2015

Investigating the Influence of Professional Development on Teacher Perceptions of Engineering Self Efficacy

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INVESTIGATING THE INFLUENCE OF PROFESSIONAL DEVELOPMENT

ON TEACHER PERCEPTIONS OF ENGINEERING SELF-EFFICACY

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B.S Education, University of Maine, 1992

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A DISSERTATION

Submitted in Partial Fulfillment of the

Requirements for the Degree

Doctor of Philosophy

In Public Policy

The University of Southern Maine

August 2015

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INVESTIGATING THE INFLUENCE OF PROFESSIONAL DEVELOPMENT ON TEACHER PERCEPTIONS OF ENGINEERING SELF-EFFICACY

By Stephen D. Marquis, M.A.

Dissertation Advisor: Dr. Catherine Fallona

An Abstract of the Dissertation Presented in
Partial Fulfillment of the Requirements for the
Degree of PhD. in Public Policy
August 2015

This mixed-methods study examines the influence of a professional-development intervention to support educators in the integration of engineering education at the elementary level. Particular consideration focused on the evolution of teachers' perceptions of engineering self-efficacy following engagement in professional development intended to support the introduction of engineering in selected grade-five classrooms. The significance of this study rests in the reality that as interest in K-12 engineering grows, reform efforts necessary to support the professional development and instructional needs of educators too must grow. Through enhanced teacher professional-development, and increased levels of self-efficacy, the ultimate goal of strengthening the United States' position as a global leader of innovation and design may be achieved.

A review of relevant literature on engineering goals, teacher knowledge, teacher knowledge of engineering, and professional development, was completed to gain a better

understanding of the issues educators face as they plan to include engineering in elementary schools. From that review, two research questions for further examination were developed. (1) How do teacher perceptions of engineering self-efficacy evolve during implementation of an instructional unit in engineering? (2) What is the relationship between a professional development intervention in engineering and teachers' perceptions of their content knowledge and pedagogical-content knowledge in engineering?

Qualitative and quantitative data-collection strategies were conducted concurrently. Data were collected by three means: (1) three in-depth interviews with each participant; (2) pre- and post-intervention focus-group interviews with participants; and (3) an engineering self-efficacy scale completed at both the outset and conclusion of the study by research participants. The Teaching Engineering Self-Efficacy Scale (TESS) for K-12 Teachers survey instrument was selected for this study as it provided a means by which to measure change in engineering self-efficacy.

The results of the study reveal that all three study participants reported gains in all six sections on the TESS instrument. Pre- and post-TESS survey results reflect teacher perceptions of measureable improvement in their engineering pedagogical-content knowledge following a professional development experience, and subsequent presentation of an instructional unit in engineering. Those gains were consistent with findings from interviews with study participants that reflect perceived gains in confidence in the ability to teach engineering concepts in their grade-five classrooms.

This study suggests that elementary teachers with minimal, if any, formal academic preparation in engineering curriculum, assessment, and instruction can indeed

integrate engineering concepts into their teaching. Through interactions with students, colleagues, and professional development interventionists, teachers developed increased levels of teaching engineering self-efficacy. This study suggests that professional development experiences that require participants to experience and present hands-on and student centered engineering tasks, learn engineering concepts as they teach them. One contribution of this study to the literature is underlining the fact that the ultimate goal of teacher-education professional-development experiences should not be simply preparing highly efficacious teachers, but more importantly preparing highly efficacious teachers who have solid engineering content knowledge.

ACKNOWLEDGEMENTS

The writing of this dissertation has been one of the most significant chapters of my life. Without the support, patience and guidance of the following people, this study would not have been completed. It is to them that I owe my deepest gratitude.

- Dr. Catherine Fallona who served as my advisor and grounding force throughout the course of my doctoral program and dissertation writing. Her wisdom, knowledge, and commitment to the highest standards inspired and motivated me.
- Dr. Whitney and Dr. Eickmann, who each provided the gift of time and supportive recommendations that served to strengthen my work on this study as members of my dissertation committee.
- Dr. Hawes and Dr. Porter, doctoral cohort colleagues who were always ready for a question, or to provide words of encouragement as I muddled through writing.
- Mrs. Littlefield, a very special teacher who believed in an eight-year-old when he needed it most.
- My siblings and in-laws, who were always on the sidelines rooting for me, and offering words of encouragement and support.
- Jeanne and Robert Marquis, my parents, without whom this effort would have been worth nothing. Your love, support and constant patience have taught me so much about sacrifice, discipline, and compromise throughout my life.
- Benjamin and Samuel Marquis, my sons, who understood when I was unable to attend sporting events, or provide family fun time as I completed doctoral work. I am deeply sorry for the time we spent apart.

- And most importantly, Erika Marquis, my wife, for believing in me when I did not always believe in myself, when I questioned my ability to finish what I had started. If it were not for her kissing one cheek as she slapped the other, I NEVER would have finished. Her support, encouragement, patience and unwavering love allowed me to be ambitious and for that I am forever grateful.

This dissertation is dedicated to Erika, Benjamin, Samuel, my parents, and Mrs. Littlefield.

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Introduction

Statement of the Problem

As a nation, we face the challenge of increasing interest in engineering as a career choice (NAE, 2010). That challenge may be met through a concerted and developmentally appropriate introduction to engineering at the elementary level that serves to ignite the creative minds of underrepresented and diverse groups of students. Awareness of STEM (Science, Technology, Engineering, and Mathematics), is gaining traction in K-12 education, given increased attention from educational leaders, engineers, and industry (Lachapelle, Phadnis, Hertel, & Cunningham, 2012). Though there is significant movement afoot to introduce and promote engineering at the elementary school level, efforts on a national scale are lacking (Benenson, Stewart-Dawkins, & White, 2012). The United States may need a wake-up call, similar to that given by the launch of Sputnik more than a half-century ago, which resulted in the first moon landing. (Bybee, 2007). Policymakers have begun to emphasize the importance of STEM education through active legislation which requires the inclusion of engineering standards within existing science standards (Wang, 2012; NRC, 2013; NGSS, 2013; & NAE, 2010). The panic over global competition has shifted attention and resources to STEM at a rapid rate, garnering increased levels of interest on the local, state, and national levels, as fewer young adults pursue careers in STEM related fields (Lewis, 2007). President Barack Obama's "Educate to Innovate" campaign provided an additional boost to a quickly growing robotics and engineering movement in K-12 schools in this country. In kicking off this campaign, President Obama stated "I believe that robotics can inspire young people to pursue science and engineering." Central to the lofty goal of increasing interest in engineering is teacher preparation and ongoing teacher professional-development. There are few studies that accurately describe factors to consider when implementing professional development intended to support the integration of engineering concepts at the elementary level. Furthermore, research data on teaching engineering design at the elementary level are lacking (Marulcu, 2010). This study seeks to contribute to the field of education by building upon previous educational research in K-12 teacher professional-development, engineering design, and teacher self-efficacy. Effective professional development is key to supporting quality education and the United States' goal of remaining a global leader in industry and commerce. Little educational research has been devoted to teachers' attitudes toward the integration of engineering in their classrooms (Douglas, Iversen, and Kalyandurg, 2004). As new science and engineering standards are implemented, teachers must be prepared to effectively teach engineering at the elementary level if they are to successfully prepare students for the Next Generation Science Standards (NGSS), Common Core State Standards (CCSS), Maine Education Assessment (MEA) science assessment in grades 3, 5, and 8, and recently adopted Smarter Balanced Assessment Consortium (SBAC) assessment. To that end, an accurate assessment of current realities of educational practice will serve to improve the quality of professional development provided to teachers who will be asked to integrate engineering within their instructional day (Hynes, 2012).

Purpose of the Study

The purpose of this study was to examine the influence of a professional development intervention to support educators in the integration of engineering in STEM (science technology, engineering, and mathematics) education at the elementary level. Particular consideration focused on the evolution of teachers' perceptions of engineering self-efficacy following engagement in professional development intended to support the introduction of an inquiry based science unit aligned with the *Next Generation Science Standards* and the National Research Council's *A Framework for K-12 Science Education* in selected grade-five classrooms.

Research Question

1. How do teacher perceptions of engineering self-efficacy evolve during implementation of an instructional unit in engineering?
2. What is the relationship between a professional development intervention in engineering on teacher perceptions of their content knowledge and pedagogical-content knowledge in engineering?

Operational Definitions

Content Knowledge

Generally refers to the facts, concepts, theories, and principles that are taught and learned, rather than to related skills—such as reading, writing, or researching—which students also learn in academic courses (Shulmann, 1986).

Engineering

The application of science to practical uses such as the design of structures, machines, and systems (Dictionary.com). Engineering draws on science and the laws of nature to design and create useful products that work within scientific confines.

Engineers

Seek to understand and predict how systems react to the laws of nature.

Pedagogical-Content Knowledge

Teachers' interpretations and transformations of subject-matter knowledge in the context of facilitating student learning (Shulman, 1986).

Professional Development

The advancement of skills or expertise to succeed in a particular profession, esp. through continued education (Dictionary.com).

Teacher Perceptions

The act or faculty of perceiving, or apprehending by means of the senses or of the mind; cognition; understanding (Dictionary.com).

Significance of the Study

Interest in K-12 engineering has grown as educational reform efforts have sought to strengthen the United States' position as a global leader of innovation and design. National educational policy concerns have provided an "impetus for pursuing early education STEM curricula" (Bagiati, 2011, p. 29). The National Research Council (NRC) and The National Academy of Engineering (NAE) endorse the potential benefit of engineering design in K-12 curriculum frameworks. Specifically, the NRC (2013) recommends improvements in science instruction realized through increased exposure to engineering at the elementary level. Carr, Bennett IV, and Strobel (2012), in a comprehensive evaluation and analysis of curriculum frameworks adopted by all 50 states, determined that 41 states have engineering concepts embedded in current standards, most commonly in science and technology. "The resulting standards, like those of states with independently conceived standards, include goals for students' technological understanding, problem solving abilities, systems thinking, and other engineering related skills" (Carr et al, 2012, p. 19). While standards for engineering do exist, a uniform system for introducing engineering concepts at the elementary level on a national scale does not. The state of Maine has joined 25 other states in the adoption of the Next Generation Science Standards (NGSS). Embedded in those standards are components of engineering design at the elementary level.

> Standards and performance expectations that are aligned to the framework must take into account that students cannot fully understand scientific and engineering ideas without engaging in the practices of inquiry and the discourses by which such ideas are developed and refined. At the same time, they cannot learn or show competence in practices except in the context of specific content. (NRC Framework, 2012, p. 218)

Appendix F of the Next Generation Science Standards contains eight essential practices of science and engineering included in the National Research Council's (NRC) Framework for essential to ensure proficiency in science.

1. Asking questions (for science) and defining problems (for engineering)
2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematics and computational thinking
6. Constructing explanations (for science) and designing solutions (for engineering)
7. Engaging in argument from evidence

8. Obtaining, evaluating, and communicating information

Adoption of NGSS mandates that all Maine school children be exposed to engineering-based instruction as part of their general science and technology curriculum. It is believed that successful implementation of NGSS will require a concerted effort to prepare instructional staff. Adams, Evangeloue, English, Dias De Figueiredo, Mousoulides, Pawley, Schifellite, Stevens, Svinicki, Martin Trenor, & Wilson (2011), contend that current mechanisms to improve engineering have been hindered by the realization that "the majority of teachers have no education about engineering concepts and thinking, there is a strong need to provide professional development and appropriate resources to scaffold their understanding and pedagogical strategies to effectively integrate engineering experiences" (Carr et al, 2011, p. 61).

The National Research Council (2013) has created a framework for engineering and scientific practices for K-12 education. That framework was developed with the intention of educating students in engineering and science to prepare them to be the scientists, technologists, engineers, and innovators of tomorrow. The goal may be best realized if teacher capacity is supported and expanded through professional development (NRC, 2013). Additionally, the Report of the 2012 National Survey of Science and Mathematics Education (NSSME) coordinated by Horizon Research (2013), with support from the National Science Foundation, found that only four percent of elementary school teachers reported that they were well prepared to teach engineering within their classroom setting as part of their teacher-preparatory programs and post-secondary engineering-course completions. Even more worrisome: 2.3 percent of elementary school teachers felt well prepared to encourage females to participate in science and engineering;

2.2 percent felt well prepared to encourage low socio-economic participation; and 2.2 percent felt well prepared to encouraged participation on the part of racial and ethnic minorities. “As the *Next Generation Science Standards* include engineering concepts for K–12, there will likely be a need for a major professional development effort focused on engineering” (Horizon, 2011, p. 25). To that end, the most effective manner by which to address the current deficiency is through thoughtfully coordinated professional development and in-service programs that support the unique needs of instructional staff (Horizon Research, 2013). Integration of engineering education at the K-12 level will likely continue to gain momentum in the United States as educators and policymakers call for school reform to inspire and prepare the next generation of engineers and innovators. In the absence of professional development, teachers’ appraisals of engineering self-efficacy are likely to remain low.

Integration of the crosscutting concepts of science and engineering (i.e., Patterns; Causes and Effect; Scales, Proportions and Quantity; Systems and System Models; Energy and Matter-Flows, Cycles, and Conservation; Structure and Function; and Stability and Change) within the elementary-level curriculum will expose students and teachers to higher-order thinking through hands-on activities that require them to connect, apply, and reinforce knowledge in math and science. Research connected to such programs is highly valued by educators and policymakers given the enormous economic investments devoted to STEM initiatives, and the challenge to inspire the engineers and scientists of tomorrow. Quality professional development is urgently needed to support informed instructional decisions (Wang, 2012). The importance of engineering on innovation and technology (Douglas, Iversen, & Kalyandurg, 2004) is at the heart of the

STEM movement. Consequently, it is paramount that quality professional development be offered as a means to prepare educators with the tools to successfully teach. That is the essential catalyst for school reform in STEM education (Hynes, 2012). Many teachers possess a limited background in engineering, and therefore, may not be prepared to teach concepts of engineering during core-content instruction in math, science, and technology classes.

Recent admission trends at U.S. colleges and universities reflect declining interest in engineering careers. The decline in interest may be due, in part, to limited knowledge and understanding of engineering on the part of both teachers and students. Teacher professional development in elementary engineering may positively impact student aspirations in engineering and STEM related career choices. The importance of preparing the next generation of innovators warrants close examination of current teacher professional- development practices as we seek to enhance student achievement and understanding through STEM education (Nadelson, Seifert, Moll, & Coats, 2012). Students who are exposed to quality engineering instruction may form more positive interactions with engineering, which quite possibly could lead to an increase in STEM career exploration (Cunningham & LaChappelle, 2012).

The results of this study will add to the knowledge base of educators involved in developing engineering curricula at the elementary level aligned with reform efforts in K-12 science education, which are, in turn, aligned with the Committee on Engineering Education's report, Engineering in K-12 Education: Understanding the Status and Improving the Prospects (NAE and NRC, 2009). Contained within that report were three core principles, (1) K-12 engineering should emphasize engineering design; (2) K-12 engineering education should incorporate developmentally appropriate math, science, and technology knowledge and skills; and (3) K-12 engineering education should promote habits of mind with respect to engineering. As schools introduce engineering concepts at the elementary level, thoughtful planning for implementation is paramount. As pointed out by John (2012), attention must be paid to the identification of obstacles that hinder initial implementation and administration of a policy change. To that end, the results of this study will provide information to practitioners, school leaders, policymakers, and researchers on the importance of professional development to elementary-school engineering instruction, and the impact those experiences have on teaching engineering self-efficacy.

The importance of exposure to engineering concepts in elementary education cannot be overstated. Though educational reform efforts to support the inclusion of engineering content are necessary, implementation efforts are sparse. “Regarding engineering, slow scattered introduction attempts have started and standards have begun to be developed; they are different in every state in the U.S., though, since no common national framework exists yet for early education engineering” (Bagiati, 2011, p. 32). Engineering education at the elementary level can provide an impetus for change towards classroom instruction that cultivates meaningful learning opportunities grounded in engineering. Changing pedagogical methodology to integrate engineering into existing curriculum frameworks will prove challenging in the absence of effective professional development. Though instructional improvements have been realized on the part of teachers who have participated in professional-development experiences at the middle- and high-school settings, further study of teacher professional-development at the elementary level is warranted. Focused professional-development offerings in engineering design may support teachers as they seek to prepare students for a rapidly changing world. As engineering concepts are not typically taught at the elementary level, elementary school teachers are commonly viewed as the least prepared and least interested in the integration of engineering in their instruction.

A review of relevant literature devoted to engineering goals, teacher knowledge, teacher knowledge of engineering, and professional development, was completed to gain a better understanding of the issues educators face as they plan for the inclusion of elementary engineering instruction is presented in chapter 2. The methods used to conduct this study are outlined in chapter 3. Chapter 4 presents essential findings from the qualitative and quantitative collection of data described in chapter 3. Chapter 5 details analysis, conclusions, and policy recommendations in relation to findings related to research questions.

