaying the mathematical and simulation portions of the curriculum. The project leaders concluded that these challenges cannot be remedied with "short/intermittent professional development workshops, but rather demonstrates a need for long-term fundamental shift in the training of technology education teachers" (Ross & Bayles, 2007, p. 9-10).

Evaluation

In terms of evaluation, the workshop begins and ends with a survey. Based on previous surveys of teachers, the project's leadership has concluded that "successful professional development activities for technology education must be *local* and *specific to the discipline*" (Ross & Bayles, 2007, p. 7). In addition, they found that a particularly effective aspect was the '"cross-fertilization' of practical ideas that occurs among the teachers" (Ross & Bayles, 2007, p. 5). As one of the project leaders stated, they have found that "the teachers really learn a lot from each other. And are very good about giving one another suggestions and you know, trading contact information, and that kind of thing, supporting one another."

Summary

Curriculum dissemination and implementation are the focus of the *INSPIRES* professional development. The format of the workshop is structured around exposing teachers to the sequence of the module. The workshop is structured around: (a) PowerPoint presentations delivered in a lecture-style format, (b) self-guided online tutorials and assessments, and (c) hands-on design challenges and demonstrations. In addition, discussion and reflection were integrated throughout the workshop to regularly draw the teachers' attention back to classroom implementation.

As evidenced by the workshop, the content of the module was less important than stressing students' critical thinking and design problem solving skills. The primary goal of the project is to engage students in design-based activities so they develop creative solutions that enable them to apply mathematics and science knowledge. In addition, based on the instructional strategies used in the workshop, the essential pedagogies to teach this module can be divided into three main approaches: (a) lecture to deliver content, (b) demonstrations, and (c) facilitation of self-guided online tutorials and hands-on design challenges. When asked about the particular pedagogies used to deliver the module one of the teachers stated, "I'm pretty much the facilitator as this is set-up."

Summary of Findings

Below is a discussion of the findings from the five case studies organized into categories directly related to the study's research questions. The case studies were synthesized by conducting a cross-case search for patterns and issues within each case study's findings. The relevant categories that emerged as a result of the cross-case analysis included: philosophy, format, teacher recruitment, instructional design, fundamental content knowledge, essential pedagogies, challenges, effective strategies, and evaluation. The issues within each of these categories are discussed further below.

In addition, Table 6 outlines some of the major issues related to engineering-oriented professional development within some of these categories. The philosophical underpinnings related to secondary level engineering education, the format in number of days, the online component, teacher recruitment, design model, instructional design, and instructors are displayed in the table to provide a side by side comparison of each project.

Philosophy

The five projects involved in this research study had distinct philosophies guiding their approach to engineering-oriented education at the secondary level. The philosophy of EtF and MSTP was oriented toward engineering as an avenue toward technological literacy for all students. As EtF's Teacher Guide (2008) stated, the course is "meant to help all students—whether they eventually choose to attend a university, another tertiary education institution, or enter the world of work—better understand the designed world and the wide variety of career paths a person might take in designing, manufacturing, maintaining, or using technologies" (p. xv). Although the emphasis of MSTP was on mathematics infusion, their approach to engineering appeared to be oriented toward technological literacy for teachers rather than a specific pre-engineering focus.

Table 6

Major Engineering-Oriented Professional Development Design Issues

Design Issues	Projects				
	EtF	PLTW	MSTP	The Infinity Project	INSPIRES
Philosophy	Technological Literacy	Pre-engineering	Technological Literacy	Pre-engineering	Pre-engineering
Format	4 Days	10 Days	8 Days	5 Days	2 Days
Online	Course	Virtual Academy	Blackboard	Blog	Online modules
Teacher Recruitment	Self Selection	School Agreement	Self Selection	School Agreement	Self Selection
Model	Curriculum-linked	Curriculum-linked	Partnership	Curriculum-linked	Curriculum-linked
Instructional Design	Scaffolded Problem-solving	Scaffolded Problem-solving	Scaffolded Problem-solving	Self-guided Learning	Self-guided Learning
Instructors	Project Leaders	Master Teachers & Engineering Faculty	Master Teacher & Mathematics Consultant	Master Teachers	Project Leaders (Engr. Faculty)

The philosophy of PLTW, *The Infinity Project*[sm], and *INSPIRES* was oriented towards pre-engineering or the development of students' aptitudes toward pursuing post-secondary engineering. According to PLTW's website, the courses are "modeled after introductory engineering courses taught at the university level" so students "gain first hand experience in different facets of engineering and discover where their strengths lie." *The Infinity Project*[sm] is advertised as an "early college engineering education program." These projects also emphasized understanding technology and equity. For example, *The Infinity Project*[sm]'s website states that the course is designed for all types of students. The emphasis on equity is an important element to the *INSPIRES* project, as well. The curriculum was designed to "encourage interest and participation in engineering and technology by all groups, including women and minorities" (Ross & Bayles, 2007, p. 4).

Format

The first research question driving this study focused on understanding the professional development design elements, including the format selected. The length of the in-person aspects of the professional development differed among the projects including two and four day; one and two week formats. The length of the workshop was often related to the goals of the professional development. For example, PLTW's in-person workshops last for two weeks. Their design included having the teachers participate in as much of the curriculum as possible so that they are fully prepared to implement the curriculum as it is intended. The *INSPIRES* in-person workshops, on the other hand, typically meet for two days. Their professional development goals were oriented toward curriculum dissemination and making teachers aware of the materials, one module at a time, lending itself to a shorter format.

All of the projects developed a daily agenda which outlined and largely guided the day's logistics. The projects varied on how closely they adhered to the agenda. For example, the EtF workshop was outlined in a daily agenda, which was distributed during the morning of each day and adhered to closely. The MSTP project, on the other hand, was more flexible with its daily agenda. The project leadership met at the end of each day to discuss the plans for the next day's proceedings. If the teachers needed more time to complete an activity or an additional activity was needed, this was built into the agenda. However, the team was careful to adhere to the overall goal of the workshop, developing the lesson plan that would be used in the research project.

In addition to in-person workshops, all of the projects included an online component to their professional development. The online component of most of the projects was designed to provide additional follow-up support to the teachers after they had attended the in-person workshop. The most structured online support was developed by the EtF project. In addition to online news, file storage, discussion boards, and resources, an online course for college credit was developed. PLTW also formalized their online support with their virtual academy serving as a continuous training mechanism. The virtual academy is an online system where teachers can download lessons. The *INSPIRES* modules are accessible online and much of the workshop is spent in a computer lab allowing teachers to work through the online tutorials.

Teacher Participants

Teacher recruitment is another important professional development design decision. Some of the projects sent direct mailings marketing their professional development workshops to area schools. Teachers interested in attending the professional development workshop register by completing an application. A few of the projects required an agreement to be completed by the school district administrator before the teacher could attend. For example, PLTW sends the school an agreement of quality standards that the school must agree to in order to join. Schools become “Infinity Schools” by completing and submitting an online application. The school principal and teacher are then interviewed by a staff member.

Many of the projects noticed trends to the type of teachers involved in the professional development, with the majority being drawn from technology and science disciplines. For example, teachers involved in *The Infinity Project*[sm] are “split between physics teachers and calculus teachers,” with a few technology teachers. Most of these teachers have “at least five years teaching experience” and represent a 50/50 “gender mix.” Interestingly, this project is oriented toward pre-engineering. The PLTW leadership indicated that about 70% of the teachers currently participating are technology education certified. The remaining 30% are mathematics and science teachers, as well as a few business teachers. Most of the teachers attending *INSPIRES* workshops have been technology education teachers with a few science teachers attending.