Chapter Two

Literature Review

As a nation, our educational system is not sufficiently preparing a suitable number of engineers and innovators for the future. Currently, few teachers report that they are well prepared to encourage their students to pursue careers in engineering. Many studies suggest that one notable barrier may be that elementary teachers neither understand the work of engineers nor have training to teach engineering concepts**.** That barrier may be removed through refinements in teacher preparation. If teachers had increased engineering self-efficacy, they would be more likely to ignite creativity in their students. But there are few studies that accurately describe factors to consider when implementing professional development intended to support the integration of engineering concepts at the elementary level. Furthermore, reliable research data on engineering design at the elementary level are lacking (Marulcu, 2010). Background literature relevant to teacher professional-development, and elements of K-12 engineering education, are examined in this chapter to provide a framework from which theoretical and empirical evidence surrounding the research questions is grounded. Interest in K-12 engineering has grown as educational reform efforts have taken root through enacted policy. Currently, educational researchers are completing a variety of studies intended to inform elementary engineering- implementation efforts. Research of that nature is highly valued by educators and policymakers, given the enormous economic investments devoted to STEM initiatives, and the challenge to inspire the engineers and scientists of the future.

Engineering Goals and Standards at the Elementary Level

There is great interest in expanding current practices in preparing students for a changing world through STEM education at the K-12 level. To realize gains from that heightened interest, a variety of elements in existing K-12 education must change to support the inclusion of engineering in elementary STEM education as state and national standards are developed and implemented. The introduction of engineering concepts at the elementary level will require increased teacher engineering-self-efficacy so that teachers feel more confident in their abilities to integrate hands-on learning and creative problem solving within their classrooms. The evolution of pedagogical and self-efficacy changes of that nature will require systemic changes in the way teachers teach, serving to magnify the challenges of supporting STEM education (Rogers & Portsmore, 2004).

There have been many recent changes at both the national and state level that have illuminated science education as it relates to STEM, and in particular, K-12 engineering. The National Research Council has served as a strong voice for school reform, through the publication of, A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas (NRC, 2012). The committee recommends that science education in grades K-12 be built around three major dimensions.

- Scientific and engineering practices
- Crosscutting concepts that unify the study of science and engineering through their common application across fields
- Core ideas in four disciplinary areas: physical sciences; life sciences; earth and space sciences; and engineering, technology and applications of science

It is believed that a renewed focus on the dimensions of science education will serve to support students in meaningful learning in engineering and science. The NRC contends that all three of those dimensions need to be integrated into standards, curriculum, instruction, and assessment, if successful improvements in K-12 science education are to be fully realized. The NRC's framework is intended to serve as a guide for education that actively engages students in scientific and engineering practices over multiple years, deepening an understanding of science and engineering that extends well beyond the formal classroom setting. To that end, the NRC conveys two overarching goals for science education: (1) Educating all students in science and engineering; and (2) Providing foundational knowledge to the engineers, scientists, and technologists of the future. Conversely, "the framework and subsequent standards will not lead to improvements in K-12 science education unless the other components of the system, curriculum, instruction, professional development, and assessment change so that they are aligned with the framework's vision" (NRC, 2012, p. 17).

At the state level, the Maine Department of Education (MDOE) has created a "Vision for STEM Education in Maine." Contained within MDOE's vision are three goals intended to provide greater access to quality STEM teaching and learning within the K-12 setting. "The Department of Education envisions an educational system in which all students;

- Have equitable access to effective STEM instruction;
- Receive instruction in which STEM concepts are applied and integrated;
- Understand the relevance of STEM to their communities and to their own career aspirations.

As a strategy to prepare students for a changing world, the state of Maine has joined the Next Generation Science Standards (NGSS) movement. Those standards are arranged in a format that integrates the disciplines of science, technology, engineering and mathematics in grade K-12 classrooms. NGSS Science and Engineering Practices stress the importance that all students be provided authentic opportunities that allow them to acquire engineering design practices (NGSS, 2013). The adoption of the Next Generation Science Standards represents a commitment to integrate engineering design into the structure of science education by raising engineering design to the same level as scientific inquiry when teaching science disciplines at all levels from K-12 (NGSS Release, 2013, p. 1).

> At the upper elementary grades, engineering design engages students in more formalized problem solving. Students define a problem using criteria for success and constraints or limits of possible solutions. Students research and consider multiple possible solutions to a given problem. Generating and testing solutions also becomes more rigorous as the students learn to optimize solutions by revisiting them several times to obtain the best possible design (NGSS release 2013, p. 4).

The Next Generation Science Standards are strictly expectations for learning, and should not be considered formalized curriculum. Those grounded expectations serve as a guide for teachers to follow as they develop lessons that will prepare students to share what they know, and are able to do at the conclusion of a grade or grade span. Appendix F of the NGSS provides benchmark criteria that students must be exposed to during science instruction aligned with standards. The NGSS practices are not stand-alone items. As teachers navigate a curriculum, the practices can be intentionally overlapped and interconnected. And that is where teachers may experience difficulty: they have traditionally received minimal exposure to some or all of the practices embedded in NGSS through formal and informal training during pre-service and in-service training. The literature indicates that elementary teachers simply do not have the knowledge of engineering, engineering instructional pedagogy, and engineering self-efficacy deemed essential to addressing science and engineering reform efforts.

Teacher Knowledge

At the heart of quality instruction is the level of teacher knowledge of content and pedagogical knowledge. Content knowledge "generally refers to the facts, concepts, theories, and principles that are taught and learned, rather than to related skills—such as reading, writing, or researching—which students also learn in academic courses" (Education Reform, 2014). Shulman (1986) defined the concept of content knowledge with the introduction of pedagogical-content knowledge wherein teacher interpretations and transformations of subject matter knowledge served to facilitate student learning. As conveyed by Shulman (1986), content knowledge includes knowledge of concepts, theories, ideas, organizational frameworks, knowledge of evidence, and proof. In the case of science and engineering, teachers would command a deeper understanding of engineering design processes, engineering connections with daily life, appropriate materials for engineering activities and evidence-based reasoning. In the absence of sufficient content knowledge, students may receive incorrect information and misunderstandings about the content (NRC, 2012). "Pedagogical knowledge requires an understanding of cognitive, social, and developmental theories of learning and how they apply to students in the classroom" (Koehler & Mishra, 2009, p. 64). Furthermore, "The importance of forging connections among different content-based ideas, students' prior knowledge, alternative teaching strategies, and the flexibility that comes from exploring alternative ways of looking at the same idea or problem are all essential for effective teaching" (Koehler & Mishra, 2009, p. 64). Many elementary-level teachers possess insufficient engineering content-knowledge and engineering pedagogy-knowledge to provide quality instruction in elementary engineering. Limitations of that nature have been found to result in teacher reports of low engineering self-efficacy.

Teachers' knowledge is commonly associated with the realities of a particular classroom. Teachers typically communicate and share their knowledge of content matter with colleagues through the use of narratives and stories. According to Carter (1990) teacher knowledge is anchored by classroom situations that include the realities teachers are confronted with as they carry out intentional instruction of content matter. She contends that teachers ultimately learn by teaching. Pedagogical-content knowledge includes what teachers know about particular content, as well as how they are able to translate that knowledge during classroom instruction with their students.

Teacher Knowledge of Engineering

Though K-12 engineering is a relatively new concept, recent research has been completed on teacher knowledge of engineering and teacher self-efficacy in engineering. Douglas et al, (2004) provided an executive summary of K-12 engineering that highlights the need to make engineering a vital component of STEM education. Collected data reflected teacher acknowledgement of the importance of engineering in their classrooms, though teachers conceded that they did not have the time or resources to adequately implement engineering in their classroom lessons. Perceptions of that nature hinder efforts to inspire students to pursue study in engineering and STEM fields. Sun, Boots, and Strobel (2012) conveyed similar findings that indicate elementary school teachers are poorly prepared to teach engineering concepts. They assert that “elementary teachers have misconceptions and overly broad ideas about engineering and technology and low self-reported familiarity with DET. The concerns reported, such as meeting state standards, and barriers perceived, such as lack of time, resources, and administrative support, reflect elementary teachers’ hesitance to teach engineering” (Sun et al, 2012, p. 4). Professional development may address lack of awareness and training, and might support teachers as they prepare to engage and inspire future engineers.

In a qualitative study completed in the United Kingdom, Clark and Andrews (2010), examined the barriers that exist with the provision of primary-level engineering education. The authors summarized their findings in three domains: (1) pedagogic issues, (2) exposure to engineering education, and (3) children’s interest in engineering and science. Teachers in the study were found to lack awareness of engineering pedagogy, and formal professional-development training in elementary engineering lesson-design that would support their efforts in teaching engineering in their classrooms. Limited awareness and understanding of engineering content-knowledge and pedagogy may impede the ability of teachers to engage and inspire engineers of the future (Clark and Andrews, 2010).

Similarly, Nathan, Tran, Atwood, Prevost, and Phelps (2010) examined teachers’ beliefs and expectations about pre-college engineering instruction using a survey tool called the Engineering Education Beliefs and Expectations Instrument. Teacher responses to the survey were then compared to evaluate differences in teachers’ views and perceptions. The study found that teacher instruction was influenced by student interest, family background, and prior educational performance. The researchers concluded that engineering education in K-12 settings may be supported through promotion of technology literacy for all, rather than focusing on a select few, when seeking to integrate K-12 engineering education as a more global approach. Reform of that nature may positively affect recruitment, instruction, and assessment practices in engineering on the part of educators.

Nadelson et al, (2012) studied a four-day residential summer institute attended by 230 teachers of grades four through nine. They found that teachers exhibited increases in content knowledge, use of inquiry instruction, and teacher efficacy when teaching STEM. Those findings indicate that gains in teacher perceptions and conceptions of STEM education can be achieved through focused professional-development attendance.

> The association between teachers' comfort and contentment with their pedagogy validates the creation and offering of professional development designed to enhance pedagogical contentment for teaching STEM. Increases in teacher comfort and pedagogical contentment in STEM are likely to lead to an increase in teacher competencies and effectiveness with STEM, providing justification for attending to teacher discontentment in PD in STEM (Nadelson et al, 2012, p. 70).

Nadelson, et al., found that increased levels of comfort in teaching STEM were correlated to an increased number of college science courses taken. Lack of exposure to higher levels of science inquiry served to validate the need for a model of teacher professional-development grounded in scientific experiences (Nadelson et al, 2012). They contend that professional development in scientific inquiry is critical to teacher success when teaching unfamiliar STEM content. As teacher knowledge in math and science increased, teachers expressed increased levels of comfort and self-efficacy when teaching STEM content. "The shift in perceptions of teaching STEM along with content/subject matter knowledge of STEM provides further support for the influence professional development can have on an array of variables related to teaching" (Nadelson et al, 2012, p. 80).

Teacher preparation in blending engineering concepts into standard curriculum frameworks may lead to improved student learning and career aspirations (Brophy, Klein, Portsmore, & Rogers, 2008). Those researchers contend that teacher perceptions may hinder engineering implementation efforts because many teachers do not view engineering as an achievable career choice for many of their students. The findings shed light on the significant impact that teacher perceptions and background may have on subsequent student interest and career exploration in STEM professions including engineering.

Similar to Nadelson et al.'s (2012) work, Duncan, Diefes-Dux, and Gentry (2011), examined the influence and impact of a week-long summer academy attended by elementary school teachers at the Institute for P-12 Engineering Research and Learning (INSPIRE). The INSPIRE program followed adopted guidelines established by the American Society for Engineering Education for improving K-12 engineering education. Change in teacher recognition and understanding of engineering was measured through close analysis of pre- and post-academy photo journals kept by institute participants. Analysis of photo journals and a corresponding coding system allowed researchers to successfully measure teacher change with respect to engineering concepts. Results indicate that teachers who participated in the professional-development intervention demonstrated change in both understanding and recognition of engineering concepts.

The findings are similar to those of Cunningham and Lachapelle (2012) in their study of teachers who participated in the Engineering is Elementary curriculum training conducted by the Boston Museum of Science, and that of Hynes (2012), wherein teachers completed a week-long training in the engineering design process. Duncan et al.'s (2011) results assert that teachers who participated in the summer professional-development experience demonstrated change in their abilities to understand and recognize engineering through real-world applications. Though gains were noted on the part of participating teachers, the authors recommend further study to determine if enhanced teacher knowledge of engineering is readily transferrable to students within the classroom, and if such knowledge affects their students' attitudes, aspirations, and knowledge of engineering (Duncan et al, 2011). In summary, teachers who participated in active professional-development experiences focused on K-12 engineering experienced change in perceptions that likely lead to change in perceptions on the part of students (Lachapelle et al, 2012; Capobianco, B., Diefes-Dux, H., Mena, I., and Weller, J., 2011; Duncan et al, 2011; Cunningham and Lachapelle, 2012; and Hynes, 2012).

Brophy et al (2008) explored how integration and advancement of engineering practices in PK-12 classrooms can support acquisition of prerequisite STEM skills needed to solve real-world problems. The study was born from concern that the talent pool of students available for post-secondary study in engineering lacks quantity, quality, and diversity. The authors highlight the challenges for PK-12 engineering education, most notably teacher readiness and professional development. The researchers shared that many teachers possess limited exposure and background to K-12 engineering concepts achieved through formal training and life experiences. The authors assert that teacher preparation in blending elementary engineering-concepts into standard curriculum frameworks can lead to improved student learning in engineering, and to career aspirations in engineering and STEM related fields. Brophy et al. (2008), assert that teacher perceptions may hinder elementary engineering-implementation efforts as many teachers do not view engineering as an achievable career choice for many of their students. Those findings shed light on the significant impact that teacher perceptions of engineering may have on student interest and career exploration in STEM-related professions. In addition to focused efforts to support in-service teacher professional-development, the authors call for expanded professional development and training for pre-service educators who will be required to teach engineering concepts as part of their daily instructions. Those limitations are similar to those of members of the general public who indicate that they are not "well informed" or interested when it comes to the work of engineers. Similarly, Sun and associates share the concern that "the challenge of preparing elementary teachers for engineering teaching also lies in the fact that elementary teachers are generally disinterested in and intimidated by science content" (Sun et al, 2012, p. 4). They recommend professional development as a natural remedy to that perceived ailment. Those assertions support the work of Zuger (2012) who found that lack of professional development needed to support STEM instruction in K-12 classrooms was but one of the hurdles to be cleared for the successful integration of engineering practices at the K-12 level.

Professional Development

Central to school-reform efforts is the importance of ongoing educator training. "Policymakers increasingly recognize that schools can be no better than the teachers and administrators who work within them" (Guskey, 2002, p. 381). The advancement of the profession may be best achieved through high-quality, results-driven, professional development. The primary purpose of professional development is to prepare and support teachers through intellectual opportunities to gain knowledge and skills needed to support increased levels of students' achievement (U.S. Department of Education, 1996; Darling-Hammond, 1998). Additionally, Glickman, Gordon, and Ross (2004) contend that, "Education is a human enterprise. The essence of successful instruction and good schools comes from the thoughts and actions of the professionals in the schools. So if one is to look for a place to improve the quality of education in a school, a sensible place to look is the continuous education of educators-that is, PD" (Glickman, et al, 2004, p. 370). Consistent with that claim: "The first goal of professional development is to design training that enables staff to learn and transfer knowledge and skills to their classroom practice" (Blazer, 2005, p. 5). Such training produces changes in teachers' instructional practices, which can be linked to improvements in student achievement. The time teachers spend engaged in learning with other teachers is just as important as the time they spend teaching students. The National Research Council (2012) suggests that professional development can be best improved through coordinated learning opportunities for teachers to deepen their conceptual understanding of science and engineering practices that will increase subject matter knowledge. "Three major goals of professional development programs are change in the classroom practices of teachers, change in their attitudes and beliefs, and change in the learning outcomes of students" (Guskey, 2002, p. 383).

Though quality teacher professional-development experiences are the gold standard, the reality is many such experiences have proven to be ineffective for numerous reasons. “Despite evidence showing characteristics of effective professional development, teachers generally do not have many positive professional development experiences” (Ragan and Liston, 2008, p. 4). Stark differences exist between what are commonly considered effective professional-development opportunities for teachers and current professional development afforded to teachers (Ragan and Liston, 2008). “Despite a consensus in the literature on the features of effective professional development, there is limited evidence on the specific features that make a difference in achievement” (Wayne, Yoon, Zhu, Cronen, and Garet, 2008, p. 469). Though there is relative consensus that high-quality instructional staff benefit from effective training practices, there has historically been an overuse of professional development in the form of single-day workshops that focus on organizational structures rather than high-quality instruction to support student learning (Darling-Hammond, 1998). Additionally, there is often a disconnect between what teachers expect from professional-development experiences and what they actually receive (Reeves, 2010) as some experiences are short term, and lack a formal structure that affords follow-up. Structures of that nature greatly limit teachers in their ability to learn, and integrate new technologies into their work with children (NCES, 2000).

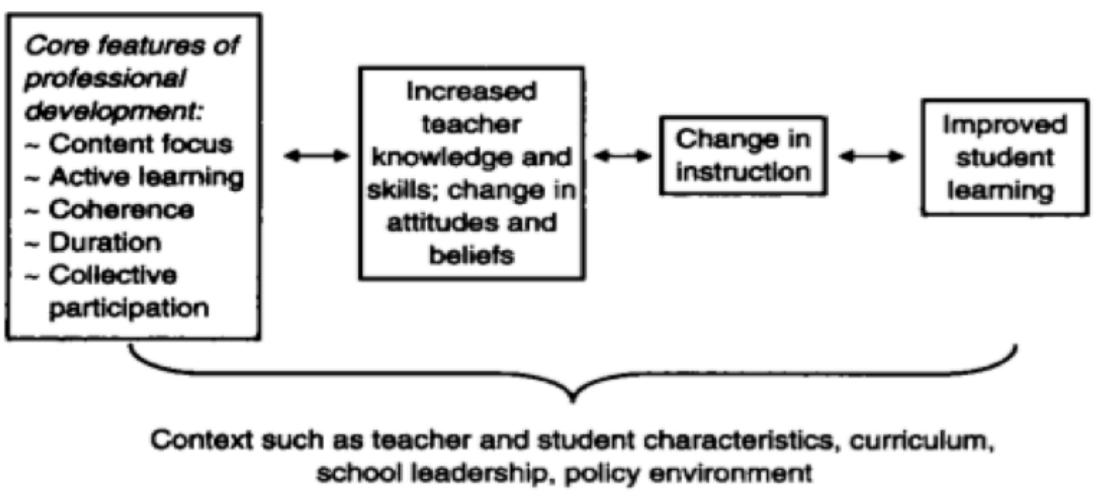
An abundance of research suggests that quality professional development is achieved through programs that have clear and specific goals and objectives, actively involve participants, and include multiple training sessions over an extended period of time. The value of high-quality professional development has been directly tied to student learning, balances student results with teacher practice, and focuses on the practice rather than programs (Reeves, 2010). “We know what effective professional learning looks like. It is intensive and sustained, it is directly relevant to the needs of teachers and students, and it provides opportunities for application, practice, reflection, and reinforcement (Reeves, 2010, p. 23).” One factor for the mixed findings of the effect of professional development on student outcomes may be due to the challenge of estimating the impact of teacher training on teacher quality, given methodological challenges (Harris and Sass, 2011). Additionally, many professional development initiatives lack continuity that may lead to ineffectiveness (Bybee, 2007) that may limit measurements of effectiveness.

In a comprehensive analysis of more than 1,300 studies of teacher professional development, Yoon, Duncan, Lee, Scarloss, and Shapley (2007) for the U.S. Department of Education, Institute of Education Sciences, National Center for Education Evaluation and Regional Assistance, and Regional Educational Laboratory Southwest, only nine studies met the What Works Clearinghouse evidence standards. The report found that professional development averaging 49 hours or more of exposure focused on elementary teachers and their students provided evidence of measureable gains in student achievement. The sheer number of professional-development experiences that did not translate into academic gains by students highlights the challenge educators face when developing professional-development offerings. In particular, professional-development studies are often limited by problems with study design that make evidence-based research criteria difficult to achieve (Yoon, et al 2007). Similarly, Guskey and Yoon (2009), found that professional-development programs that included at least 30 hours of contact with teachers were found to achieve positive effects on student learning.

"Effective professional development requires considerable time, and that time must be well organized, carefully structured, purposefully directed, and focused on content or pedagogy or both" (Guskey and Yoon, 2009, p. 499). Many professional-development offerings consistently fail to consider what motivates teachers to engage in professional development, and the process by which change in teacher knowledge and pedagogy are achieved (Guskey, 1986). The importance of program evaluation for effectiveness by professional-development planners and implementers cannot be underscored.

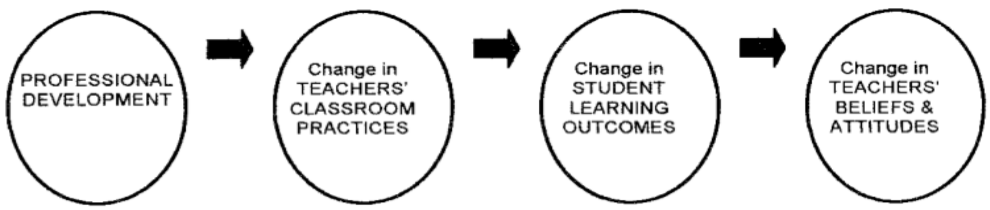
The vast body of research on professional development for teachers has focused on extraneous outcomes associated with the experience, at the cost of true staff improvement and subsequent student achievement gains. Desimone (2012) suggested that a renewed focus be placed on the results achieved through professional development, and the processes by which such offerings are organized to support teacher growth. Such a "solution is to focus on the features of professional development activities that lead to teacher learning, rather than on the types of structural aspects of activities in which teachers engage" (Desimone, 2010, p. 29). Her empirical research suggested that effective professional development be grounded in the core principles of: (1) subject matter content focus; (2) active learning by participants; (3) coherence in professional development activities; (4) duration of no less than 20 hours of contact time; and (5) collective participation in professional-development activities that strengthen the overall learning community. Going further, and similar to Guskey (1986), Desimone contends that successful professional development contains an accepted conceptual framework containing critical steps that participants collectively experience. Teachers first experience professional development, which enhances their knowledge and skills, changing their attitudes and beliefs. That leads them to improve the content of their instruction or approach to pedagogy, and results in improved student learning of content. Improving teachers' professional development may best be realized through the use of conceptual frameworks that "understand how best to shape and implement teacher learning opportunities for the maximum benefit of both teachers and students" (Desimone, 2009, p. 181). Figure 2.1 represents Desimone's conceptual framework for studying professional development. It suggests that teacher change can happen in either direction. For example, increased teacher knowledge and skill may lead to change in instruction and, consequently, gains in student learning. Conversely, gains in student learning may alter teacher instruction, which leads to changes in attitudes and beliefs about learning and instruction. Embedded in the framework are the critical components suggested by Guskey.

Figure 2.1: Desimone Conceptual Framework for Studying Effect of Professional Development on Teachers and Students



The framework for effective professional development is similar to that of Guskey (2002) presented in Figure 2.2. Using those models, the essence of quality professional development is not simply the experience of an educator participating in an offering, but rather how implemented professional development leads to changes in teachers' attitudes and beliefs. When teachers believe results are achieved as a result of professional development, their beliefs and attitudes have been reshaped (Guskey, 2002). As teachers gain confidence in new practices, they are more inclined to use newly acquired knowledge repeatedly with their students.

Figure 2.2: Guskey A Model of Teacher Change



(Professional Development and Teacher Change, Thomas Guskey, 2002).

Central to the impact of professional development is the premise that increased exposure to professional development leads to positive and significant changes in teacher content-knowledge, and consequently to increased levels of student achievement. In particular, the most effective professional development offerings on student learning may be those that involve extended and focused work for educators. As school districts and state level policy decisions rely more heavily on in-service professional development as a means of achieving desired reform efforts, a clear picture of best practices in professional development is needed to plan for the integration of engineering. Though there have been increases in staff training in the form of professional development, those efforts may not always lead to significant gains in student achievement. That suggests that current practices intended to support staff development may not sufficiently raise standards of student outcomes (Jacob and Lefgren, 2004). The National Staff Development Council states that effective professional development programs are results-driven, standards-based, and job-embedded.

Professional development is widespread in schools, but often lacks both intensity and rigor. Professional development for teachers may be more effective as teachers are acknowledged for their instructional improvements (Jackson, 2012). The catalyst for change may be achieved through thoughtful preparation and training of instructional staff. Most elementary teachers are not sufficiently prepared to teach integrated engineering concepts during science, technology, and mathematics class, as they lack prerequisite knowledge and familiarity with engineering instruction (Head, 2011). Professional development in engineering pedagogy may address gaps that serve as roadblocks for teachers attempting to meet Next Generation Science Standards (NGSS, 2013).

Existing research as to what teachers know about engineering design and how best to build teacher capacity is limited (Head, 2011). Deluca (2003), examined best practices in teacher preparation using a constructivist theory method wherein students and their teachers were provided opportunities to explore and create understanding through personal connections utilizing hands-on tools. The study found that participants indicated that they would be more likely to use technology in education because the professional developed they received provided them with effective background in engineering concepts. “The majority of the students expressed a greater understanding of basic engineering principles and an increased comfort level with technology” (Deluca, 2003, p. 63).

The shared experience of teachers who work together through professional-development initiatives can serve as a powerful leveraging tool. “The time teachers spend with other knowledgeable educators, engaging in teaching and learning, is just as important to students' learning as the time teachers spend teaching students." (Blazer, 2005, p.1). Work of that nature enables teachers to engage learning similar to that their students will experience in the classroom. "In professional development, it's important to address the questions participants are asking when they are asking them and pay attention to participants' needs for information, assistance, and support" (Blazer, 2005, p. 9) as these questions will likely be similar to those posed by their students. "Teachers are the linchpin in any effort to change k-12 science education. And it stands to reason that in order to support implementation of the new standards and the designed to achieve the initial preparation and professional development of teachers of science will need to change" (NRC, 2012, p. 255). As teachers increase collaboration with colleagues, they are better prepared to consider alternative approaches to teaching and learning, expand instructional strategies, and share relevant strategies that support peers in their efforts to improve student outcomes (Darling-Hammond & McLaughlin, 1995). Working alongside colleagues during exposure to professional development serves to strengthen instructional relationships among and between teachers. Teachers who are provided active learning with colleagues from the same subject, grade, or school are linked to improving teaching practice (Garet, M., Porter, A., Desimone, L., Birman, B. & Yoon, K., 2001; Ragan & Liston, 2008). Working alongside fellow educators, teachers benefit from the opportunity to apply familiar processes in the context of innovation (Nadelson et al, 2012). Research suggests that professional development of groups of teachers from the same school, department, or grade may be most helpful to the change process (Blazer, 2005). Singh and McMillan (2002) found that teachers who were exposed to school-level professional development alongside colleagues reported greater levels of relevancy to their practice than from professional-development experiences they attended at the district, state, or national level.

Job-embedded learning is learning by doing, reflecting on the experience, and then sharing insights with colleagues. Elements of professional development contained within the instructional day are critical to professional growth, and may take many forms including group study, self-study, coaching, inquiry into practice, and consultation with peers and supervisors (U.S. Department of Education, 1996). “Teachers rarely have time in their busy day to engage in professional development. Finding time for professional development and follow-up activities is essential because teachers have few of the opportunities for growth that are available in other professions” (Blazer, 2005). Generally speaking, professional development that is job-embedded is more likely to contribute to improved student achievement as teachers improve knowledge, instructional practice, and self-efficacy (Wayne et al, 2008; Garet et al, 2001).

There are many expert sources to use when investigating essential criteria for effective professional development. Provided here are a few who draw their beliefs of effective professional development from research completed in the field of education. Guskey (1986) conveyed the belief that high quality professional development requires reflection to be completed in five critical areas. The components consider that participants’ reactions to treatment are chronicled, participants’ learning is recorded, organizational support and change are embedded, participants’ use new knowledge and skills in their work, and student learning outcomes are improved. Those assertions are similar to those reported by Desimone, Porter, Garet, Yoon, and Birman (2002) wherein essential effective organizational qualities of professional development practices are centered around: a clear focus on content matter, collaborative and joint action by participants; innovative, active and vibrant learning; a commitment to long range professional development; and teachers from the same subject, grade, or school engaged collaboratively in the training.

Darling-Hammond and McLaughin (2005) espouse that effective professional development follows similar lines: it is collaborative, reflecting the importance of teacher communities of practice; it is directly relevant to their work with students in the classroom; it is sustained, ongoing, intensive, and supported through instructional support; it engages teachers in modeled practices of teaching, assessment, observation, and reflection; and it is grounded in inquiry, reflection, and experimentation for member participants. Similarly, Bowgren and Sever (2010), conveyed the belief that for teacher learning to best be transferred to classroom practice, professional development must include four vital components; (1) teachers must be provided with and understand the theory supporting the strategy; (2) teachers must have the opportunity to watch a skillful demonstration of the strategy; (3) teachers must be given time to practice the strategy; and (4) they must engage in follow-up sharing of practice and participation achieved through peer coaching. Furthermore, Bowgren and Sever (2010) found in their research that teacher transfer of knowledge varied based upon the format of professional development to which they were exposed, wherein:

- Five percent transfer new knowledge that was learned through presentations and workshop.

- Ten percent transfer new knowledge when presentations are combined with demonstrations by leaders.
- Twenty percent transfer new knowledge when presentations and demonstrations are combined with opportunities to practice.
- Twenty five percent transfer new knowledge when presentations, demonstrations, and opportunities for practice are combined with feedback.
- Ninety percent transfer new knowledge when ongoing coaching is combined with presentations, demonstrations, and opportunities for practice with feedback.

Thus the introduction of engineering and design in the K-12 setting may lead to improvements in STEM attitudes, knowledge, skills, and interest in careers for students. Such introduction will require improved teacher engineering-content knowledge achieved through effective professional development that may also serve to evolve teacher perceptions of engineering self-efficacy. Given the need to advance interest in engineering and STEM-related careers, knowledge and understanding of engineering practices are valued on the part of elementary school educators. Existing research on teacher perceptions of engineering self-efficacy and effective professional development may provide insight for increased support for engineering instruction at the elementary-school level. The ideas and suggestions gained from the analysis of current practices and guidelines in engineering reflect the need to enhance K-12 engineering education through outreach, hands-on learning, interdisciplinary integration, standards development, and professional development for teachers.

Transformative learning theory addresses adult learners who are asked to reflect on their individual learning experiences regarding the change process.

> The theory of teacher change is the intervention's theory about the features of professional development that will promote change in teacher knowledge and/or teacher practice, including its theory about the assumed mechanisms through which features of the professional development are expected to support teacher learning. The theory of teacher change is not limited to the structural features of the professional development, such as its duration and span, but also includes elements and activities in which the teachers are expected to engage during the professional development and the intermediate teacher outcomes these activities are expected to foster (Wayne et al, 2008, p. 472).

Through analysis of practice and student learning, teachers' beliefs about learners, learning, and instruction may serve to alter teacher perceptions of the professional-development experience, and their perceptions of evolution of engineering self-efficacy. "Measurement of mediating variables is especially critical in making use of study results to draw conclusions about the theory of teacher change and the theory of instruction on which the professional development intervention is based" (Wayne et al, 2008, p. 475). Wayne contends that prior to implementing professional development activities, initially measuring teachers current realities is essential. The degree to which teachers change through professional development will have a direct impact on student achievement based on teacher-knowledge gains (Wayne, 2008). As knowledge gains increase, student-achievement gains increase. "The adult learning theory of transformational learning provides a rich framework from which to view faculty development" (Bagiati, 2011, p.

39). She suggests that transformative learning occurs for teachers when they are presented with new concepts, methods, or skills that require reflection and dialogue. “This theory can assist in framing our understanding in regards to the changes teachers may experience in their perspectives and practice of teaching as a result of learning new k-12 content” (Bagiati, 2011, p. 39). Thomas Guskey asserts that is not the reality of most professional development activities. “However, it could be hypothesized 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” (Guskey, 1986, p. 6). Using that model, Guskey conveys the notion that desired change results as teachers progress through the following process:

- Initial change in classroom practices of teachers.
- Leads to change in their beliefs and attitudes about instruction and program adoption.
- Leads to change in learning outcomes for students.
- Leads to change in beliefs and attitudes of teachers that is contingent on their gaining evidence of change in the learning outcomes of their students.
- Ultimately leads to change in teacher attitudes and beliefs largely based on student gains.

Traditional approaches to professional development provide teachers with theoretical understanding of new concepts with sparse opportunities for authentic and relevant follow-up once workshop-embedded practice has concluded. Once removed from a professional development setting, teachers commonly have limited results in introducing newly acquired concepts within their practices. That is primarily due to lack of sustained integration efforts with newly learned content. Sparks (2002) found that in the absence of continued support and resources, fewer than 10 percent of teachers will fully integrate newly acquired skills within their classroom practices. It is anticipated that teachers will experience radical changes in their attitudes, perceptions, and teaching practices as they immerse themselves in new learning of engineering and science content that utilizes inquiry-based applications. The questions that frame student learning also frame teacher learning. When teachers understand the challenges students face, they can adjust instruction and materials, allowing them to appropriately to meet student needs (NRC, 2012).

Similarly, Borko and Putnam (1996), in the *Handbook of Educational Psychology,* suggest that several elements must be present to realize effective learning experiences for teachers:

- Addressing teachers' existing knowledge and beliefs about teaching, learners, learning, and subject matter;
- Providing teachers with sustained opportunities to deepen and expand their knowledge of subject matter;
- Treating teachers and learners in a manner consistent with the program's vision of how teachers should treat students as learners;
- Grounding teachers' learning and reflection in classroom practice; and
- Offering ample time and support for reflection, collaboration, and continued learning (pp. 700-701).