The teachers who attended the workshops observed for this research project fit these general trends as well. Table 7 summarizes the characteristics of the teachers who attended the workshops and completed the survey across two dimensions: (a) subjects taught and (b) gender. Across the five projects, the majority of the teachers were male (71%) and taught technology education, industrial technology, pre-engineering, or computer science subjects (n=47).

Table 7

Teacher Characteristics

Project	Total	Gender	Subjects Taught
EtF	2	Female: 0 Male: 2	TE, IT, Pre-engr, Computer: 1 Mathematics: 0 Science: 1
PLTW	12	Female: 1 Male: 11	TE, IT, Pre-engr, Computer: 11 Mathematics: 1 Science: 0
MSTP	11	Female: 0 Male: 11	TE, IT, Pre-engr, Computer: 11 Mathematics: 0 Science: 0
The Infinity Project	26	Female: 11 Male: 15	TE, IT, Pre-engr, Computer: 13 Mathematics: 14 Science: 9
INSIPRES	12	Female: 6 Male: 6	TE, IT, Pre-engr, Computer: 11 Mathematics: 0 Science: 2
Totals	63	Female: 18 Male: 45	TE, IT, Pre-engr, Computer: 47 Mathematics: 15 Science: 11

Instructional Design

All but one of the five projects in this study began as a curriculum development project, developing curriculum-linked instructional design models. The curriculum-linked designs were focused on providing an overview of the curriculum and discussing practical implementation issues. In addition, these projects modeled their professional development around having the teachers experience the curriculum as a student. However, there were distinct decisions made concerning how much of the curriculum to cover in the workshop. For example, the EtF project devoted each day to a module, covering all of the modules in the curriculum. However, *INSPIRES* devoted an entire workshop to just one of its modules. PLTW and *The Infinity Project*sm designed their workshops around having the teachers experience the entire scope of a course. MSTP was the only project initiated as a professional development project using a partnership approach focused on mathematics infusion into science and technology lessons.

In addition, there were two patterns of instructional design that emerged: (a) scaffolded problem solving and (b) self-guided learning. Three of the projects' approach to instructional design was to scaffold design-based activities on top of developing skills and knowledge related to the hands-on activities. For example, with EtF, the teachers were guided through the "quick build" activities using a step-by-step process. The culminating open-ended design project was briefly discussed, but not engaged in. PLTW's approach was to guide the teachers through the basics of CAD. Three distinct stages were observed: (a) observing a demonstration of a set of CAD techniques, (b) using the learned CAD techniques to draw an object following specific instructions, and (c) designing and drawing another object to fit specific constraints. A similar process was observed with the MSTP project with their use of Knowledge Skill Builders (KSBs), which were taught to the teachers prior to engagement in the bedroom design activity.

The other instructional design pattern observed could be categorized as a self-guided learning. Teachers were briefly introduced to the content of the curriculum and then given time to work through the activities or labs at their own pace. For example, *The Infinity Project*^{sm} briefly reviewed PowerPoint presentations in a lecture-style format to deliver the content and then the majority of time spent in a computer laboratory completing the various labs within the curriculum. The master teacher was available to answer questions but the teachers spent much of the time working through the labs at their own pace constructing their own understandings. Similarly, the *INSPIRES* Project pursued more of a self-guided approach to its instructional design. For example, teachers worked through the online tutorial at their own pace and the two design challenges were completed without much instruction from the instructors.

Although the instructional design varied across the projects, four primary instructional strategies were used to deliver the professional development within all of the projects: (a) lecture, (b) hands-on activities, (c) cooperative learning, and (d) reflective discussions. Lecture was the primary strategy used to provide an overview of the project and review content in all of the projects. In addition, all of the projects had teachers engage in hands-on activities using cooperative learning or working in groups. For example, *INSPIRES* devoted time during the workshop to having the teachers experience the pre- and post-module design challenges in groups. *The Infinity Project*^{sm} also incorporated brief lectures on the content of the chapters of the textbook, hands-on activities focused on the LabVIEW labs, and encouraged cooperative learning.

Related to the focus on hands-on activities, three of the projects devoted a large portion of the professional development to learning software tools. PLTW focused on hands-on activities as they related to developing the teachers' skills in CAD, which was central to the course the teachers were being prepared to teach. *The Infinity Project*^{sm} also devoted much of its workshop in having teachers learn to use LabVIEW. This software tool is central to *The Infinity Project's*^{sm} curriculum. Although less of a focus, the MSTP also introduced the teachers to a software tool, Google Sketch Up, as a way for teachers to implement the design challenge with their students.

Reflective discussions were also an instructional strategy used, however used limitedly. Some of the projects built reflection into their agendas. EtF followed each hands-on activity with a brief reflective discussion concerning implementation issues related to that activity. *INSPIRES* ended the two day workshop with a lengthy discussion answering teachers' questions and offering advice and support concerning implementation. Within some of the other projects, spontaneous discussions occurred, where instructors answered questions or offered advice concerning implementation. However, little consistent emphasis was placed on reflecting on the professional development process (e.g., why particular activities were selected, what techniques work, what concepts were being learned, etc.). Much of the reflective discussion that occurred was devoted to implementation issues.

An important decision related to the instructional design and strategies is the selection and preparation of the instructors used to deliver the professional development. There were three main types of instructors, with some projects using a combination of the three: (a) master teachers, (b) project leaders, and (c) engineering faculty. Most of the projects had master teachers deliver aspects of the professional development. These were teachers who had previously attended the project's professional development and had implemented the curriculum for a period of time. They were then recruited by the project's leadership, trained, and became instructors for the project's professional development. For example, PLTW had a well-defined process for preparing their master teachers. Master teachers are selected through an application process and are required to have at least two years of experience teaching the course before they can instruct a professional development class.

Three of the projects' leaders also served as instructors, many of which were also engineering faculty. For example, *The Infinity Project*^{sm} and *INSPIRES* had engineering faculty as the project leadership. EtF's instructor was one of the curriculum developers and part of the project's leadership. Although not part of the project leadership, PLTW includes an engineering faculty member as part of the team of instructors. In addition to a master teacher and the project's leaders, MSTP also included a mathematics consultant as part of its team of instructors.

Fundamental Content Knowledge

The second research question asked about the fundamental content knowledge provided in the professional development programs. Although all of the projects included mathematics, science and technology content, the professional development programs devoted little time to reviewing or learning that content. As evidenced by the case studies, engineering content was largely defined in terms of process. For example, the EtF instructor stated that the engineering "process and the content are all married together to us, they're not separating them out, saying this is content, this is process." The PLTW instructors stated that engineering content was more appropriate at the university level and that the intent of the workshop was to focus on the process of design. An *INSPIRES* project leader stated, that their project focuses on the engineering process and transferable skills; "much, much less about specific domain knowledge."

In addition to engineering content and process, many of the projects conducted activities that featured science, technology, and/or mathematics content. For the particular module explored during the *INSPIRES* workshop, the focus was on key concepts related to energy. Much of the content associated with the activities in the EtF workshop centered on technology (materials, brake press, manufacturing processes) and physics (strength, energy, power). The concepts central to *The Infinity Project's*^{sm} workshop were related to digital technologies. Much of the content within the PLTW workshop focused on basic drafting concepts such as view orientations and center line representations. With regard to mathematics content, the MSTP project focused primarily on ratio, proportion, and creating and folding nets.