This particular study, devoted to the investigation of the influence of professional development on teacher perceptions of engineering self-efficacy, will contribute to the field of education. It will provide deeper understanding of the challenges teachers and educational institutions face when implementing new and complex concepts first to teachers and subsequently to students. As the importance of addressing engineering content at the elementary level is discussed in greater detail, implications for enhanced teacher professional development will be made more visible. Similar to the findings of Katehi, Pearson and Feder (2009), teachers will likely experience significant changes in their attitudes, perspectives, and teaching practices as they familiarize themselves with the new engineering content through focused professional development and ongoing discourse with colleagues. The process is intended to afford them with newly acquired skills and knowledge to then introduce new concepts into their instructional practice. This study recognizes “that requiring teachers to implement new content or using new methods in class must take into consideration what teachers will also have to go through” (Bagiati, 2011, p. 40).

Summary

The literature review demonstrates that exposure to quality professional development to support teachers with increased knowledge and pedagogy in STEM instruction is lacking. Various studies have addressed teacher professional-development. However, limited research has been completed in professional development intended to support STEM instruction, in particular elementary engineering and the influence those activities have on teacher-engineering self-efficacy. Based on the limited research on the relationship between teacher learning and engineering-design content, this study seeks to contribute to this area of research. The focus of this research is to blend best practices in professional development using commonly cited conceptual frameworks that lead to increased teacher knowledge and skills as their attitudes and beliefs and engineering self-efficacy evolved. The study sought to advance theory, design, and practice that lead to teachers' perceived evolution of engineering self-efficacy. Chapter 3 focuses on the theoretical and methodological approach used to design the study, and collect and analyze data.

Chapter Three

Methodology

This chapter explains the methods employed to complete this study. The purpose of this study was to examine the influence of a professional development intervention to support educators in the integration of engineering in STEM (science technology, engineering, and mathematics) education at the elementary level through a mixed-methods research design. Particular attention focused on understanding the ways in which teachers perceive the influence of professional development on their engineering self-efficacy. Professional-development activities served to support and inform the introduction of an inquiry based science unit aligned with the *Next Generation Science Standards* and the National Research Council's *A Framework for K-12 Science Education* in selected grade five classrooms. This chapter provides an overview of methodology of this mixed-methods research study. The specific questions guiding this study are:

1. How do teacher perceptions of engineering self-efficacy evolve during implementation of an instructional unit in engineering?
2. What is the relationship between a professional development intervention in engineering on teacher perceptions of their content knowledge and pedagogical-content knowledge in engineering?

Methodological Overview

This is a concurrent mixed-methods case study of the influence of professional development on elementary teachers' perceptions of engineering-instruction self-efficacy.

"A case study is an in-depth description of a bounded system" (Merriam, 2009, p. 40) that examines a contemporary phenomenon in real-life contexts. The bounded unit of analysis for this case study was a group of fifth-grade teachers participating in the intervention study. As suggested by Yin (2014), a case study seeks to answer "how" and "why" questions for the researcher. Utilizing case study data-collection methods, a "thick description of the phenomenon under study" (Merriam, 2009, p. 43) was achieved. "Anchored in real-life situations, the case study results in a holistic account of a phenomenon. It offers insights and illuminates meanings that expand a reader's experiences" (Merriam, 2009, p. 51). Given the nature and focus of this study, a mixed-method case study design provided a broad understanding of the beliefs and behaviors held by study participants, capturing in-depth information through qualitative interviews and quantitative survey-data collection (Creswell, 2009). Mixed-methods designs provide a clearer understanding of current realities than what may be achieved solely through quantitative or qualitative research techniques alone. In this model, the quantitative and qualitative methods were used to offset relative weaknesses in either approach.

School Setting

The school in this study was selected from a southern Maine school district composed of 2,666 students during the 2013-14 academic year. The district has three K-5 elementary schools, one grades 6 to 8 middle school, and one grades 9 to 12 high school. All school-aged residents of the community are eligible to attend those five public schools. The school selected for the study educated 427 students during the 2013-2014 academic year, and was chosen due to convenience for the researcher, and for his relative knowledge of the district.

Participants

The three teachers selected for this study currently serve as fifth-grade classroom teachers in the same school. Seidman (2013) contends that a deep level of understanding can be drawn from a small sample when completing qualitative research.

Abby first became interested in becoming a teacher as a young girl. Upon graduation from high school, she attended a teachers college in a neighboring state prior to transferring to a teachers college in Maine. Following student teaching in an eighth grade classroom, Abby was hired as a first-grade teacher initially, but elected to teach sixth grade for three years prior to transitioning to her current school and teaching fifth grade for the past four years. During her pre-service and subsequent in-service training experiences, Abby has participated in limited professional development and training in the area of science, though she possesses strong background and experience in mathematics.

Bea has been teaching elementary education for the past ten years as a fifth-grade classroom teacher. She attended business school upon completion of high school, and worked a number of years in human resources and management. .When corporate layoffs affected her and her family, she enrolled in a graduate-level teacher-preparatory program at a local university. Upon completion of her internship at her current school of employment, she was hired as a fifth-grade teacher. Leading up to her employment and following, she has completed one course in science methods. Bea currently represents her school on her district's science committee and also participates in Maine Math and Science professional development offerings on a regular basis. Bea is a self-described

"Cliff Clavin," a fictional character on the television show Cheers, who is the bar's "know it all" when it comes to science.

Like Bea, Nancy was not initially drawn to the field of education. She embarked on a career in business following college graduation. Following several years of work at the corporate level in southern Maine and Boston, she too enrolled in a graduate-level teacher-preparatory program at a local university. Upon completion of her internship, Nancy was hired to teach fourth grade at her current school where she has continued to teach for the past fourteen years. She has also taught third grade, and for the past three years, fifth grade. Like her grade-level colleagues, she has had limited exposure to professional development and training in science.

Intervention Treatment

This study provided classroom teachers with professional development aimed at increasing their content knowledge and instructional pedagogy through focused professional-development intervention, and reflective conversation with colleagues. Utilizing LEGO Education's renewable energy curriculum, teachers introduced and taught inquiry-based lessons. Study participants were provided:

- Onsite and offsite professional guidance and training.
- Release time to complete the offsite experience.
- Teachers guide to renewable energy curriculum.
- Use of renewable energy Add On Kits.
- Use of LEGO Education Resource Kits.

Facilitators

Shelly**,** the primary facilitator of this study holds a bachelor of science degree in elementary education, with a concentration in mathematics, from the University of Maine and a master's degree in technology education from Lesley University. Following graduate school, she completed master-teacher certification. As a classroom teacher, she taught middle school math, science, and language arts for 19 years in southern Maine schools. For the past two years, she has served as the technology and curriculum integrator, and STEM coordinator, in her district of employment. She has provided ongoing professional development to teachers, parents, and coaches on LEGO WeDo, NXT Mindstorms, First LEGO League (FLL) challenges, and LEGO Renewable Energy Kits, while also supporting robotics teams at the elementary and secondary levels. The team coached by the study facilitator was recognized at the 2012 FLL Maine state robotics competition for winning performances with the Robot Game and Mechanical Design competitions.

Mike, the secondary facilitator earned a bachelor of science degree in elementary education from the University of Maine. He has five years of experience teaching fifth grade in schools in eastern and southern Maine. He has completed professional development training under the direction of the primary facilitator of this study. Given his level of understanding of the LEGO curriculum, and engineering content-knowledge and engineering pedagogical-knowledge, he has served as a primary resource for colleagues within his elementary school. Most recently, he was named as coordinator of the elementary robotics program in his school district.

The initial training session included an overview of teacher resources, renewable energy, potential and kinetic energy, and the element guide. Key learning objectives were reviewed for each lesson. Facilitators provided introductions to the topic of renewable energy and definitions of the essential terms. Following a review of materials, building instructions were reviewed in preparation for teacher creation of models. Overview of materials followed LEGO Education's "Four C" which requires individuals and groups to Connect, Construct, Contemplate, and Continue learning. Study participants were provided with strategies that supported the management and organization of materials used within their classroom. Additionally, participants were provided strategies and time suggestions deemed necessary to complete each investigation that would require students to explore, build, and investigate solutions to stated problems. Participants viewed a number of short video clips produced by LEGO Education that contained key elements of the renewable energy curriculum. Each video was intended to strengthen participants' content knowledge. Partnered with hands-on learning experiences and active discourse, teachers expanded their understanding of engineering-content pedagogy. (A selection of videos and resources included during training is provided below.)

The facilitators of the professional development provided direct science-learning experiences that enabled study participants to integrate sample activities during instruction within their own classrooms. The renewable energy curriculum professional development supported the introduction of STEM concepts into elementary science and mathematics instruction. Teachers were provided pedagogical and content knowledge that enabled them to introduce concepts of engineering design through the use of hands-on inquiry-based activities. The facilitators challenged participants to make assumptions and predictions that drew on their personal experiences and knowledge of engineering design as they attempted to solve problems through real-world investigations. In that way, the teachers experienced learning activities similar to those which would be presented to their students as they themselves engaged in during engineering and design activities intended to expand their knowledge and understanding of these activities.

LEGO Education resource kits and accompanying professional development allowed participants to gain experience and knowledge through authentic hands-on applications. Participants took an active role in their own learning, forging a solid foundation in elementary-engineering pedagogy and engineering content-knowledge as they collaborated, planned, designed, constructed, and tested their creations. LEGO Education resources were selected for use in this study as they are aligned with the National Science Education (NSES) Standards, National Council of Teachers of Mathematics (NCTM) Standards, and the Next Generation Science Standards. Study facilitators provided participants with background information that prepared them to introduce and teach the topic of renewable energy to their students, expanding their engineering content knowledge and engineering pedagogical knowledge. This professional development was designed to enable participants to better facilitate student learning through active engagement in the learning process.

LEGO Education Materials

The LEGO Education materials within this study and the implementation of professional development were aligned with The National Research Council's (NRC) *A Framework for K-12 Science Education: Practices, Cross Cutting Concepts, and Core Ideas* (2012) for engineering. As provided below, the core tenets contained within the standards serve as the foundation on which the inquiry based learning afforded by the structure of the LEGO Renewable Energy professional development was built. This curriculum allowed teachers and students to better understand engineering practices as they designed and built models and systems based in real life applications.

Dimension 1: Engineering Practices

1. Asking questions (for science) and defining problems (for engineering): **Engineering** begins with a problem, need, or desire that suggests an engineering problem that needs to be solved. A societal problem such as reducing the nation's dependence on fossil fuels may engender a variety of engineering problems, such as designing more-efficient transportation systems, or alternative power-generation devices such as improved solar cells. Engineers ask questions to define the engineering problem, determine criteria for a successful solution, and identify constraints.

2. Developing and using models: **Engineering** makes use of models and simulations to analyze existing systems so as to see where flaws might occur or to test possible solutions to a new problem. Engineers also call on models of various sorts to test proposed systems and to recognize the strengths and limitations of their designs.

3. Planning and carrying out investigations: **Engineers** use investigation both to gain data essential for specifying design criteria or parameters, and to test their designs. Like scientists, engineers must identify relevant variables, decide how they will be measured, and collect data for analysis. Their investigations help them to identify how effective, efficient, and durable their designs may be under a range of conditions.

4. Analyzing and interpreting data: **Engineers** analyze data collected in the tests of their designs and investigations; that allows them to compare different solutions and determine how well each one meets specific design criteria—i.e., which design best solves the problem within the given constraints. Like scientists, engineers require a range of tools to identify the major patterns and interpret the results.

5. Using mathematics and computational thinking: In **engineering,** mathematical and computational representations of established relationships and principles are an integral part of design. For example, structural engineers create mathematically based analyses of designs to calculate whether they can stand up to the expected stresses of use, and if they can be completed within acceptable budgets. Moreover, simulations of designs provide an effective test bed for the development of designs and their improvement.

6. Constructing explanations (for science) and designing solutions (for engineering): **Engineering design,** a systematic process for solving engineering problems, is based on scientific knowledge and models of the material world.

7. Engaging in argument from evidence: In **engineering,** reasoning and argument are essential for finding the best possible solution to a problem. Engineers collaborate with their peers throughout the design process, with a critical stage being the selection of the most promising solution among a field of competing ideas. Engineers use systematic methods to compare alternatives, formulate evidence based on test data, make arguments from evidence to defend their conclusions, evaluate critically the ideas of others, and revise their designs in order to achieve the best solution to the problem at hand.

8. Obtaining, evaluating, and communicating information: **Engineers** cannot produce new or improved technologies if the advantages of their designs are not communicated clearly and persuasively. Engineers need to be able to express their ideas, orally and in writing, with the use of tables, graphs, drawings, or models and by engaging in extended discussions with peers.

Dimension 2: Crosscutting Concepts

1. *Patterns.* Observed patterns of forms and events guide organization and classification, and prompt questions about relationships and the factors that influence them.

2. *Cause and effect: mechanism and explanation*. Events have causes: sometimes simple, sometimes multifaceted. A major activity of science is investigating and explaining causal relationships, and the mechanisms by which they are mediated.

3. *Scale, proportion, and quantity.* In considering phenomena, it is critical to recognize what is relevant at different measures of size, time, and energy, and to recognize how changes in scale, proportion, or quantity affect a system's structure or performance.

4. *Systems and system models.* Defining the system under study—specifying its boundaries and making explicit a model of that system—provides tools for understanding and testing ideas that are applicable throughout science and engineering.

5. *Energy and matter: flows, cycles, and conservation.* Tracking fluxes of energy and matter into, out of, and within systems helps one understand the systems' possibilities and limitations.

6. *Structure and function.* The way in which an object or living thing is shaped, and its substructure, determine many of its properties and functions.

7. *Stability and change.* For natural and built systems alike, conditions of stability and determinants of rates of change or evolution of a system are critical elements of study.

The professional development offering will serve to provide participants with a theoretical lens by which to frame engineering knowledge and engineering pedagogical-content knowledge. To that end, the renewable energy curriculum resources interweave engineering practices, crosscutting concepts, and disciplinary core ideas as described by the National Research Council.

Figure 3.1 provides an overview of the professional-development intervention timeline for this study. The intervention was completed in the following steps. The researcher met with study participants prior to the intervention to explain the process, and answer questions presented by selected teachers. Additionally, the initial focus group interview took place during the teachers' scheduled professional-learning community time. Following the meeting, teachers were each assigned the task of completing the Teaching Engineering Self-Efficacy Survey. The initial step in the professional-development intervention program required study teachers to spend a full school day working with facilitators at a school approximately 30 miles from their home school. That experience was intended to provide them with theoretical and pedagogical knowledge deemed beneficial to the introduction of engineering within their classrooms. Teachers left that training with the understanding that they would be teaching elements of engineering the following day with their students. On the third day of the intervention sequence, a study facilitator spent an entire day at the study-school site, teaching classroom lessons within all three classrooms, in addition to devoting significant time meeting collectively and individually with study teachers to provide clarification, and answer questions. Though the timeline provided below formerly concluded five weeks from the beginning of the study in October, participating teachers extended their use of kits well into December with their students. Participants and study facilitators communicated with one another throughout the process, and worked closely together as research participants sought guidance and support with grant writing in their quest to acquire similar curriculum resources as those used during the professional development intervention and subsequent instruction.

Figure 3.1: Timeline for research design

Coverage	Date	Session	Time	Topic	Location
PLC Time	10/16	1	45-60 Focus Group Interview	Introductory meeting	Study School
NA	10/16-20	NA	15-20 minutes	Pre TESS Survey Completion	NA
Shared half day sub	10/27	2	45-60 Individual Interviews	Interview Protocol 1	Study School
Full day subs	10/28	3	Full Day	Overview/Engagement	Intervention Site
Full Day shared sub	10/29	4	30-60 Facilitator taught lessons with students	Potential/Kinetic Energy	Study School
			Individual time with facilitator	Lesson Debrief with facilitator	Study School
NA	10/30	5	30-60	Potential/Kinetic Energy	Study School
NA	10/31	6	45-90	Potential/Kinetic Energy	Study School
NA	11/3	7	30-60	Hand Generator	Study School
Shared half day sub	11/5	8	45-60	Modified Hand Generator	Study School
NA	11/6	9	45-60 Individual Interviews	Modified Hand Generator Interview Protocol 2	Study School
NA	11/7	10	45-60	Wind Energy	Study School
NA	11/12	11	45-60	Wind Energy	Study School
NA	11/13	12	45-60	Wind Energy	Study School
NA	11/14	13	45-60	Wind Energy	Study School
Shared half day sub	11/20	14	45-60 Individual Interviews	Interview Protocol 3	Study School
PLC Time	11/20	14	60 Focus Group Interview	Summary Focus Group	Study School
	11/24-12/6	NA	15-20 Survey	Post TESS Survey Completion	NA

Facilitators were available to answer questions and provide support as deemed necessary by participants. Session length are provided as a guide for anticipated duration of instruction . (Revised 10/14/14)

Methods to Collect and Analyze Research Data

Concurrent data collection strategies that included both qualitative and quantitative methodologies were conducted. Data were in the forms of: three in-depth interviews with each participant; pre- and post-intervention focus group interviews with participants; and an engineering self-efficacy scale completed at the outset and conclusion of the study by research participants.

Qualitative Data-Collection Methods

Individual Interviews

To elicit an understanding of the effect of individual teacher's professional development and engineering integration, qualitative interview data were collected for analysis. The data were collected prior to, during, and following professional development to assess teacher-reported changes in engineering-content knowledge and engineering-pedagogical-content knowledge . "At the root of in-depth interviewing is an interest in understanding the lived experience of other people and the meaning they make of that experience" (Seidman, 2013, p. 9). That format of data collection placed value in each participant's story and lived experience.

Using Seidman's interview protocol model, three individual interviews were completed with each study participant. The interviews occurred prior to exposure to professional development experiences, during the instructional segment, and following the completion of the renewable energy unit of study with students. Establishing a trusting and professional working relationship with research participants was of critical importance to collecting relevant information about the case over a relatively brief period of time. Each interview served a specific purpose as outlined in each interview guide.

Interview one was used to gather information focused on each participants' real-life history wherein "the interviewer's task is to put the participant's experience in context by asking him or her to tell as much as possible about him or herself in light of the topic up to the present time" (Seidman, 2013, p. 21). Interview two focused the conversation with participants on the lived experience afforded to them through the professional development being completed. Interview two sought details of the experience,, rather than participant opinions of the experience that were forged through the experience. Finally, interview three elicited participants' feedback that required them to reflect on the meaning of the professional-development experience. To that end, "the question of 'meaning' is not one of satisfaction or reward, although such issues may play a role in the participants' thinking. Rather it addresses the intellectual and emotional connections between the participants' work and life" (Seidman, 2013, p. 22).

The three-step interview process was completed over a six-week timeframe in the fall of 2014. All interviews were scheduled for approximately one hour in length, were completed at the participants' place of work, and were recorded by a digital audio recorder, as well as a smart-phone, for follow-up transcription, coding, and analysis.

Focus Group

Group process can be used as an insight-producing tool that enables participants to clarify their beliefs and feelings in ways that may not be captured in individual interviews (Creswell, 2009). Relatively structured in nature, focus group interviews serve a particular purpose that may guide the design of future interventions. This study included both pre- and post-intervention focus groups with study participants, and a post-intervention focus group with study facilitators. The conversations enabled the researcher to collect data from participants relevant to their perceptions of the intervention, and to work with colleagues and facilitators, and to answer clarifying questions from participants.

Methods to Analyze Qualitative Data

Data analysis in this qualitative research required close examination of data collected through participant interviews and associated artifacts, generally through an iterative process that moved from general to more specific observations. The researcher completed constant comparative analysis (Merriam, 2009) as data was collected, transcribed, reviewed, and discussed with study participants following transcription.

> Constant comparative methods involve comparing one segment of data with another to determine similarities and differences. Data are grouped together on a similar dimension. The dimension is tentatively given a name; it then becomes a category. The overall object is to identify patterns in the data. (Merriam, 2009, p.30)

The first stage of data analysis sought to ensure that the data were organized in a usable format given the vast quantity of information contained within the qualitative interviews.

> Although there is no right way to organize the research process and the materials it generates, every moment the researcher spends paying attention to order, labels, filing, and documentation at the beginning and in the formative stages of the study can save hours of frustration later. (Seidman, 2013, p. 115)

Informal data analysis began promptly once interviews were initiated, and continued throughout transcription. Transcription was completed following interviews by the lead researcher and the contracted services of Voice Base, a paid transcription-service provider. Following transcription, interview and focus group transcripts and other documents were coded employing an open-coding process to isolate patterns and categories. The process supported the development of themes and descriptions embedded in frequently used words contained in the data. “Coding is the process of organizing the material into chunks or segments of text bringing meaning to information” (Rossman & Rallis, 1998, p. 171 cited in Creswell, 2009, p. 186). Coding of that nature allowed the researcher to develop an image of the study setting, in addition to themes and categories for analysis as main ideas emerged as patterns. Themes emerge from close examination of patterns from quantitative survey-instrument data.

Quantitative Data-Collection Methods

The Teaching Engineering Self-Efficacy Scale (TESS) for K-12 Teachers survey tool was selected for this study as a tool to determine whether teachers had a positive reaction to professional development treatment, and sustained collaborative work with study facilitators and grade-level colleagues. The TESS survey was developed by Yoon et al, 2012, following an extensive review of literature on reported teacher self-efficacy, and review of more than ten major commonly used self-efficacy instruments including the Science Teaching Efficacy Belief Instrument(STEBI) and Bandura’s (2006) Teacher’s Self-Efficacy Scale which supported the development of the TESS. Though many self-efficacy instruments existed, one that measured teachers’ engineering self-efficacy was absent from the literature. As a means of correcting that deficiency, those researchers completed an exploratory factor analysis of data from 153 teachers to investigate survey items in an attempt to develop and validate the TESS instrument. (The TESS instrument can be found in the appendix.)

Utilizing the TESS survey instrument, data were collected on teacher-reported self- efficacy in the contexts of teaching engineering prior to and following a professional development intervention and subsequent instruction by all three study participants. The survey tool contained 41 Likert Scale items for participants to report their own perceptions of self-efficacy, allowing the collection of baseline data that informed qualitative data-collection methodologies. “Survey design provides a quantitative or numeric description of trends, attitudes, or opinions of a population by studying a sample of that population” (Creswell, 2009, p. 145). Pre- and post- survey data on teacher efficacy served to inform teacher change in engineering content knowledge, understanding, and engineering-content pedagogy.

Methods to Analyze Quantitative Data

In this study the quantitative data allowed the researcher to report descriptive statistics achieved through pre-test and post-test survey practices that resulted in statistical means, standard deviations, and variance in responses of the teachers who served as study participants. The statistical mean refers to the mean or average used to determine the central tendency of the data in question. It is determined by adding all the data points in a population and then dividing the total by the number of points. The resulting number is known as the mean or the average. Standard deviation is the measure of the variation of a set of data from its mean. The more spread apart the data, the higher the deviation. Standard deviation is calculated as the square root of variance. Finally, the variance is the measurement of the spread between numbers in a data set. The variance measures how far each number in the set is from the mean. Variance is calculated by taking the differences between each number in the set and the mean, squaring the differences (to make them positive) and dividing the sum of the squares by the number of values in the set.

The Teaching Engineering Self-Efficacy Scale for K-12 Teachers provided a framework that supported the analysis of dimensions of engineering self-efficacy. The 41 Likert Scale items were categorized into six factors or groupings, which were used in this study for deeper confirmatory analysis. The factors of self-efficacy are "engineering pedagogical-content knowledge , motivational, instructional, engagement, disciplinary, and outcome expectancy" (Yoon et al, 2012, p. 11). Using clustered information provided by the structure of the TESS, the dimensions of teacher self-efficacy with respect to engineering curriculum, assessment, and instruction could be analyzed. "When preparation of teachers occurs through in-service, pre-service, or professional development programs, the instrument allows researchers to examine how teachers initiate their own beliefs, attitudes, and behavior patterns in the beginning of the programs and shape them throughout the programs" (Yoon et al, 2012, p. 13). Changes in participant scoring on the TESS survey and individual dimensions reflect change in self-efficacy. The six dimensions or clusters of the TESS are found in Figure 3.2.

Figure 3.2: TESS Survey Dimensions

Teacher Engineering Self-efficacy Scale (TESS) for K-12 Teachers Developed by Yoon, Evans, and Strobel (2012)	
Dimensions	Item Numbers
Engineering Pedagogical-content knowledge Self-efficacy	1-17
Motivational Self-efficacy	18-20
Instructional Self-efficacy	21-25
Engagement Self-efficacy	26-29
Disciplinary Self-efficacy	30-35
Outcome Expectancy	36-41

Trustworthiness

In mixed-methods case-study research of this nature, the researcher takes steps "to check the validity of both the quantitative data and the accuracy of the qualitative findings" (Creswell, 2009, p. 219). To ensure the integrity of the research, verification and internal validation strategies are of critical importance to the study as the research strives to maintain accurate and credible data that is free from personal bias (Creswell, 2009). The researcher completed several procedural steps to ensure reliability of qualitative findings. Those included transcript review, member checking, and peer-debriefing of survey results to determine validity and reliability of quantitative findings. A weighted priority was given to the qualitative elements of the study as both data sources were collected concurrently.

Triangulation

For this study, multiple forms of data were collected and analyzed to assure trustworthiness through triangulation of data. Qualitative and quantitative data sources included participant interviews, focus group interviews, observations, field notes, survey responses, document analysis, member checking, and peer debriefing. Triangulation of data was used to ensure accuracy of findings using multiple perspectives to interpret a single set of data (Creswell, 2009). That process served to enhance trustworthiness, ultimately conveying to the audience of interest that the findings of the study are meaningful and warrant attention. To achieve trustworthiness, the researcher collected meaningful information until data saturation occurred. Once exhaustive data was collected, transcribed, and calculated, triangulation of data sources was completed. Triangulation allowed the researcher to seek convergence in meanings attained through those methods (Creswell, 2009). Throughout the process of collecting, analyzing, and interpreting meaningful data, findings were discussed with the participants in the study to establish credibility and ensure reliability. Continual and ongoing analysis of data allowed for reduction of materials that enabled the researcher to establish the significance of important themes that linked to larger theoretical and practical issues. Triangulation of data led to convergence of evidence that increased reliability through external observation and review (Yin, 2014). Data were interpreted through descriptive and interpretive approaches that allowed the researcher to show evidence that supported a clear, credible, and convincing argument of study findings (Merriam, 2009).

Specifically to this study, data triangulation provided an additional level of completeness, enhancing reliability and validity of results, strengthening the research design. Following the completion of three individual interviews with each study participant and focus group conversations, triangulation of data served to illuminate divergent dimensions of the phenomenon in question. Varying viewpoints produced elements that were counter to the findings gleaned from individual interviews. Differences realized through methodological triangulation served to strengthen the findings of the research study through attainment of diverse theories of the problem. To that end, triangulation of data enabled the examination of the research topic from a number of different perspectives and social realities.

Member Checking

Study participants were provided verbatim copies of transcribed interviews to validate content (Merriam, 2009). Through the process of member checking, also commonly referred to as respondent validation, the researcher provided relevant material from the study to participants who were the source of the material. The process did not include the sharing of findings.

At the conclusion of the study, member checking was broadened to provide a framework to test interpretations and conclusions. That served to increase the validity of the account. Member checking also established credibility as it provided an opportunity for participants to correct any misconceptions on the part of the researcher, and for the researcher to summarize findings. The final form of member checking took place following the completion of all individual and focus group interviews.

Limitations and Delimitations

Limitations: (1) This study was limited to three teacher participants in one school; therefore, findings may not be generalized. Findings are applicable only to those who deem them as relevant to their context(s). (2) The personal connection between the lead researcher and the school principal in the research setting may have presented issues of bias and subjectivity, given the professional working relationship they have developed through their doctoral programs of study. It was essential for the researcher to form a trusting relationship with study participants grounded in confidentiality and to create a barrier between them and their school administrator. (3) Additional limitations may have included necessary time to complete comprehensive case-study interviews given job-embedded responsibilities required of study participants; the teachers had limited time to complete the professional-development unit given the multitude of instructional demands they faced during the academic year. (4) The lead researcher was keenly interested in achieving measureable achievement progress, and providing sufficient resources for this initiative to be successful. (5) Throughout the duration of the study, it was important the lead researcher be mindful of checking his own biases.

Chapter Four

Findings

The purpose of this chapter is to present the findings from the qualitative and quantitative collection of data described in the previous chapter. The primary goal of this study was to examine the influence of a professional-development intervention to support educators in the integration of engineering in STEM (science technology, engineering, and mathematics) education at the elementary level. Existing research indicates that teachers' perceptions of high self-efficacy impact classroom dynamics between students and their teachers (Yoon et al, 2014). The analysis described in this chapter investigates teacher perceptions of their evolution of engineering self-efficacy, and how this experience resulted in perceptual change in content knowledge and pedagogical-content knowledge in engineering. Central to all nine individual interviews was the presence of increased confidence throughout the duration of the study.

Findings are presented in this chapter through the framing of each of the six sections of the Teaching Engineering Self-Efficacy Scale (TESS):

Section 1: Engineering Pedagogical-content knowledge Self-efficacy

Section 2: Motivational Self-efficacy

Section 3: Instructional Self-efficacy

Section 4: Engagement Self-efficacy

Section 5: Disciplinary Self-efficacy

Section 6: Outcome Expectancy

Those six sections comprise the first part of this chapter, providing quantitative findings of perceptual change through pre- and post-participant survey completion. Following quantitative data in each section, qualitative data collected through multiple interviews are then used to illustrate the teachers' perspectives on their self-efficacy related to each of the quantitative findings. The second part of this chapter presents findings pertaining to teacher beliefs in the form of qualitative interview data associated with professional development.

Qualitative data in the form of personal interviews were assigned to specific individuals whereas quantitative data, in the form of survey results, were assigned by the final four digits of each participant's social security number. Upon close examination, relative consistency in survey responses was present across participants with notable gains in individual and full-group self-efficacy ratings. Given that reality, findings are reported individually for identifiable qualitative data, and holistically for quantitative data. A similar format for sharing findings was used for each of the six TESS subcategories

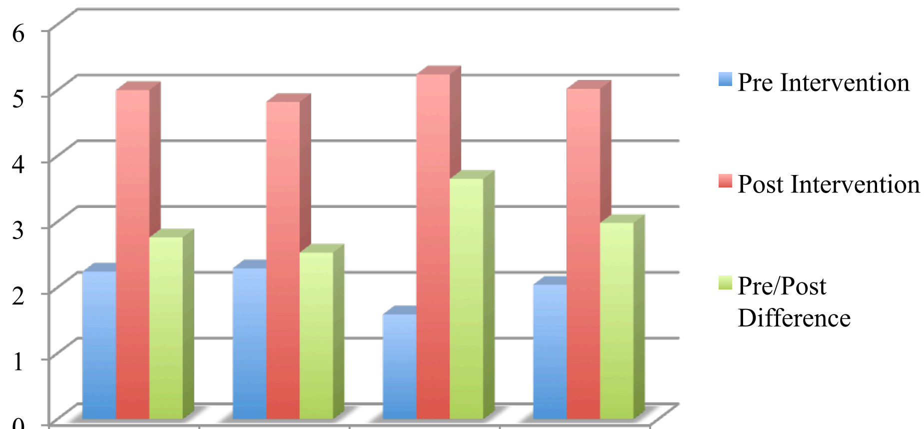
PART 1: Teaching Engineering Self-Efficacy

Engineering Pedagogical-Content Knowledge Self-Efficacy

Engineering pedagogical-content knowledge is a way of describing the knowledge possessed by expert teachers to articulate the core knowledge, skills, and dispositions that define instructional practice. Specific to this study, teaching engineering requires a teacher to draw upon not only subject matter knowledge, but just as importantly, the knowledge and skills inherent to engineering instruction (Hynes, 2007). Hynes (2007) extends that assertion in sharing that "in the case of engineering, pedagogical-content knowledge would include strategies to guide students through the engineering design process, create links from math, science, and engineering to contexts the students can relate to, and knowledge of students' misconceptions or ideas relating to engineering and the engineering design process" (p.39). Of importance to this study is the manner in which study participants' believed their engineering pedagogical-content knowledge evolved over the course of this study. All three teachers' engineering pedagogical-content knowledge self-efficacy increased over the course of this intervention study, as measured by respondent data on the TESS survey instrument.

The purpose of this section is to describe how teachers perceive their engineering pedagogical-content knowledge as they teach, explain, discuss, describe, and plan for engineering instruction with their students. Section 1 of the TESS Survey, Engineering Pedagogical-content knowledge self-efficacy, realized the greatest change in teacher reported gains in self-efficacy, with a total change in self-efficacy on the Likert Scale from a group mean of 2.04 to one of 5.02 for a total increase of 2.98 points. All three participants reported gains associated with each of the 17 items contained in this cluster of questions which asked respondents to gauge their ability to guide student learning and solution development with the engineering design process. Participant C (+3.65) expressed the greatest level of change in reported self-efficacy and participant B (+2.53) reported the least change as seen in Figure 4-1.

Figure 4.1: Individual Teachers' Engineering Pedagogical Content Knowledge Self-Efficacy



	A	B	C	ABC Average
Pre Intervention	2.24	2.29	1.59	2.04
Post Intervention	5	4.82	5.24	5.02
Pre/Post Difference	2.76	2.53	3.65	2.98

Engineering Pedagogical Content Knowledge Self-Efficacy
TESS Items 1-17

Pre Intervention	SD = 0.31885	Variance = 0.10167
Post Intervention	SD = 0.17205	Variance = 0.0296
Pre/Post Difference	SD = 0.48298	Variance = 0.23327

At the individual item level, item 12, "I can describe the process of engineering design." exhibited the greatest overall gain from 1.67 to 5.33 (+3.67) and item 9, "I can discuss how engineering is connected to my daily life." exhibited the least dramatic change from 3.33 to 5.33 (+2.0).