Essential Pedagogical Principles

The third research question driving this research study was focused on the pedagogical principles determined to be essential for teaching engineering. Within the five case studies little emphasis was placed on how to deliver engineering content or processes. There was little to no explicit discussion of pedagogy. The focus was on having the teachers experience the activities that the students will be engaging in. When asked about the essential pedagogies, most of the instructors indicated that they were modeling the pedagogy they intended the teachers to implement and that although not made explicit, the teachers would be able to pick up on how to best teach the material.

As stated, there were four primary instructional strategies used to deliver the professional development within all of the projects: (a) lecture, (b) hands-on activities, (c) cooperative learning, and (d) reflective discussions. It could then be concluded that these serve as the essential pedagogical principles for this type of approach. When asked about pedagogical approaches, the teachers largely responded that they did not learn any new approaches to pedagogy. Many commented that they already taught using of hands-on, team-based design activities, with time for lecture and reflective discussions.

Challenges

The fourth research question underpinning this study has to do with persistent challenges unique to engineering-oriented professional development. Although similarities existed across the projects' leadership and teachers' views, there were also distinct differences in their perceptions of challenges to this type of professional development. The projects' leadership identified unique challenges to this type of professional development as they related to the teachers, in particular deficiencies in their content knowledge and skills, as well as their attitudes and beliefs. For example, three of the projects, MSTP, *The Infinity Project*[sm], and *INSPIRES*, documented the challenges related to the fundamental mathematics skills necessary to easily implement engineering-oriented curriculum or infuse mathematics into their lessons.

The teachers, on the other hand, largely identified challenges, as they related more generally to professional development and to their students. Teachers largely identified challenges such as time and money to attend professional development sessions. Some of the teachers across the projects questioned their preparedness to implement the curriculum and the amount of time outside of the workshop it would take to become prepared. Another consistent challenge reported on the survey was learning the technological skills and requirements to implement the curriculum. In addition, some of the teachers pointed to institutional barriers within their schools. For example, one of the teachers pointed out that administrators are "not as concerned about, here's this STEM, here's engineering, they're like who cares, I'm not getting money for it, I'm not being measured on it, so I'm not going to put any funds or resources or energy, and I'm not going to be as concerned about you getting professional development for that area."

Effectiveness

The fifth research question guiding this study is focused on how the projects defined and evaluated effectiveness. The projects largely defined effectiveness in terms of their project's goals. For example, a consistent goal of the curriculum-linked projects was in training the teachers to implement the curriculum as intended. This was very similar to *INSPIRES* professional development approach in having teachers experience each module in the sequence it was developed and intended to be implemented. This contributes to the project's ability to evaluate the effectiveness of their project by maximizing "the integrity of implementation from classroom to classroom such that data may be compared among trials in various schools" (Ross & Bayles, 2007, p. 4).

Related to implementation as a measure of effectiveness is the issue of teacher accountability to ensure the transfer of the curriculum as intended. This was raised most explicitly with PLTW's requirement that teachers pass the training in order to be certified to teach the curriculum. None of the other projects had this level of accountability. However, the teachers who participated in *The Infinity Project's*^{sm} professional development were required to complete agreements with their principals and the project's leadership in order to teach the curriculum prior to attending the workshop. In addition, some of the projects pursued varying levels of verbal commitment from the teachers concerning implementation.

Many of the teachers across the five projects agreed on three primary aspects of the workshops that contributed to their effectiveness: (a) hands-on activities, (b) teacher collaboration, and (c) instructor credibility. As stated previously, all of the projects included in this study devoted a majority of their professional development to hands-on activities. This was largely appreciated by the teachers when asked about what was particularly effective about the workshops. In addition, the hands-on activities allowed the teachers to work together. The ability to collaborate with other teachers both at the in-person workshops and via the online environments was consistently commented on when asked about effective aspects of the professional development by the teachers.

When asked about particularly effective aspects of the professional development, many of the teachers also commented on the credibility of the instructors, both the master teachers and engineers. As one of teachers who attended the PLTW workshop stated, "the fact that this professional development is presented by people that actually do it, and teach it" is important. In addition, many of the teachers appreciated the engineering expertise of some of the instructors. As one of the teachers who attended the *INSPIRES* project's stated, "there's just a lot of credibility there that you don't always see in professional development."

Evaluation

Most of the projects included a summative evaluation by distributing surveys to the teachers, asking feedback about the delivery of the workshop. For example, PLTW's evaluation is focused primarily on the master teachers. A few of the projects administered surveys to the teachers prior to and at the conclusion of the workshop. *The Infinity Project*[sm] has teachers complete an assessment before and after the workshop to see how well the teachers "have mastered the concepts." A few of the projects incorporated formative evaluations into their format, either formally or informally. A formal process was pursued by EtF with the daily completion of plus/delta comment cards. In addition, a few of the projects followed up with the teachers during the school year to see how they are doing while implementing the curriculum.

Due to the fact that the projects had a significant level of maturity, they were able to make some conclusions based on their evaluations. For example, the *INSPIRES* project’s leadership has concluded that local and discipline-specific professional development was needed. Through several iterations and evaluations of their professional development programs, the MSTP project leadership concluded that there are three essential elements for professional development: (a) guided lesson plan development; (b) academic year implementation; and (c) peer review and learning communities. Sneider and Brenninkmeyer (2006) outlined lessons learned from their plus-delta activities and the longer feedback forms, including that: (a) hands-on activities are appreciated, (b) opportunities to network are valued, (c) optional formats are necessary, (d) flexible implementation is appreciated, and (e) stipends help to increase participation.

CHAPTER V

DISCUSSION

This study described the professional development practices for engineering-oriented education through a multiple case study analysis. As the literature review in Chapter 2 revealed, an empirical connection has been made between teaching and student learning (Darling-Hammond, 2000; Monk, 1994). This link has warranted the pursuit of developing and implementing highly effective professional development so as to improve the teaching process. However, with teacher professional development being an "emergent area of study" (Evans, 2002), as well as engineering an emerging field within secondary education, this study sought to establish an understanding of the design decisions and implementation of professional development for secondary level engineering-oriented education.

The case selection process, as outlined in Chapter 3, was used to identify projects that contained: (a) engineering-oriented content; (b) illuminative professional development design practices; (c) a level of maturity; and (d) a coherent model. *Engineering the Future: Science, Technology, and the Design Process*™, *Project Lead the Way*™, *Mathematics Across the Middle School MST Curriculum*, *The Infinity Project*℠, and *INSPIRES* were identified and studied so as to understand the primary mechanisms, effective practices, fundamental content knowledge, essential pedagogies, and unique barriers to engineering-oriented professional development. As discussed in Chapter 4, the findings from these individual case studies resulted in consistent findings, which included the predominance of a curriculum-linked model, the inclusion of an online component, and a description of engineering content as process.

Conclusions

Given that the design of this study included descriptive multiple case studies, causal links cannot be established. However, based on the consistency of certain findings and the related literature, some striking conclusions can be made concerning secondary level engineering-oriented professional development. These conclusions warrant discussion and further research so as to better contribute to the knowledge base of engineering-oriented professional development. In addition, there were some interesting issues that emerged in some of the cases that deserve further attention in this chapter. Finally, the analysis of the cases, major findings, and conclusions contribute to recommendations for secondary level engineering research and practice. These are described more fully at the end of this chapter.

1. Professional development for secondary level engineering-oriented education predominantly uses a curriculum-linked training model.

The predominant professional development design for secondary level engineering-oriented education appears to be a curriculum-linked training model. All of the projects but one began as formal curriculum development projects and the other centered its professional development program on the implementation of a particular lesson. These projects constructed their professional development programs around dissemination and implementation of the curriculum. The assumption underpinning the design of the professional development was that the focus on curriculum implementation was sufficient to develop the program. The belief being that “good” curriculum translates into “good” professional development.