As the quantitative pre-intervention TESS survey results illustrate, participants did not consider themselves knowledgeable about K-12 engineering, and lacked high levels of engineering pedagogical-content knowledge self-efficacy at the outset of the study. Perceptions of low engineering pedagogical-content knowledge self-efficacy endorsed in the initial surveys were consistent with those shared during the first of three individual interviews by each study participant. Participants initially expressed limited background and awareness of engineering pedagogical-content knowledge given minimal or no formal training and experience with elementary level engineering. Abby initially shared that “I don’t know engineering. I don’t know about LEGOs and doing these builds.” She continued by sharing:

> I was never a science person. I was one of those kids who, I would just learn it. Eat up information. Take it as face value but I did not always think about the why’s and how’s of the connections. So for me, this has been eye opening…I was, you know, thinking to myself, oh yeah, that is how a bike gears work and to make that connection and apply it to what we are working on, it’s a whole different way of thinking.

The contents of each initial individual interview were similar in nature, and can be characterized by the comments shared by Abby as she indicated that she understood that there are “lots of different kinds of engineering.” But beyond that, her view of engineering instruction at the elementary level lacked depth and breadth related to the process of engineering design, and the impact engineers have on our daily lives. Similar to her colleagues, Abby viewed engineers as people who “have a problem and find ways to respond to the problem. Fixing a problem but other than that, I can't really define it.” When asked to define STEM, she shared that:

> I probably would tell them STEM would be science, technology, engineering and mathematics. Having some of kind of questions posed in those disciplines. There

> are problems, they have to come up with solutions and work together often to create and use different materials. Less is given to the kids. They kind of have to figure out more on their own through working together to solve those problems. I would hope they wouldn't ask me anything more.

Those descriptions were similar to those provided by Bea and Nancy. Specific to engineering, the concept of building items was the first thing that came to mind for all three participants when considering the work of engineers. Abby conveyed the belief that engineering is “the kind of kinesthetic part of building something to help solve a problem, to certain specifications, but kind of the building, and then re-designing, re-tooling, rebuilding.” Similarly, Bea shared that she too possessed a limited awareness of engineering pedagogical-content knowledge. As a participant in the study, she reported changes in the manner in which she viewed the introduction and integration of engineering at the elementary school level as a result of the experience:

> In terms of making engineering accessible for my students, it was never anything that I thought about for fifth grade students. In my mind, engineering was always like, a middle school or a high school, but seeing what they did throughout this unit really made me stop and think, wow, I really need to do more engineering-based activities for them because I can do it.

She openly acknowledged that “at first I was kind of apprehensive. I’m like, oh gosh, I don’t know enough about this. How am I going to know? What’s this going to entail? I don’t know anything about that and I was just so unsure. Not that I am an expert or anything at this point. I still have a ton to learn but I am energized and I am excited...” Bea then expanded her thinking associated with her perceptions of change as this work gave her “pause to want to integrate more engineering type activities into my instruction of science. I don't want to call it a Science Block anymore. I really want to call it a STEM Block because I want them to see the interconnection between all of the disciplines.” She then provided examples of evidence of her perception of growth in engineering pedagogical-content knowledge, and her beliefs about her work with engineering in the future. “I see it only growing from here. I mean that's pretty much what this experience has been for me. In a nut shell, just having the experience lends to the confidence which lends to overall learning for everyone, me and the students.”

Nancy shared similar comments about her perceptions of engineering during her initial interview. “I didn't necessarily feel prepared. Through this process, I am not as scared as I was. It's given me a level of comfort and I'm more curious of seeing the engagement of the kids and what we can do next.” During her final interview, Nancy’s perceptions of her understanding of engineering pedagogical-content knowledge reflected an evolution in her engineering pedagogical-content knowledge self-efficacy during the study. This work “Is pushing me in the right direction. I just need more experience, that's all… We want the kids to get more out of what we are teaching. I'm just really excited about where this will take us.” Those remarks were consistent with those shared by Abby.

Abby spoke in detail about change in her perception of engineering, and how those perceptional changes enhanced her thinking about the introduction of engineering-embedded instruction within her classroom. “It started off overwhelming, but getting our feet wet right away made it so that it’s very doable…Before, things were kind of murky about what the process was, not having any training or not having any real specifics on how to do engineering with our grade level.” The active emersion into engineering and design activities served to increase each participant's engineering pedagogical-content knowledge. All three participants shared comments similar to those provided by Abby. "It is something that even though I don't have personal experience in engineering, I can teach it. I can get the kids to think in that way." Abby continued by stating that

> I think, for me, it was sort of more about what engineers do and how I can relate that to kids and then getting them to think more in the broader mindset… think the biggest change is just understanding more about what engineering is and what engineers do. I've had some knowledge but not a whole lot before we started this whole experience… I know more about it and I feel more comfortable talking about it with kids.

As the comfort level of the participants grew, the level of ease in communicating with students about engineering and the work of engineers grew. As conveyed by Abby, change in engineering pedagogical-content knowledge was born from understanding and appreciating how engineering content can be incorporated within daily instruction.

> I think part of the biggest change is just realizing how doable it is for this age. You know when we first talked about this, I thought, engineering, for fifth grade, isn't that a little, like, later on, not something we need to think about now. Now that I realize more clearly what engineering really is. I realize it is very doable for this age or even lower. I think one, it's doable, and two, you know, it's something that we can easily put into the units that we already have existing to teach, get them to think, to design something.

Being able to draw on real world experiences forged a firm connection with content delivery for study participants. "Having the kids realize that it's broader than just you know, the step by step procedure. That there is real life examples that people do every day and improving, redesigning, and talking about it." Such ongoing dialogue with students served to enhance participant perceptions of gains in engineering pedagogical-content knowledge self-efficacy.

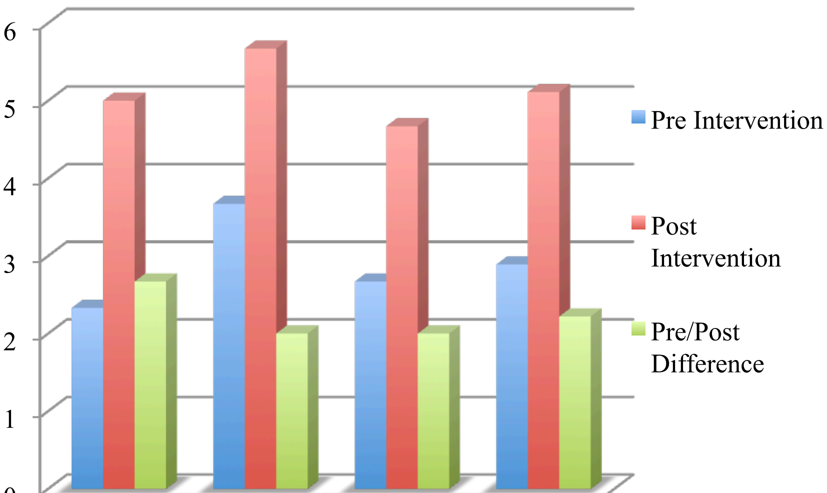
At the conclusion of the study, all three study participants shared their perceptions of growth in their understanding of engineering pedagogical-content knowledge and comfort with instruction in engineering. Nancy shared that "I definitely feel a lot more comfortable with it, and definitely the students' engagement in it sparked that passion again. The importance of having the kids get their hands on something, especially at this age. In a more general sense, feeling like I can try on new things with science." That thinking was consistent with that offered by Bea. "In a nut shell, just having the experience lends to the confidence which lends to overall learning for everyone, me and the students." Increased levels of confidence led to increased levels of buy-in to elementary engineering instruction on the part of participants. Abby asserted that "I've bought in, I'll say that. I bought in, my kids bought in. I have seen really good things for my kids and then I've seen not so good things that have been good teachable moments for them and through the whole process it seemed doable." She went further with her assessment of new learning, stating "I think the kind of the reflective at the end says that I changed my attitude about STEM education and engineering at this level and my ability to teach it because now I feel completely differently than I did at the very beginning." Similarly, for Nancy, that comfort level was associated with her first completing the builds that her students would experience, followed by "doing the work with students that led to natural conversations about engineering." Though initially very timid about being asked to complete a unit of study with her students grounded in engineering and design, Nancy expressed genuine appreciation and desire to include engineering concepts as part of her instructional day. “I'm not as afraid of it. You want me to teach what? I think, not that I was closed to it before but I'm just more open to embracing it. If it gets kids this excited, then I need to train myself and increase my knowledge so that I can bring it to them.” Nancy shared her conviction that this experience has “been really powerful, that, how do you make it better? This whole thing has just been a spark.” Finally, Abby’s summary comment on her perceptions of change in engineering pedagogical-content knowledge self-efficacy. “Now that we have had this experience, we've done this process we've seen engineering work for our grade level. We've seen the kids engagement and now I think it's easy to make that jump to how can we pose things in a different way to have the same kind of learning continue.” The teachers conveyed perceptions of increased student engagement that may have led to changes in their motivational self-efficacy.

Motivational Self-Efficacy

Motivational self-efficacy is the personal expectation or judgment concerning one's capability to execute courses of action required to attain desired outcomes. The degree to which teachers assess their levels of personal instructional self-efficacy in motivating and promoting learning positively impacts the learning environments they create, and the academic achievement realized by their students. Individual self-efficacy contributes to how people set goals for themselves, exert effort, work through challenges, and exhibit resiliency to failure (Bandura, 1993). Self-efficacy for a given task both influences and is influenced by performance on a task. Self-efficacy theory predicts that individuals work harder and longer when they judge themselves as capable to perform a task. Teachers with high levels of motivational self-efficacy believe that if they do a good job, students will be motivated by the instruction. All three teachers' motivational self-efficacy increased over the course of this intervention study.

The purpose of this section is to describe how teachers perceive their personal beliefs in their ability to motivate and increase student interest in learning engineering to facilitate student engagement through engineering activities. Section 2 of the TESS Survey, Motivational self-efficacy, realized change in teacher-reported gains in self-efficacy, with a total reported change in self-efficacy on the Likert Scale from 2.89 to 5.11 for a total increase of 2.22 points. All three participants reported gains associated with each of the three, items contained in the cluster of questions which asked respondents to assess their ability to motivate students with low interest in learning engineering, ability to increase student interest in engineering, and ability to create engineering activities that make students enjoy class more. Motivation and action are guided by forethought, and the belief about one's ability to anticipate likely outcomes of those actions (Bandura, 1993). Participant A (+2.67) expressed the greatest level of change in reported self-efficacy and participants B and C (+2.0) reported the least change in the area, as seen in Figure 4.2. Teachers exhibited gains in the area similar to the overall self-efficacy rating gains when compared to the collective data for items 1-41 on the TESS survey.

Figure 4.2: Individual Teachers' Motivational Self-Efficacy



	A	B	C	ABC Average
Pre Intervention	2.33	3.67	2.67	2.89
Post Intervention	5	5.67	4.67	5.11
Pre/Post Difference	2.67	2	2	2.22

Pre Intervention	SD = 0.56874	Variance = 0.32347
Post Intervention	SD = 0.41604	Variance = 0.17309
Pre/Post Difference	SD = 0.31584	Variance = 0.09976

At the individual item level, item 18, "I can motivate students who show less interest in learning engineering." exhibited the greatest overall gain from 2.33 to 5.33 (+3.00) and item 20, "Through engineering activities, I can make students enjoy class more." exhibited the least dramatic change from 3.33 to 5.00 (+1.67).

As the quantitative pre-intervention TESS survey results illustrate, participants initially rated themselves low in instructional strategies that would serve to motivate their students when completing instruction in engineering. All three of the study participants reported gains in the manner to which they were able to motivate students who commonly exhibit low interest during science instruction. Additionally, they reported increases in student interest in learning engineering through activities aimed at getting students to enjoy class more.

During our initial interviews, study participants expressed relevant concern with how best to engage reluctant learners, students who may float off task or appear disengaged, and girls who may express limited interest in engineering and design elements based on LEGO Education products. Study participants shared that students were motivated throughout the renewable energy unit. The motivation extended beyond the solitude of each individual classroom setting, as noted by Abby and endorsed by Bea and Nancy, as she discussed the value of having instruction being simultaneously completed in all three fifth-grade classrooms.

> That we were all doing it at the same time allowed it to be a more meaningful experience for the kids too because the kids could talk about it. Once they realized that it wasn't just their class doing the activities, I think that was big for the kids, that we are all doing this together. There is a power in that, you know, as well, so that we could enrich it and make it more meaningful. Then the kids could also continue to talk about it and make those connections outside of just our homeroom class.

Enhanced motivation achieved from the shared experience with the fifth-grade team was present in each of the classroom settings. In Bea's classroom, "They really started to find some success in building their models and some confidence that their designs were on target for what we were looking to do with some of those changes that we were making."

At the heart of good instruction is enhancing student motivation and excitement for learning. Nancy expressed the importance of this assumption to her work in stating:

> I think that that's one of my purposes of being an elementary school teacher is to build that excitement. So if we can do things in a meaningful way that the kids think is fun that they are allowed to move and get their hands on something and work with each other and solve problems together, that's going to be long-lasting. The knowledge that they gain, or just the experience way beyond just the science.

These words rang true as teachers shared the reality that students who routinely leave the classroom for specialized instruction were asking to remain in the classroom, expressing more enjoyment than during previous units of study. Abby shared that she has "kids who leave the room for different things and they don't want to leave the room because we're doing engineering and that's a big deal…I think keeping it focused on, you know, the engineering ideas and then energy gives it something that is very concrete for the kids to latch onto and think about and talk about." Nancy indicated that her students were very motivated from the start, which, in turn served as a motivation point for her work with them. "I'm excited about it. Kids are excited about it. I think it's really opened their eyes to some possibilities or just what the process is to create something or improve something." Student motivation, in Bea's eyes, could be readily observed as concepts were presented through hands-on applications that empowered students as they interacted with curriculum materials. "It makes it easy for them to want to be involved." That belief was consistent with those of Nancy and Abby who both conveyed that they were able to motivate their students and keep them engaged throughout the unit of study as their own confidence in their instruction grew.

That confidence enabled them to motivate the most reluctant of learners. Nancy expressed excitement in sharing about "One student, who was kind of a reluctant learner, very slow to finish anything. Wonderful, great kid. But oh, this is great, I love this, I love engineering, I want to be an engineer when I grow up and then another little girl who was helping all the groups with their connections." Each teacher was guiding her students as they took risks. Abby expressed pleasure in the manner in which her students were eager and motivated to complete whatever challenge she placed before them.

> That was nice for them to really discover on their own. The excitement that they have and then one of the things that's been nice is having certain kids that might not step up in the same way, step up…The kids really like it. It's hands on and they get to do a lot of activities and experiments. Parents saying how they have noticed their kids talking about it and some of the excitement that is building and maybe changes, like with this kid. He is really invested.

Bea expressed the importance of motivating those students who typically take a back seat to those students who frequently experience consistent success in the classroom or on the playing field. Through the unit of study, she observed several role reversals.

> We all have those students who excel at everything. They are good readers. Good math students. They're just good at everything...Everything always goes their way and then we always have those students who struggle with math, struggle with reading, and don't have a whole lot of social skills. Aren't as successful in school as some of the students. I saw a huge role reversal with some of my students in this process.

In Bea’s classroom, students “are just having a really good time and they are seeing themselves as engineers. They are loving learning…There is a lot of learning going on a lot of different levels…Letting those other students who don't feel as successful at school rise to the top and feel really successful about something, probably for the first time, in a long time, has been very positive.” Student motivation was believed to be built on fun. “Just letting them have a good time and they are learning. They are learning what they are supposed to be learning but it’s not the sit and get, where I'm just kind of droning on and on.” That increased level of motivation was also observed by Abby and Nancy in their work with students. In Abby’s classroom, she has “these kids who might not think that this is a strength, realize I can do this and I'm not giving up. I am going to do this by myself. That's been really cool to see that.” Similarly, for Nancy, “They are so excited about it. They really are working well in their groups.” In her classroom, students are expressing their motivation as they communicate how much they enjoyed working with the renewable energy materials that supported the introduction of engineering and design within the curriculum.

> The, I love engineering, this was great. I want to be an engineer when I grow up, you know that was wonderful. It's been interesting that different people took a leadership role than I thought would. That is really eye opening. I learned a lot about my kids through this…I don't have all the answers and to say, let's find that out together. I think it is good for them to know. You want them to have confidence in you as the teacher. That you know everything that you are supposed to but their, our world is changing so rapidly.

Similarly, Abby found that “They are thinking that way and improving. I have a lot of persistent kids in a lot of ways and I think this is a good, natural outlet for that. Like we're going to keep pushing and we're going to keep trying, and we're not going to let things go…They are being a very insistent on finishing and they are persevering. They are not giving up on these challenges.” The level of perseverance was not impeded by previous student disengagement.

Study participants expressed success in their abilities to motivate girls in their classrooms. When the study began, each participant expressed genuine concern related to how their girls might do with the unit of study, given that LEGOS are commonly viewed as toys used by boys. Those concerns were removed during the early stages of the unit of study. In Abby’s classroom several of her girls “initially were kind of hesitant. Now there is not hesitation in any of my girls. They are jumping right in. They are helping each other out and they are just all about it.” For Bea, “Having girls think about, wow, I could be an engineer. I might want to do more career exploration…talk about bringing professionals from the field of engineering and have discussions about what they do on a regular basis as part of their work. Having them being more aware.” To that end, Nancy conveyed the importance of motivating and inspiring girls to take interest in engineering.

> If we can excite our female students and get them excited too about traditionally male fields, that’s such a great part of our job, to inspire, encourage, and engage. I think that the kids see the relevance…and I had mentioned something about an electrical engineer and she's like, well that's what my father does. I said, oh, perfect. I think it made her feel just so valuable. Just seeing some different kids step up has been wonderful.

For Abby, “ Those will be the things that they remember, that they are able to connect back to or maybe be a springboard for interest for a later career, in this case, engineering.” For Bea, “now that we can introduce this at fifth-grade level is really exciting. To sort of get their minds percolating about future career options and new ways of thinking about the world around them.” All three teachers reported gains in motivational self-efficacy which enabled them to motivate their students with engineering activities, maintain student interest for the duration of those activities, and guide instruction in a manner that was enjoyable for their students. These teachers shared that as a result of student motivation, their level of instructional self-efficacy increased.

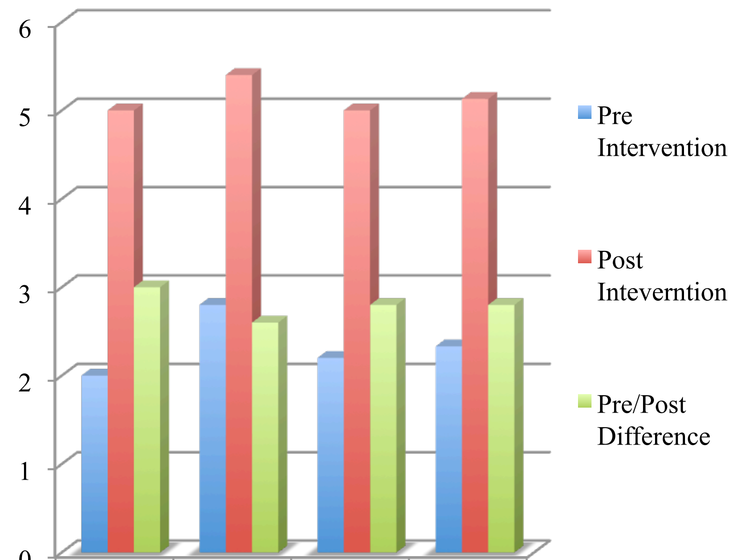
Instructional Self-Efficacy

Instructional self-efficacy is useful in guiding educational design and instructional practice as it offers explanations of how teachers’ beliefs about their ability to deliver instruction influences their effort. In the case of teaching elementary engineering, the teachers provided clear and realistic pictures of desired outcomes by assisting each student to gain an understanding of how to assess his or her own individual success. The transfer of skills was supported as the teachers assisted students in making connections between the tasks they were completing during instruction with similar tasks that they will undertake in their daily lives outside of the classroom.

The purpose of this section is to evaluate how teachers perceive their instructional self-efficacy as they employ assessment and instruction strategies aimed at gauging student comprehension of engineering and application of their engineering knowledge in real world situations. All three teachers’ instructional self-efficacy increased over the course of this intervention study as measured by TESS survey data. Section 3 of the

TESS Survey, Instructional self-efficacy, realized measureable change in teacher reported gains in self-efficacy with a total change in self-efficacy on the Likert Scale from 2.33 to 5.13 for a total increase of 2.8 points. All three participants reported gains associated with each of the five items contained in the cluster of questions which asked respondents to gauge their ability to plan, assign, and assess their instructional practices while teaching engineering. Participant A (+3.0) expressed the greatest level of change in reported self-efficacy and participant B (+2.6) reported the least change in this area as seen in Figure 4.3. Teachers exhibited gains in this area similar to the overall efficacy rating for the entire survey.

Figure 4.3: Individual Teachers' Instructional Self-Efficacy



	A	B	C	ABC Average
Pre Intervention	2	2.8	2.2	2.33
Post Inteverntion	5	5.4	5	5.13
Pre/Post Difference	3	2.6	2.8	2.8

Instructional Self-Efficacy
TESS Items 21-25

Pre Intervention	SD = 0.33993	Variance = 0.11556
Post Intervention	SD = 0.18856	Variance = 0.03556
Pre/Post Difference	SD = 0.1633	Variance = 0.02667

At the individual item level, Item 25, "I can help my students apply their engineering knowledge to real world situations." exhibited the greatest overall gain from 2.00 to 5.33 (+3.33) and Item 21, "I can use a variety of assessment strategies for teaching engineering." exhibited the least dramatic change from 2.66 to 4.66 (+2.00).

As the quantitative pre-intervention TESS survey results illustrate, participants' possessed limited knowledge of K-12 engineering instruction and low levels of instructional self-efficacy at the outset of this study. Perceptions of low instructional self-efficacy endorsed in the initial survey were consistent with teachers' verbal comments shared during the first of three individual interviews with participants. Participants initially expressed limited background and awareness of engineering instructional self-efficacy given minimal exposure to training deemed associated with the presentation of engineering related curriculum. Nancy's initial comments were consistent to those of her peers. "I really feel sometimes like I'm lacking. Sometimes I just feel like I'm one step ahead of the kids. What's nice is just the way that we are interacting in that I'm not just up at the board driving everything and telling them."

Though initially skeptical about their abilities to teach engineering and design to their students, each teacher expressed pleasure in knowing that she could present instruction in a powerful way to their students as the study concluded. Success with instruction was grounded first in the teachers' ability to organize students for learning. Grouping of students was critical to each classroom setting as articulated by Bea. "I really engineered the groups. I knew who would be successful working with other certain students. I was so careful in the way that I placed students together in their respective teams…I just think the careful grouping helped the girls feel successful." Once groups were soundly in place, instruction grew from the use of strategic questioning techniques which were born from Bea's own experience working with her colleagues and LEGO Renewable Energy curriculum materials. The materials were the same materials that study participants used during their work with students. Bea provided comments representative of those shared by her peers.

> I can teach them different ways to sort of get under it and look at it from a different perspective. It's been a long time since we've been ten years old. It's hard for us to sort of embed ourselves in their way of thinking and understand what they're struggling with so that we can better help them. I think that inquiry is a natural part of science. What do you need to learn? What do you need to figure out? I think it always starts with questions. I think that questions are a natural avenue toward inquiry. More importantly, it's having them get their hands on things and making sense of their learning on their own, constructing that meaning, through doing.

That "doing" required time and preparation on the part of all three teachers to support engaging instruction. During the initial days of instruction, gauging the time needed for each build was difficult for each teacher to sort through. For Abby,

> It definitely proved to me that I had planned less time than it really took, especially at first. What we found was that it was more of the, let's keep ourselves focused on the job at hand. The kids were like I want to play with all the stuff and I want to play with this car. I didn't really budget in enough time for that kind of experience when we were doing it. You know, time constraints, so that was my learning for myself was that I need to plan more time. I think allowing enough time because you know it is a different kind of learning. It's not I am going to tell you the answers and you retain it. We work toward the answer together. Sometimes I forget how long that takes…It's often easier to just give the answer

> and move on, instead of just saying, well, what do you think? Why would that be the case? I found myself doing that more and more with this unit, rather than just, okay, here is the answer, let's move on to the next thing. Just feeling like I can slow down a little. We can talk about it and make those big connections, those meaningful connections.

The time required to dig deeper into the content served to broaden student learning in Bea's classroom:

> We took moments to pause and say okay, so what worked last week when we were working together to build the pieces? What didn't work so well? What can we do today to make sure that it's fun and successful for everyone?"…In the past some of them didn't know what engineering was or had no clue what concepts related to engineering…Anytime you are talking about doing a change, it's a natural conversation for engineering because you have something that is already there, but you somehow make a change to make it better.

These natural conversations during instruction served to expand interest through active collaboration with their teachers. Similar to the comments shared by Abby and Bea, Nancy spoke about how the experience altered her view of instructional practice and ongoing communication with and among students.

> I don't have all the answers and to say, let's find that out together. I think that is one of my purposes of being an elementary school teacher is to build that excitement…We're actually working through these things together. We are working together. Our conversations are just that much, they're richer, as a result you know, I, I love it. I love how the kids are trying to, this isn't working, why

> not? You know, “have you checked your connections?” They are helping each other and they are getting a little frustrated but it's been such a great experience for the kids interacting with each other and for us…That really stepped up and you know, they would say, well, no, I disagree and this is why. They were really having some really good discussions. They were disagreeing politely. They were communicating clearly. You know, just some of the engagement by some of my students that are so disengaged.

That discourse during instruction enabled Bea to help her students apply their engineering knowledge to real world situations. The realization of the change was readily apparent to each teacher as articulated by Bea.

> My big a-ha, moment was just kind of stepping back a little bit and letting them figure it out on their own. That figuring out piece is what it's all about. It's not about me telling them what to do or how to do it. It's them sort of making sense of it…Children were asking me, does this look right? I was like, I don't know. I guess so. Did you follow the instructions? I was able to kind of push back a little bit and say, I don't know…I was really trying hard to not put my fingers on their work last week. I really just kind of wanted to put it back on them…We talked about how engineers, you know, things work fine, but engineers make it better. That whole process piece was really positive…You know, trying to give them different ways of thinking, not telling them how to think.

Those connections with real-world situations led to insightful conversations between teachers and students. In Abby’s classroom

> They were making those connections and talking about why they thought what they did because of their real world experiences and because of what they read…I think they've made some good connections with the material. They refer back to their experiences that they had doing the builds, which has been interesting…They bring back to the experiment that we've done. There was a lot of outside connections…Just more of a you know pose a problem rather than, you know, solve this hypothesis…How are the ways we can make this better? Having it be more open ended for the kids to brainstorm and experiment with materials that they might be able to use to solve that. Providing the materials and the framework to come to these understandings on their own. How do you think you can solve that and test it, design, and figure it out. Rather than do these steps that I'm guiding you towards the answer, kind of guide yourself there.

Serving as a guide during instruction provided an ignition point for each teacher. They were struck by their students' desires to engage with the renewable energy curriculum content and materials. Each teacher shared comments related to the "light bulb" moment during instruction when a student comprehends a new concept. Those experiences crystallized the learning experience for study participants. As described by Bea,

> You just see the light bulb come on and you are like, yes! It's those light bulb moments when they just all of the sudden figure something out…I just need to shut up sometimes and let my kids do the work, to put it bluntly. That really sometimes the best learning that they can have comes from them and not me telling them what they need to learn. That is probably my biggest learning…They are actually making meaning by what they are doing as opposed to me just going

> on…Really those connections that they're making are probably way more valuable than anything I could tell them. They are learning it for themselves. It's not like they're learning through me. They are learning through themselves. As I plan forward for the second and third trimester, keeping this in mind will definitely make me want to, think that wow, they are really engaged in this. What other activities can I do that would offer them the same level of engagement. Stepping away and letting them figure it out. Have some things that I usually do, but being aware of that now I can sort of play around with how I want to craft those lessons.

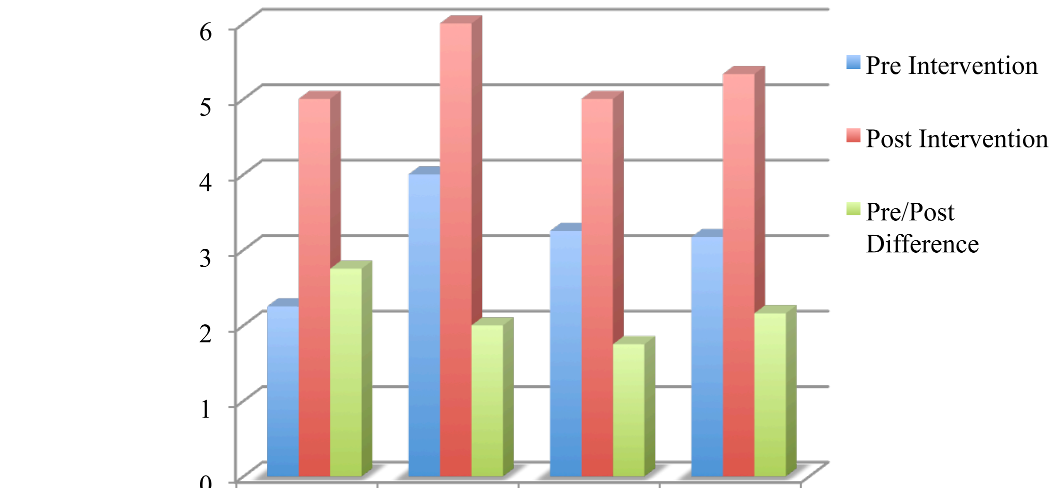
The "playing around" with lesson design by study participants reflects elements of teacher reported gains in the area of instructional self-efficacy. The manner in which teachers planned to craft new lessons was not readily evident, and how any newly crafted lessons would be structurally different is unknown. Participants were able to use a variety of assessment techniques during instruction, and were also more confident in their ability to create engineering lessons and deliver instruction in engineering. Through the process, teachers were able to help their students apply engineering knowledge to real-world situations, and think beyond the immediacy of daily instruction in engineering. The crafting of lessons that serve to ignite interest and enhance student engagement is central in importance to engagement self-efficacy.

Engagement Self-Efficacy

Teachers with a high degree of engagement self-efficacy are more likely to become actively engaged in the learning process because they believe that have some control of the outcome. Teachers with increased levels of self-efficacy are able to envision success that guides instruction and performance. To that end, the heart of engagement self-efficacy is a teacher's self-perceived ability and competence to encourage and enhance student learning during instruction. All three teachers' engagement self-efficacy increased over the course of this intervention study. It is difficult to tease out in greater detail the difference in elements of motivational self-efficacy and engagement self-efficacy as presented in TESS dimensions.

The purpose of this section is to evaluate how teachers perceive their abilities to promote positive attitudes toward engineering, and provide encouragement to students to think creatively and critically when practicing engineering. Section 4 of the TESS Survey, Engagement self-efficacy, realized the highest post-intervention teacher self-efficacy score on the Likert Scale at 5.33. That was due to a cluster change from 3.17 to 5.33 for a total increase of 2.17 points. All three participants reported gains associated with each of the four items contained in the cluster of questions, which asked respondents to gauge their ability to promote positive attitudes toward engineering as they encouraged students to interact with one another while participating in engineering activities. The gains were similar to the overall efficacy rating for the comprehensive TESS survey. Participant A (+2.75) expressed the greatest level of change in reported self-efficacy and participant C (+1.75) reported the least change in the area as seen in Figure 4.4.

Figure 4.4: Individual Teachers' Engagement Self-Efficacy



	A	B	C	ABC Average
Pre Intervention	2.25	4	3.25	3.17
Post Intervention	5	6	5	5.33
Pre/Post Difference	2.75	2	1.75	2.16

Engagement Self-Efficacy
TESS Items 26-29

Pre Intervention	SD = 0.71686	Variance = 0.51389
Post Intervention	SD = 0.4714	Variance = 0.22222
Pre/Post Difference	SD = 0.42492	Variance = 0.18056

At the individual item level, item 28, "I can encourage my students to think critically when practicing engineering." exhibited the greatest overall gain from 2.33 to 5.33 (+3.00) and item 26, "I can promote a positive attitude toward engineering learning in my students." exhibited the least dramatic change from 3.66 to 5.00 (+1.33).

As the quantitative pre-intervention TESS survey results illustrate, participants did not initially believe that they possessed high levels of engagement self-efficacy in K-

12 engineering. Perceptions of low engineering-engagement self-efficacy endorsed in the initial surveys were consistent with those shared during the first of three individual interviews with study participants. Participants initially expressed limited background and awareness of engineering engagement, given minimal or no formal training and experience with elementary level engineering.

At the heart of student engagement was the level of student interest in manipulating and interacting with the LEGO Education Renewable Energy curriculum materials. Student engagement was viewed as a function of student enjoyment first and foremost. Student interest enabled each teacher to encourage her students to think critically when practicing engineering, and promote positive attitudes toward engineering learning in their students.

In Abby's classroom,

> The kids liked it. They were able to connect with our conversation on potential and kinetic energy…I've noticed they're very possessive of their work. Other kids will come over and say, can I help, and they say no, I've got it. They are right in there. Having the kids say that they are proud of what they did. We did that first build with the jeep, one of my girls, they are just holding it and she did the hand crank and she was just playing with it. I looked at her and I was like, "feeling pretty proud of yourself right now?" She was like, "yeah I am feeling really proud of myself"…I can tell they're already feeling like experts. The writing that I've gotten is incredible, and I don't know if it's because they know that it's something they're going to work with, or if they are passionate about it now. They are really putting in all their effort.