The focus on curriculum is not a new professional development design; it is "one of the oldest strategies for attempting to influence classroom instruction" (Ball & Cohen, 1996, p. 6). Curriculum-linked professional development is centered on the pedagogical strategies, materials, and assessments "associated with particular curricula" (Penuel et al., 2007, p. 928). Design decisions are rooted in the curriculum, with the focus on delivering or emphasizing the knowledge, skills, and abilities deemed necessary to implement the curriculum. This model, however, has been criticized for its emphasis on training teachers to implement a curriculum as a "deskilling" process, in that teachers are not developed beyond the boundaries of the curriculum.

The overwhelming emphasis on curriculum within engineering-oriented professional development indicates that the design and development of a more comprehensive program has not been pursued. This is consistent with the literature where "the adoption of new materials is rarely seen as one component of a systemic approach to professional development." (Ball & Cohen, p. 7). Effective teacher professional development incorporates numerous other strategies beyond curriculum implementation. For example, Desimone et al. (2002) argued that high quality professional development must include "a focus on content and how students learn content; in-depth, active learning opportunities; links to high standards, opportunities for teachers to engage in leadership roles; extended duration; and the collective participation of groups of teacher from the same school, grade, or department" (p. 82).

With the strong link to the curriculum within these programs, the developers designed the professional development around providing training on specific implementation skills. For example, almost all of the projects' focused their programs on providing training on specific software used in the curriculum. With a curriculum centered on software, the needs of curriculum implementation require a majority of professional development time be devoted to this end. Thus, a training model is an appropriate label for these programs, because this model is associated with teaching technical skills and competencies (Gordon, 2004).

Historically, training has been the primary teacher professional development model. However, this model has been increasingly challenged. For example, Little (1993) argued that the training model for teacher professional development is “not adequate to the ambitious visions of teaching and schooling embedded in present reform initiatives” (p. 129). Cochran-Smith and Lytle (2001) added that professional development “needs to focus on culture-building, not skills training” (p. 46). Gordon (2004) outlined other challenges including that the training model is inadequate in preparing teachers for the complexities involved in teaching and that teachers should become reflective practitioners, not technicians.

When combined with the curriculum-linked model, training in specific skills embedded within the curriculum raises concerns about the transfer of learning beyond the curriculum. As Knight (2002) argued, the transfer value and life expectancy of new learning is “directly proportional to its fit with the community of practice” (p. 232). What do teachers learn and are able to implement into their particular community of practice beyond the boundaries of the curriculum? If teachers decide not to enact the curriculum, how does this type of professional development impact their learning and practice? This model may be more than adequate for the goal of curriculum implementation. However, with the emergence of engineering at the secondary level, perhaps more comprehensive professional development is necessary to account for the non-existent, or at best minimal, teacher preparation in engineering at the pre-service level.

2. Two distinct philosophies guide secondary level engineering-oriented professional development: (a) technological literacy, and (b) pre-engineering.

Across the projects, two distinct philosophies were evident: (a) technological literacy, and (b) pre-engineering. Although there were co-existing elements to the projects philosophies (mathematics infusion, technology focus, equity issues), these distinct philosophies guided the professional development program design and impacted how engineering was conceptualized. Those projects that aligned with a technological literacy philosophy indicated that the emphasis was on developing critical thinking and problem solving capabilities in all students. Engineering was largely seen as an avenue to help accomplish this goal; not as a way to create more engineers. The professional development design of these programs was largely centered on problem solving and engineering design activities, without much discussion or connection to the engineering discipline. In addition, the leadership and instructors within these projects were largely drawn from technology education.

A pre-engineering philosophy was also evident in some of the projects, with the emphasis on making strong connections to post-secondary engineering education and careers. These projects were largely conceived as “pipeline” or career pathway initiatives, with the intent to spark students’ interest in pursuing majors in engineering. In addition, these projects were housed or originated within engineering departments at universities and had engineering faculty as their leaders. As evidenced by one of the projects’ leader’s (who was also an Associate Dean of an engineering college) speech to the teachers, the connection was consistently made within the program to the larger philosophy of pre-engineering. She urged the teachers involved in the program to educate their students about what it takes and is like to be an engineer.

These two distinct philosophies are important because this gets to the heart of what is meant by engineering at the secondary level. How engineering is conceived impacts the design of curriculum, instruction, teacher preparation and professional development. In addition, it may impact where in the K-12 curriculum engineering is housed. The focus on technological literacy situates pre-college engineering firmly within technology education. The *Standards for Technological Literacy* (ITEA, 2000), with endorsement from the National Academy of Engineering, outlined what students should know and be able to do to be technologically literate. With two of the five groups of standards focused on design and the designed world, many have indicated that engineering is a nice fit within technology education in that it is a way to develop technological literacy (Lewis, 2005; Wicklein, 2006).

However, a point of contention surrounding the incorporation of engineering within technology education is how it is incorporated into the curriculum. Lewis (2005) characterized two approaches to engineering design: (a) conceptual and (b) analytic. Conceptual design is the point where engineering science, practical knowledge, production knowledge and methods, and commercial aspects are brought together. Lewis argued that this type of design is “within the normal purview of technology education” (p. 48). This type of design also seems to fit best within technology education. Analytic design, however, relies upon mathematics and scientific principles to make decisions and “poses a challenge” (p. 48) for technology educators, who generally have had less preparation in mathematics and science. In addition, as Gattie and Wicklein (2007) argued, mathematics and science are not mentioned within the *STL*, leading to “a fuzzy, non-focused basis for infusing engineering design into technological literacy” (p. 16).

This issue also relates directly to the “inauthentic” approach of teaching engineering at the pre-college level. Many instructors have taught problem solving and design with a prescriptive, step-by-step model or a trial-and-error approach. Wicklein and Thompson (2008) stated that this approach has common features including: (a) the identification of a problem, (b) the development of a proposal, (c) the creation of a model or product, and (d) the evaluation of the model or product. Engineers, however, design in an iterative, non-predetermined manner and typically “*predict the behavior* of the design and the *success of a solution* before it is implemented” (Wicklein & Thompson, p. 57). In addition, design is context-specific, in that it is “shaped by the tools and resources available and adapts to the specific, and changing, situation” (McCormick et al., 1994, p. 6), further complicating its implementation into the K-12 classroom.

These issues raise concerns about a technological literacy approach to pre-college engineering. The alternative, a pre-engineering approach, models engineering at the post-secondary level, with a strong emphasis on mathematics and science. As Adelman (1998) found in a study of student pathways, a student’s decision to pursue engineering was related to taking advanced mathematics and science in high school. Thus pre-college engineering programs should increase their mathematics and science rigor. Concerns have been raised however about serving only a select population of students interested and capable of pursuing pre-engineering with this type of approach.

Perhaps two models of pre-college engineering can co-exist; one targeting technological literacy and the other developing an engineering pipeline. However, this may lead to an even more confusing picture of what engineering is at the pre-college level and how to best prepare teachers to teach engineering. In addition, this directly relates to the next conclusion of this particular study; the fact that engineering content is not well-defined making it difficult to clarify what it is and how it should be translated into curriculum and professional development.

3. Engineering content is not well-defined for secondary level education.

As evidenced by the case studies and related literature, engineering content is not well-defined for secondary level education. The projects' leaders, instructors, and participant teachers discussed engineering content in terms of the engineering design process. As indicated in the literature, much of the discourse about the implementation of engineering design into K-12 education has largely centered on process or "problem solving and the application of scientific understanding to a given task" (Hill & Anning, 2001, p. 118). As Brophy, Klein, Portsmore, and Rogers (2008) stated, this instructional approach is not surprising because many studies support the fact that design-based activities can "develop deep conceptual understanding of the knowledge and principles of a domain and support the development of self-guided inquiry skills" (p. 372)

The challenge is to identify "engineering contexts that are accessible to the learners, difficult enough to be interesting and rich enough to provide links to the breadth of content knowledge to be learned" (Brophy, et al., 2008, p. 372). Engineering contexts, however, have been translated artificially into a prescriptive, step-by-step approach, typically through a design process model. The prescriptive approach to teaching design however has been increasingly criticized because it contradicts both expert and novice designers' approaches to the problem solving and design process (Lewis, Petrina, & Hill, 1998; Mawson, 2003; Welch, 1999; Williams, 2000).

The fact that the focus of secondary level engineering has been on process is largely due to the fact that engineering content has not been defined. As mentioned, the *STL* have been cited by many as providing direction for pre-college engineering, with its design-oriented standards. However, the *STL* do not specify engineering content; focused only on the design process. In addition, numerous studies have been conducted to identify engineering-oriented outcomes and competencies (Childress & Rhodes, 2008; Dearing & Daugherty, 2004; Harris & Rogers, 2008). However, these studies resulted in lists that focused heavily on process and the "soft skills" of engineering (communication, interpersonal skills, etc.). For example, Childress and Sanders (2007) examined the related literature and engineering curricular materials, concluding that "the relatively large number of concepts identified in the literature makes it challenging to create a framework that might be helpful in developing 'engineering' instructional materials for secondary schools" (p. 5).

The literature within science and mathematics professional development, however, consistently points to the need for a defined content base to be integrated into teacher professional development. As Guskey (2003) stated, enabling "teachers to understand more deeply the content they teach and the ways students learn that content appears to be a vital dimension of effective professional development" (p. 749). Desimone et al. (2002) agreed, arguing that high quality professional development must include "a focus on content and how students learn content; in-depth" (p. 82). Loucks-

Horsley et al. (1996) added that teachers "need deep, thorough knowledge of the disciplines they intend to teach" (p. 2). Similarly, Supovitz and Turner (2000) outlined components of quality science education professional development and concluded that focus on subject-matter knowledge and deepening teachers' content skills was critical.

The lack of well-defined engineering content appears to be a concern for the future of secondary engineering education. Without content, pre-college engineering curriculum, instruction, teacher preparation, and professional development may continue to struggle without a well-defined target. In particular, engineering concepts can serve as organizers for a strong content base. As Perkins (2006) argued, concepts "carve up the world we already see and posit the unseen or even the unseeable" (p. 41). Concepts outline the "principles governing a domain and the interrelations between units of knowledge in a domain" (Rittle-Johnson, 2006, p. 2). The National Research Council's (1999) report *How People Learn: Brain, Mind, Experience, and School* stressed the importance of building students' conceptual understanding by pointing to the research on how experts organize their knowledge structures around concepts or big ideas.

Within post-secondary engineering, it has been argued that, "understanding conceptual knowledge is critical to the development of competence in engineering students and in practicing professionals" (Streveler, Litzinger, Miller, & Steif, 2008, p. 279). There are, however, significant challenges to defining secondary level engineering content. For example, there may not be one generalized engineering discipline from which to base content. As Oakes, Leone, and Gunn (2006) described, there are many different engineering disciplines including aerospace, agricultural, chemical, civil, computer, electrical, industrial, and mechanical. From these "many additional engineering specialties have evolved over time, for a total today of over 30 different fields in engineering" (p. 21). Streveler, et al. (2008) narrowed their discussion of foundational concepts to three related domains of engineering science (mechanics, thermal science, and electric circuits), instead of universal engineering concepts. This issue raises the question of whether secondary-level engineering content should be discipline-specific or an attempt should be made to identify foundational concepts generic to all engineering disciplines.

Some educators have offered engineering design as the focus for secondary level engineering to help resolve this issue. However, this is also problematic because design is not all-encompassing to what engineering is and not all engineers design. Oakes et. al (2006) pointed to basic classifications of jobs across the various engineering disciplines. In addition to design, these job classifications include research, development, testing, analysis, systems, manufacturing and construction, operations and maintenance, technical support, customer support, sales, consulting and management. They added that it was important to note that "all the fields of engineering have roles in each of the main functions" (p. 33); thus not all engineers perform all of these functions.

In addition, even though science and mathematics professional development is dependent on content, this finding may not necessarily apply to engineering-oriented professional development. Pre-college engineering may in fact be process-oriented. However, this focus would still need to be well-defined to provide a consistent framework from which to base curriculum and instruction. Engineering process(es) would need to be articulated beyond the prescriptive, step-by-step models that have been increasingly criticized. As Brophy et al. (2008) articulated, a "more thorough roadmap is needed to show how educators, learning scientists, and engineers are currently bringing engineering concepts and practices to P-12 learners and to identify the kinds of learning pathways students will experience during their formal education" (p. 371). This roadmap is dependent upon "a more clear definition of engineering" (p. 371).

4. The two instructional design approaches dominant in secondary level engineering-oriented professional development are: (a) scaffolded problem solving and (b) self-guided learning.

The two instructional design approaches dominant in secondary level engineering oriented professional development are: (a) scaffolded problem solving and (b) self-guided learning. Although the intended outcome was the same, competency in the skills and abilities necessary to implement curriculum, these two distinct approaches were visible in engineering-oriented professional development. With the scaffolded problem solving approach, guided instruction on tool usage progressed into more open-ended design based activities. With the self-guided learning approach, broadly structured conceptual information was presented with minimal instruction on tool use. The majority of time was devoted to the teachers self-directing their learning, where they developed more fully the use and applications of the tools.

There appears to be a relationship between the philosophy, instructional design, and the type of teacher who participated in the professional development. Many of the projects that focused on technological literacy incorporated a scaffolded problem solving approach to their instructional design. These projects had a predominance of non-engineers within their leadership and the teachers who participated were largely drawn from technology education. The majority of the mathematics and science teachers, who participated, did so in those projects that pursued a self-guided learning approach to professional development. These teachers also predominantly had backgrounds in engineering. The project leadership was also engineers; the projects housed in engineering departments at universities. One exception was PLTW, whose philosophy is oriented toward pre-engineering, but the design of their professional development used a more scaffolded problem-solving approach. PLTW's instructional design, however, is largely informed by technology education teachers, which may explain this exception.

The projects' recruitment strategies may explain this connection. Most of the projects recruited through direct mailings targeting specific disciplines. This seems to have informed the instructional design of the programs. Those projects that worked with technology teachers decided on strategies that scaffold learning around the tools involved in problem-solving activities. This approach is consistent with technology education's pedagogical strategies. As Sanders (2001) found in a survey of technology education teachers, "more than half (56.9%) of the instruction delivered 'engages students in problem-solving' and a full third of the programs surveyed (32.7%) devote 80-100% of their instruction to problem-solving activities" (p. 47). In addition, historically technology education has focused largely on tool use development. Although the philosophical underpinning of technology education has attempted to move away from instruction on tools and an artifact-driven view of technology (Dakers, 2006), in practice (Sanders, 2001), and as evidenced by the programs in this study, this focus is still apparent. The curriculum appears to align with technical courses that focus on "developing the knowledge and skills to use tools, machines, and equipment at a proficient level of capability" (Hansen & Lovedahl, 2004, p. 20).

Those projects that worked with science and mathematics teachers, who largely had engineering backgrounds, incorporated more self-guided learning practices. This approach to learning is consistent with how engineering has been historically taught at the college level. As an introduction to engineering textbook outlined, engineering faculty teaching styles often require more self-guided learning, where it is the students' job to "fully engage in the learning process" (Oakes et al., 2006, p. 538) and deal with the instructors' "varying personalities and gain as much information as you can" (p. 538). Although there have been calls for reform pointing to this approach as a "weeding" out strategy, it appears to be an approach modeled after in some of the secondary level professional development programs included in this study. If pre-college engineering is focused on pre-engineering then perhaps it makes sense for teachers to prepare students' self-guided learning abilities.

5. Science, technology, and mathematics teachers have different professional development needs to incorporate engineering into their curriculum.

The secondary level engineering-oriented projects drew primarily from science, technology, and mathematics. With the diverse backgrounds in preparation and education of teachers in these three disciplines, there appears to be a variety of needs that require attention in a program that draws from these three areas. Most of the projects' participants were recruited through a self selection process. Projects sent direct mailings marketing their professional development workshops to area schools. Although this resulted in participation largely of technology education teachers, science and mathematics teachers also participated in most of the programs included in this study.

Perhaps one engineering-oriented professional development model is not appropriate given this fact.

There were three mechanisms that emerged in some of the projects that could help projects “level the playing field.” Some of the projects included pre-screening mechanisms to assess teachers’ abilities in certain areas. Although not intended to restrict access to the programs, these mechanisms were intended to indicate areas for teachers to “brush-up” on prior to attending. Another mechanism that could help programs deal with the complexities involved with serving three disciplines is the insistence on school district interviews and agreements prior to attendance. A few of the projects required interviews with the teachers and administrators, as well as formal agreements to be completed by the school district or administrator before the teacher could attend. This can help projects determine the needs of particular teachers and schools and help tailor the programs accordingly.

In addition, the master teacher/engineering faculty combination, used across most of the projects, provided an avenue for both engineering and classroom expertise to be integrated into the professional development. In addition, this combination increased teacher participants’ motivation and buy-in, adding a certain level of credibility to the projects. This combination speaks to adult learning principles, one of which states that adults need to relate learning activities to their working lives (Gordon, 2004). This is accomplished by master teachers who are better able to connect the professional development to the classroom by their own examples. Motivated adult learners also spend the required time to learn a new task or solve a problem (Bredeson, 2003). As indicated by the teachers' who participated in the programs included in this study, master teachers and engineering faculty impacted their motivation to participate.

However, a related issue, particular to the needs of teaching engineering content, is the level of science and mathematics knowledge and abilities required. Most definitions of engineering emphasize the application of mathematics and science or engineering fundamentals. For example, the Accreditation Board for Engineering and Technology defines engineering as the profession in which knowledge of the mathematical and natural sciences, gained by study, experience, and practice, is applied with judgment to develop ways to use, economically, the materials and forces for the benefit of mankind.

As Oakes et al. (2006) pointed out, analysis is an important engineering function "performed in conjunction with design, development and research" (p. 36). Analysis often involves mathematical models, scientific understanding, and computational tools. In particular, design requires "knowledge of scientific and mathematical laws, coupled with experience" (Oakes et al., 2006, p. 35). As Brophy et al (2008) stated, from an engineering perspective, cognitive processes "include constructing conceptual prototypes of a system using mathematical models (equation, diagrams, graphs) and generating data to predict performance" (p. 371).

Due to the discrepancies of the science and mathematics requirements within science, mathematics, and technology pre-service teacher education, teachers' capabilities vary across and within these three disciplines. However, with the majority of the professional development devoted to curriculum implementation, little emphasis was given to the science and mathematics involved in engineering. The level of science and mathematics apparent in these projects was not extremely intensive and few approaches targeting teachers with varying levels of knowledge in these areas were observed. One of the projects developed a remediation program for teachers who needed additional help, specifically in mathematics. However, this was pursued at the discretion of the individual teacher and not directly connected to the professional development program.

Perhaps this issue is of less importance if pre-college engineering focuses primarily on process-oriented curriculum and skills; requiring only a minimum level of mathematics and science. Teachers' disciplinary backgrounds are of less importance with the focus on developing knowledge and skills around engineering-related processes. However, if pre-college engineering moves toward a pre-engineering content focus, with an emphasis on mathematics and science, engineering-oriented professional development would face challenges in meeting the needs of teachers with varying levels of science, technology, engineering, and mathematics backgrounds. For example, if technology education is to embrace analytic design and then teachers would need to be prepared accordingly. Wicklein and Thompson (2008) argued that technology education teachers have been "reluctant to address the analytical aspects of design primarily because of limitations with mathematics, both from the teachers' and students' perspective" (p. 70).

Again this issue is related to where in the secondary level curriculum engineering curriculum is best suited. Should teachers from all three disciplines incorporate engineering or is there a natural fit with one particular discipline? Perhaps this type of content should be team-taught between the three disciplines and professional development designed accordingly.

6. Active engagement in hands-on activities with minimal reflection on the learning processes involved is a consistent pattern in secondary level engineering-oriented professional development.

Active engagement in hands-on activities appears to be a hallmark of engineering-oriented professional development. The programs included in this study devoted most of their instructional time towards teacher engagement in hands-on activities. This focus is consistent with the fact that many of the projects were well-connected to technology education. As Sanders (2001) found, “the field remains committed to hands-on instruction” (p. 47). This focus is also consistent with current P-12 engineering education initiatives, largely operating under the assumption that “engineering contexts naturally engage learners to participate in an active learning process” (Brophy et al., 2008, p. 380). In addition, the emphasis on active engagement also aligns with adult learning theory, which points to the need for adults to be actively engaged. As Gordon (2004) pointed out, professional development that incorporates adult learning principles includes opportunities for adults to learn by being actively engaged.

The use of reflective strategies beyond implementation issues, however, was minimally integrated across the professional development programs. Little instructional time was devoted toward meta-cognitive reflection, on either the teacher or student learning involved (e.g., what concepts are being learned, why were these concepts are important, how the activities selected teach these concepts, how the curriculum is intended to impact student learning and account for students’ misconceptions, etc.). In other words, activities were often engaged in as the primary focus of the professional development without attention toward the learning goals involved. This is also consistent with critiques of how technology education has been implemented in the classroom.

The importance of reflection has been consistently pointed to as key to both student and adult learning (Adey, 2004; Lieberman, 1994; Gordon, 2004). The National Research Council's (1999) report *How People Learn: Brain, Mind, Experience, and School*, makes it clear that teachers need to incorporate meta-cognitive approaches to help students identify learning goals and monitor progress toward attaining those goals. Meta-cognition or guided reflection enables "the process of conceptual change, and conceptual change re-structures the intuitive knowledge upon which teaching practice rests" (Adey, 2004, p. 158). As Brophy et al. (2008) stated, learning is "not just the process of constructing products through hands-on activities; learning includes the precursor activities of reflection on what you already know and generating learning goals for what more you 'need to know' (establishing individual learning goals)" (p. 376).

Used within the context of professional development, guided reflection enables educators to model these skills with teachers so that they learn strategies to incorporate into their own teaching with their students. Whether or not the focus is on process-oriented skills or content-based knowledge, guided reflection is crucial because it impacts the transfer of learning back into the classroom. In addition, particular to engineering-oriented curriculum and professional development, "design context provides learners with an opportunity to be generative, reflective, and adaptive in their thinking as they engage in activities of planning, making, and evaluating a device, system or process" (Brophy, et al., 2008, p. 375).

Recommendations

Based on the findings and conclusions of this study and the related literature, there are important implications for the practice and research of secondary level engineering-oriented professional development. This study provided the groundwork for future professional development efforts and outlined consistent practices, as well as areas lacking in comparison to professional development in related disciplines such as science and mathematics. Following are a few of the most relevant recommendations for practice and research.

Recommendations for Practice

1. The design of secondary level engineering-oriented should be more comprehensive beyond the focus on training in curriculum implementation.

The first recommendation for practice is that the design of secondary level engineering-oriented should be more comprehensive beyond the focus on training in curriculum implementation. Although the stated goals of much of the engineering-oriented professional development were focused on curriculum implementation, the literature indicates the need for the design of more comprehensive programs when it comes to professional development. As Craft (2000) discussed, there "has been a trend towards a broader view of what constitutes as professional development, and towards a greater emphasis on what happens before an in-service training event (needs identification) and afterwards (evaluation and follow-up)" (Craft, 2000, p. 13). Thus, even when anchored on specific curriculum, the design of the professional development should include more comprehensive needs assessments, evaluation, and follow-up. In addition, for a more comprehensive engineering specific professional development, it should be structured around transferable skills and knowledge within engineering; using the curriculum to support this structure.

2. Engineering-oriented professional development programs should incorporate adult learning principles and effective professional development practices.

Engineering-oriented professional development programs should incorporate more adult learning principles and effective professional development practices so as to better impact teachers' learning transfer back into the classroom. In addition to engagement in activities, programs need to incorporate a strong focus on engineering content and allow for and help enable reflection on the learning of this new content, as well as skills. The fact that most of the engineering-oriented programs were not informed by research findings on cognition and the principles of adult learning theory is not surprising. Much of the research on teacher professional development has revealed the lack of attention to these elements. As Bredeson (2003) stated, it is "ironic that much of what we know from research about the factors and conditions that promote effective student learning is often ignored when it comes to the adults who work in schools" (p. 44). However, as discussed in Chapter 2, studies have indicated the need for teacher professional development to be designed with attention to the principles of cognition (Blandford, 2000; Gordon, 2004; Peery (2004).

3. Consider the diverse needs of science, technology, and mathematics teachers.

The designers of engineering-oriented professional development need to better consider the needs of teachers from different disciplines. As stated, engineering-oriented primarily from three disciplines: (a) science, (b) technology, and (c) mathematics. With the diverse backgrounds in preparation and education of teachers in these three disciplines, there appears to be a variety of needs that require attention in a program that draws from these three areas. Thus, programs should incorporate thorough needs assessments, as well as include teachers during the design of the professional development. This will help to ensure that their needs are adequately represented and increase the likelihood of the transfer of learning.

4. Actively recruit teachers from diverse populations to participate in engineering-oriented professional development.

Related to better understanding the needs of teachers, another recommendation specific to engineering-oriented professional development is to actively recruit teachers from diverse populations. Most of the projects recruited teachers by direct mailings to technology education departments in schools. Due to the fact that “technology education is still taught mostly by middle-aged white men” (Sanders, 2001, p. 52), this has resulted in a predominance of white male teachers involved in engineering-oriented professional development. The one project that targeted science and mathematics teachers had a more equitable gender representation. This issue is important because the engineering, as well as science and mathematics, community is looking for ways to increase the diversity of their student populations.

As Malcom (2008) stated, “engineering needs to offer a different face to students, especially if there is an interest in attracting females and minorities” (p. 237). Leslie, McClure, and Oaxaca (1998) revealed that “it is the difference in the numbers of men and women who enter science and engineering curricula, the much-discussed ‘pipeline effect,’ that largely explains gender differences in graduation rates, graduate study, and employment in science and engineering” (p. 268). If technology education continues to be populated by white men, other disciplines should be actively recruited to add another "face" to engineering at the pre-college level.

Recommendations for Research

1. Define and research an engineering-oriented content base.

Perhaps the most important finding of this study is the lack of well-defined engineering content. A recommendation for future research is to define this content base so that professional development designers have a strong base from which to design programs. The dominant focus on process may not be adequate. As McCormick (1997) pointed out, the "crucial finding from decades of research is that problem-solving skill is dependent upon considerable domain knowledge" (p. 146). Design problem solving "fosters the kind of cognition that combines declarative knowledge, the *what*, with procedural knowledge, the *how*" (Welch & Lim, 2000, p. 34).

In addition, as has been thoroughly discussed in mathematics education, a focus on process may not lead to conceptual learning (Eisenhart et al., 1993; Rittle-Johnson & Alibali, 1999; Rittle-Johnson et al., 2001). For example, Antony (1996) argued that teachers "may be lulled into a false sense of security by providing students with numerous investigations, open-ended problem-solving experiences, and hands on activities with the expectations that students are successfully constructing knowledge from these experiences" (p. 351). This need for conceptual learning calls into question educational programs that try "to focus on procedural knowledge such as problem solving or design, while assuming that the domain and context within which this takes place are either irrelevant or at best secondary" (McCormick, 1997, p. 149).

The need for engineering content makes the issue of establishment of engineering education content standards for K-12 more viable. The establishment of content standards provides a consistent foundation for the development of engineering curriculum, professional development, and assessment. In addition, established engineering content allows for closer examinations of engineering-oriented pedagogical content knowledge. As evident within science education, pedagogical content knowledge is an important element to effective teaching. Pedagogical content knowledge focuses attention on student learning and the transfer of learning within professional development. As Shulman (1986) stated, “to blend properly the two aspects of a teacher’s capacities requires that we pay as much attention to the content aspects of teaching as we have recently devoted to the elements of the teaching process” (p. 8).

2. Study engineering-oriented professional development programs that are not curriculum-based.

Another recommendation for future research is to study engineering-oriented professional development programs that are not curriculum-based. The selection criteria used for this study generated projects that were focused on engineering content, utilized illuminative professional development design practices, contained a level of maturity; and developed a coherent model. This yielded projects that were predominantly curriculum based. With a different set of selection criteria, perhaps different programs would be identified and additional insights into engineering-oriented professional development would result. How do programs structure their programs if not around curriculum or lessons? What type of content is emphasized and explored? Do these projects make different design decisions concerning instructional strategies, participant recruitment, and the selection of instructors?

3. Conduct rigorous formative and summative evaluation to improve engineering-oriented professional development during and after its implementation.

Another research recommendation for engineering-oriented professional development that overlaps with recommendations for practice is to design, conduct, and publish formative and summative evaluation of the programs. Most of the projects in this study focused on the teachers' reactions to the professional development. Reaction is the first level of evaluation, according to Kirkpatrick (1994). Kirkpatrick argued that long-term evaluation should measure four levels of impact: (a) level 1 – reaction, (b) level 2 – learning, (c) level 3 – transfer, and (d) level 4 – results.

Rigorous evaluation is an important form of research that can provide better understanding of how people learn, change their practice, and affect student learning. Guskey (2000) outlined five critical levels of the evaluation of teacher professional development that should be incorporated into a comprehensive evaluation plan. These levels are hierarchically arranged from simple to more complex: (a) teachers' reactions to the experience; (b) indicators of participant learning; (c) indicators of organizational support and change; (d) if and how participants use their newly acquired knowledge and skills in practice; and (e) student learning outcomes.

4. Study the link between teacher participation in engineering-oriented professional development and student learning.

Lastly, an important recommendation for future research in engineering-oriented professional development is to study the link between teacher participation in professional development and student learning outcomes. This link has not been thoroughly explored in any of the disciplines but with the increasing attention on accountability within educational reform, it is important that this be emphasized in future research. As Fishman et al. (2003) pointed out, to “create excellent programs of professional development, it is necessary to build an empirical knowledge base that links different forms of professional development to both teacher and student learning outcomes” (Fishman et al., 2003, p. 643).

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APPENDIX A

INFORMANT SCRIPT

1. Introduce study and research questions.

- Multiple case study project to identify best practices in engineering-oriented professional development of secondary level teachers; Funded by NCETE.

2. Explain case study approach.

- Identifying 4-6 sites for data collection

- Identified individuals in the field knowledgeable about engineering-oriented PD

3. Explain selection criteria.

- Engineering-Oriented Content: The cases had to contain elements that are interesting, applicable, and useful for engineering-oriented professional development at the 9-12 level.

- Illuminative Professional Development Design Practices: The initiatives needed to contain an effort to include "best practices" (e.g., standards based, pedagogically sound, context driven, authentic, and assessment based) and creative design practices that can illuminate and inform future professional development in this area.

- Maturity: Priority was given to mature initiatives with an established track record for delivering professional development over a sustained period of time (at least two years).

- Coherent Model: Priority was given to projects that were grounded in a coherent and documented model for professional development.

4. Ask the following:

- Which projects fit these criteria? Who were the principal investigators?

- How does the project(s) fit the criteria (the rationale for inclusion)?

- What do you know about these projects? What was your involvement with these projects? *(code: extreme, somewhat, marginal)*

- Do you know who the sponsors are?

5. Ask to rank the projects mentioned.

- Of the projects identified rank the top 3 sites according to how well they fit the criteria
    - Meets more of the criteria than the others *or*
    - Meets a couple of the more important criteria extremely well

APPENDIX B

PROJECT LEADERSHIP QUESTIONNAIRE

Script:

- Confirm that this is a good time; should take 45-60 minutes to complete.
- Ask that they answer the following questions to the best of their ability.
- Will be documenting comments on a computer as work through the questions.

History/Origin Questions

1. How is the project funded?
2. How long has the project been underway?
3. What was the major need that you saw being addressed by the project? (Why was the project initiated?)
4. What is the scope of the project's efforts (including and beyond the professional development efforts)?
5. How did the professional development component emerge?
    a. At what point in the project?
    b. What factors contributed to the development and diffusion of the professional development?
6. What are the goals and objectives of the professional development?
7. Have the initial goals changed over time?
    a. If so, why? In what ways?

Participant Questions

8. How are/were the participants selected?
    a. How did that process go?
9. Is there prerequisite knowledge/experience needed for a teacher to participate?

10. Who is the “typical” participant? (Discipline, age, gender, experience level, etc.)

PD Structure & Delivery Questions

11. How do you structure/organize the logistics for the professional development experiences?

12. What is your schedule/format for delivery?

13. What types of activities and materials do you use to deliver the PD?

14. Where did these materials come from?

15. How is the instructor(s) selected and prepared to deliver the PD?

16. How are the project’s professional development efforts evaluated and further refined?

Access to Materials

17. Can you supply us a copy of the original proposal (if funded project), evaluator reports (internal and/or external), the project’s curriculum, annual report information, and any other related documentation to us for inclusion into our case study analysis? These documents will be reviewed to better understand the project’s development, philosophy, and approach to professional development.

APPENDIX C

PROFESSIONAL DEVELOPMENT OBSERVATION FORM

<table>
<tr><td>Project:</td><td>Date:</td><td>Time:</td><td># of participants:</td></tr>
<tr><td colspan="2" rowspan="2">Synopsis of lesson, activity:</td><td colspan="2">Content knowledge related issues:</td></tr>
<tr><td colspan="2">Pedagogic knowledge related issues:</td></tr>
<tr><td colspan="2">Description of room:</td><td colspan="2">Pedagogical content knowledge related issues:</td></tr>
<tr><td colspan="2">Description of delivery methods:</td><td colspan="2">Challenges/Barrier Issues:</td></tr>
<tr><td colspan="4">Emergent Issues/Patterns:</td></tr>
</table>

APPENDIX D

INSTRUCTOR INTERVIEW QUESTIONNAIRE

1. How did you become an instructor for this professional development?
2. What type of training or preparation do you have to be an instructor?
3. How were the instructional materials prepared?
4. Is the delivery of the professional development scripted or is there flexibility?
5. What do you think are the most effective approaches used in the professional development?
6. What are some areas of the professional development that could be improved?

APPENDIX E

TEACHER SURVEY QUESTIONNAIRE

Please check the circle next to the appropriate response below.

1. Gender:
   O Female
   O Male

2. What is your age?

O 20 – 29	O 50 – 59
O 30 – 39	O 60 or older
O 40 – 49	

3. What grade level(s) do you currently teach?

O K – 5	O 9
O 6	O 10
O 7	O 11
O 8	O 12

4. How many years have you been teaching?

O 1 – 2	O 11 – 15
O 3 – 5	O 16 – 20
O 6 – 10	O 21 years or more

5. What subject(s) do you currently teach?

O Technology education	O Physics	O Algebra
O Industrial technology	O Life Science	O Geometry
O Pre-engineering	O Chemistry	O Calculus

   Other (please specify)____

Please circle the answer that best answers the questions.

6. How motivated are you to attend the professional development?

   Not at all   To Some Extent   To a Very Great Extent

7. How prepared do you feel to implement what you have learned in this professional development?

   Not at all   To Some Extent   To a Very Great Extent

8. To what extent do you anticipate incorporating engineering content into your teaching?

   Not at all   To Some Extent   To a Very Great Extent

9. How motivated do you think your students will be to learn the content associated with this professional development?

Not at all To Some Extent To a Very Great Extent

10. How supportive do you think the administrators at your school are to implement the content associated with this professional development?

Not at all To Some Extent To a Very Great Extent

Please answer the following questions as completely as possible.

11. What particular engineering concepts struck you as being particularly important? How so?

12. What kind of changes will you need to make, if any, to incorporate engineering content into your teaching?

13. What are some of the biggest barriers or challenges to implementing what you have learned?

APPENDIX F

FOCUS GROUP INTERVIEW SCRIPT

- Have participants read and sign the consent letter.
- Describe the questions as being divided into 3 main categories: (1) the content of the professional development, (2) how the professional development will impact their teaching, and (3) barriers to implementing what they have learned.

Content-Oriented Questions

1. What have you learned by participating in the professional development?

2. What was the focus of the professional development, as far as engineering content/concepts?

3. What do those content/concepts mean to you? (probe for understanding)

4. What aspects of the professional development were most effective/ successful? (Least effective/successful)?

Pedagogy-Oriented Questions

5. What will you be able to implement in your classroom? What will be difficult to implement? Why?

6. How will the way your teaching change as a result of your involvement with the professional development?

7. What specific techniques did you learn to teach engineering?

Challenge/Barrier Questions

8. What are some challenges or barriers you think will be in the way of transferring what you learned into the classroom?

9. What are some of the barriers they had to overcome to participate in the professional development?

10. What recommendations would you make for future professional development providers based on your experiences?

AUTHOR'S BIOGRAPHY

Jenny Lynn Daugherty was born August 14, 1979 in Hopkinsville, Kentucky. After attending public schools in Vincennes, Indiana, she obtained a B.A. in Sociology and History from Indiana University in 2001, a M.A. in American History from Purdue University in 2004, and a Ph.D. in Human Resource Education from the University of Illinois in 2008. Daugherty is currently the Managing Director for the Center for Mathematics, Science, and Technology at Illinois State University.