This level of engagement and excitement for engineering was not unique to Abby's classroom. In Bea's classroom, "The kids are super excited. They just cannot wait until the time comes that we get to work on these. That engagement piece that comes from them being excited about it, I would say, is the biggest benefit." The benefit of engagement could be seen for the duration of the renewable energy unit as students exhibited interest in science at a deeper level. As shared by Bea,

> It's really nice to see them excited about science and about the process that we are going through to create the structures and have those experiments like with the hand crank…I do hear them get really excited when they talk about the modifications that they are making to their designs. It's embedding itself into an actual conversation. They are talking about it, and they are excited about it…It is opening up so many other doors and connections for them. I really feel like they've made some good connections in the class, watching them work in groups, and watching them problem solve together. It's enhanced their communication as well, working with their peers and just generating overall excitement for science.

Similarly, Nancy expressed relative joy in the degree to which her students were responding to the renewable energy unit.

> Just seeing them so excited. They want to be here. They want to do it. They want to work together. Just watching the kids work together and watching some of the kids, you know, like kind of wondering, how is this going to work. They are stepping up because it's a real challenge for them. This is something that they can touch. The hands-on is so important and we don't do enough of it…I think it's been so powerful. I had a student that came in the other day and said, "oh, you

> know, so and so was at my house and we were looking through this book and look what we found. It was the world's largest wind turbine in Scotland and the blades were as long as a jetliner. They are on the lookout for these things now.

The level of critical and creative thinking in present in Abby's classroom is consistent with that present in Bea and Nancy's classrooms. "I think one of the things that I've noticed with them is there has been more conversations about the big ideas, the process, you know, why, reasoning." The dialogue has been heavily driven by a thirst for improvement on the part of students.

> That's been a big part…The other thing that I've noticed with the kids a lot is they want to do the improving and keep improving. I'm sure that if I wanted to keep just one activity, it could be a whole week, because they just wanted to keep designing and re designing. They weren't ready to move on to the next thing because a lot of kids have that improvement mentality…Kids are very curious about it. It's applicable to real life and their future. I think for the kids, seeing that their faces, it's that light bulb moment. This is natural for them to design and improve. Some of the kids have said they've gone home and talked about it.

As findings from pre- and post-TESS surveys and interviews with study participants reflect, all three teachers reported gains in their perceptions of their level of engineering engagement self-efficacy. Those findings indicate that teachers believe that they were able to promote positive attitudes toward engineering, and were able to encourage their students to think creatively during engineering activities and lessons. Study participants indicated that engaging their students during instruction was of little challenge. The greater challenge for teachers was how best to manage the level of student engagement, which at times necessitated redirection.

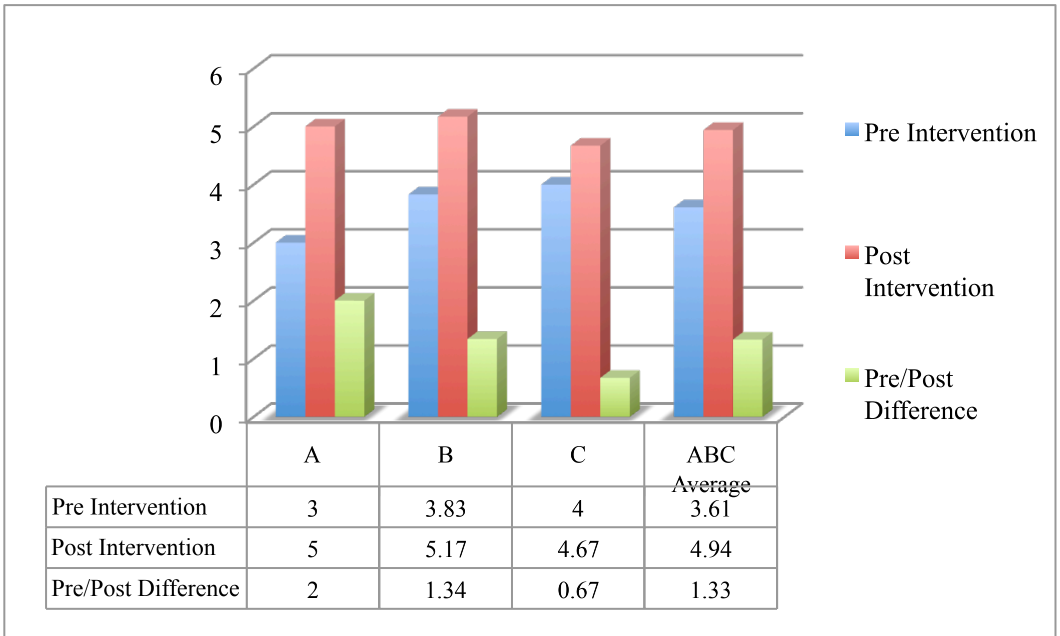
The described level of excitement on the part of students during the unit necessitated a closer examination of classroom management practices in each of the three classrooms in question.

Disciplinary Self-Efficacy

Teachers' level of disciplinary self-efficacy has been linked to their classroom behavior and practices. Teachers skilled in disciplinary self-efficacy are more likely to instill positive student attitudes towards instruction. Thus teachers may feel more efficacious when their students are doing well, and conversely, students do well when teachers feel more efficacious about their instructional practice. All three teachers' disciplinary self-efficacy increased over the course of this intervention study.

The essential purpose of this section is to evaluate how teachers perceive their disciplinary self-efficacy as they control, redirect, and engage students with behavioral challenges while teaching engineering. Section 5 of the TESS Survey, Disciplinary self-efficacy, realized the least measureable change in teacher-reported gains in self-efficacy with a total change in self-efficacy on the Likert Scale from 3.61 to 4.94 for a total increase of 1.33 points. All three participants reported gains associated with each of the six items contained in the cluster of questions that asked respondents to gauge their ability to establish a classroom management system for use during engineering activities and lessons. Teacher-reported disciplinary self-efficacy gains were lower than that realized for the collective gains achieved for the entire TESS survey. Participant A (+2.0) expressed the greatest level of change in reported self-efficacy and participant C (+.67) reported the least change in this area as seen in Figure 4.5.

Figure 4.5: Individual Teachers' Discipline Self-Efficacy



Discipline Self-Efficacy
TESS Items 30-35

Pre Intervention	SD = 0.43688	Variance = 0.19087
Post Intervention	SD = 0.20758	Variance = 0.04309
Pre/Post Difference	SD = 0.54298	Variance = 0.29482

At the individual-item level, Item 30, “I can control disruptive behavior in my classroom during engineering activities.” exhibited the greatest overall gain from 3.67 to 5.33 (+1.67) and Item 34, “I can get through to students with behavior problems while teaching engineering.” exhibited the least dramatic change from 3.67 to 4.67 (+1.00).

As the quantitative pre-intervention TESS survey results illustrate, participants initially considered themselves proficient in the area of discipline self-efficacy during instruction in engineering, as there is minimal difference in engineering discipline self-efficacy and general classroom management. Disciplinary self-efficacy had less to do with engineering, and ultimately more to do with inquiry-based learning and the fact that the materials were new to both students and staff. Those perceptions were consistent with those shared during the first of three individual interviews with study participants. Participants initially expressed a sufficient background and awareness of engineering discipline self-efficacy given their years of teaching experience. With respect to behavioral management while teaching engineering, each teacher expressed a level of relative concern with respect to unique behavioral challenges existent in their classroom settings. Those initial feelings of concern were shared by Bea as she stated that:

> My only concern is that I have a few [students with] behavioral challenges in my room. That is the only thing I'm really nervous about when we introduce the kits. It's that they won't take any instruction. They will just see them as toys and want to play with them and totally not listen to anything that's going on. That's my only trepidation that I have going forward.

That trepidation was also felt by Abby as she considered initial planning for the unit. “I think that's going to be a part where we have to really think a lot about how to group them. There is definitely going to be some of those behavior things that we are going to have to talk about and work about."

Each participant conveyed the importance of continual reminders of the behavioral expectations they held for students during the renewable energy unit. The prompts afforded teachers the opportunity to highlight for their students relative successes and areas of need of improvement, serving to guide the classroom management practices in each setting. In Bea's classroom,

> Having a few moments to talk to the class beforehand, I feel saved us a few problems that may have cropped up later on. Like it was about talking, communicating, and taking turns and not hogging the pieces and making sure the work was divided fairly. That way everybody has an ownership in the piece. If something does go wrong it's not like its one person's fault that there was an error, a design flaw. Everyone has a role to play. I felt that really helpful, to do that.

Attaining and maintaining that level of focus was deemed challenging at times for all teachers as their students elected to veer from desired tasks. In Abby's classroom. students

> want to build other things and they've created all these things that are connected. So it's, it's been kind of a blurred line with me in terms of what I let fly and what I don't let fly for my behavior management of these kids. That's been kind of not necessarily a struggle, but that's been more of the back and forth…What we found was that it was more of the, let's keep ourselves focused on the job at hand. The kids were like I want to play with all the stuff and I want to play with this car… Just those basic management, that is really the biggest thing and that was my

> biggest fear going into this. I knew I could catch up on the science, the lingo. But just the management, we are still struggling with that because it's that attitude of well, I know what I'm doing. I don't need to listen, I'm just going to keep working. She's not talking to me when she says stop for directions. Getting that in place from the very beginning, I think was very helpful for management and setting up that expectation right away… There also has been a lot more conversations about not doing what you're supposed to be doing, and not working in a group effectively because they're just so excited!...The behavior management's really been the big one. I think the girls have been more focused.

For Nancy, the struggle was how best to blend student excitement and predetermined classroom expectations. That struggle was found to be of greater concern for boys than girls.

> Classroom management I think is tough. They are so excited and it's just the little things, like, noticing that the one child is kind of hogging it because they think they are a little LEGO expert. Making sure that everybody is participating and feels comfortable to jump in…I'm always just so aware of the noise, but it's good noise because it's energized and excited and you don't want to crush that. The boys thought they were all experts at the beginning and then they learned that the girls were just as good, if not better in some cases. I found that it was more of my girls that wanted to know what, this was what I got, but this doesn't make sense. You know, they were challenging the results and then wanted to know why they really wanted that depth. The boys were just happy to, okay, this is what we got, let's move on, what's the next build?

As shared by Bea, “Managing that ahead of time helped save me time on the end.” As shared by Abby, “the behavior management has really been the big one…I have a lot of kids who have plenty of experience with LEGOs. So for them, it is very difficult to see them as separate from what I do at home and what I do now.”

As findings from pre- and post-TESS surveys and interviews with study participants reflect, all three teachers reported gains in their perceptions of their level of engineering disciplinary self-efficacy. Those findings indicate that teachers believe that they were able to control disruptive behavior, redirect defiant students, and establish a classroom management system for engineering activities and lessons. With the presence of reminders and review of expectations embedded within natural instruction, teachers were able to navigate the inherent challenges a teacher faces when working with materials that many students view as toys, not learning instruments.

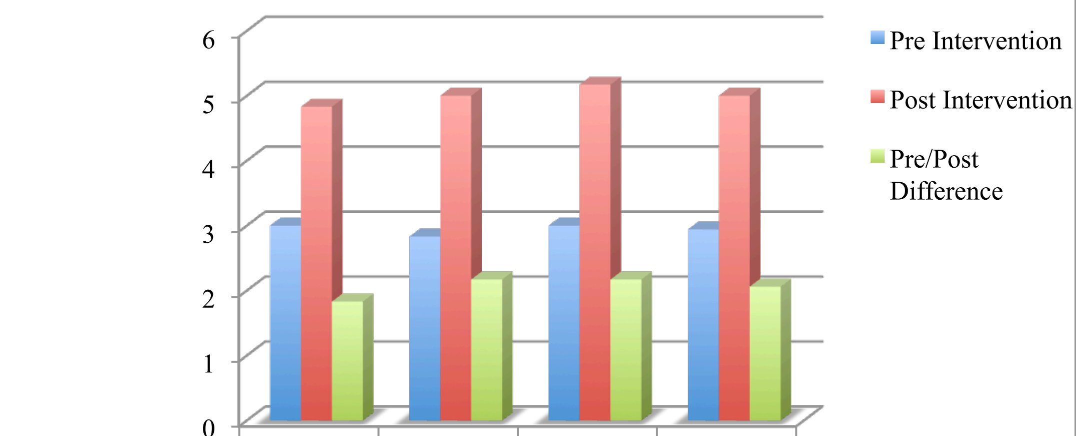
Outcome Expectancy

Outcome expectancy is a person's expectations about the consequences of an action, and the likelihood of one’s behavior leading to a specific outcome. The power of outcome expectancy rests in one’s self-belief and capability to achieve a desired task (Bandura, 1993). Similarly, instructional performance is directly aligned with a teacher’s perceptions of self-efficacy. As teachers achieve desired outcomes in the form of performance, measureable levels of self-efficacy are increased. Through that process, a teacher’s self-efficacy evolves and develops (Yoon et al, 2014). Over the course of this study, all three teachers’ engineering outcome expectancy increased.

The essential purpose of this section is to assess how teachers perceive their responsibilities, impacts, and effectiveness in teaching engineering to their students.

Section 6 of the TESS Survey, Outcome Expectancy**,** realized change in teacher-reported gains in self-efficacy with a total change in self-efficacy on the Likert Scale from 2.94 to 5.00, for a total increase of 2.06 points. All three participants reported gains associated with each of the six items contained in the cluster of questions, which asked respondents to gauge their effort and responsibility for their students' competence in engineering similar to that achieved on the entire TESS survey. Participants B and C (+2.17) expressed the greatest level of change in reported self-efficacy, and participant A (+1.83) reported the least change in this area as seen in Figure 4.6.

Figure 4.6: Individual Teachers' Outcome Expectancy



	A	B	C	ABC Average
Pre Intervention	3	2.83	3	2.94
Post Intervention	4.83	5	5.17	5
Pre/Post Difference	1.83	2.17	2.17	2.06

Outcome Expectancy
TESS Items 36-41

Pre Intervention	SD = 0.08014	Variance = 0.00642
Post Intervention	SD = 0.1388	Variance = 0.01927
Pre/Post Difference	SD = 0.16028	Variance = 0.02569

At the individual item level, item 36, “I am generally responsible for my students’ achievement in engineering.” exhibited the greatest overall gain from 2.00 to 4.67 (+2.67) and items 37 “When my students do better than usual in engineering, it is often because I exerted a little extra effort.” and 40, “If I increase my effort in engineering teaching, I see a significant change in students’ engineering achievement.” exhibited the least dramatic change from 3.00 to 4.67 (+1.67) and 3.33 to 5.00 (+1.67) respectfully.

As the quantitative pre-intervention TESS survey results illustrate, participants initially endorsed solidly average levels of engineering-outcome expectancy. Those perceptions endorsed in the initial surveys were consistent with those shared during the first of three individual interviews with study participants. Participants initially expressed moderate levels of engineering-outcome expectancy .given minimal or no formal training and experience with elementary-level engineering, but several years of individual teaching experience from which to draw.

Each teacher expressed ownership in student achievement in engineering, and in her responsibility to ensure that students would do well with the renewable energy unit. Though initially unfamiliar with K-12 engineering instruction, participants believed that their effort in teaching engineering concepts would lead to change in students’ engineering achievement. For Abby, that outcome expectancy was associated with her own effort and learning experience with the renewable energy kits that required her to think like a student during professional development. Through this experience, she indicated that she could increase her students’ achievement in engineering.

> The kids really learned a lot and I felt that it was something that was meaningful for them. It felt good for them to understand that this was applicable to their real lives… I feel like that has helped our kids too because I've actually been able to give them some pointers about my experience. It's not to take away from their experiences but, with the wind turbine, I got overconfident and I kind of rushed. I was able to say to the kids that this happened to me when I was doing it. Don't let yourselves fall into that same trap, be careful, work together, and talk to each other…They are doing better than I thought they would initially about realizing that this is a vehicle for science and not just toys… Just seeing the kids' reaction when they went through the steps. They did all these activities to see, this is a lot more broad and I can do this. I can talk with the students in this way. I can teach them this, through a real-life step-by-step process, rather than something that might seem foreign or just too prescribed to be authentic…I have a whole new take on science and how we can teach that knowing what engineering really is and how I can make that accessible to fifth graders has been very crucial. I think that going forward with other units that I can, without a whole lot work, revamp them to have it be similar in style…I feel a lot more confident…I can take on science challenges, I did it. I had a lot of help and guidance, but, you know, I have taken on, you know, a pretty big challenge in a short amount of time and the kids have been pretty successful."

That success in learning at the teacher level, and consequently the student level, was also experienced by Bea. For Bea, her effort with outcome expectancy was based on her own experiences, and the reality of an unknown future: one that extends well beyond simply learning about engineering but more importantly the overall impact of her efforts with STEM education.

> I really think STEM is a good thing because I realize I'm not really training my students for a specific job. I can only train them with habits of mind where they will be successful in any number of careers that will open up. Because it is quite possible that the job that they will be doing doesn't even exist right now… The giving them the tools and letting them think. So, that is to me what STEM is about…I know that it is a good thing and that we should be doing it. We definitely could spend more time working on it…My favorite thing is when they think something's going to happen and then something completely different happens. Anything that’s just keeping them going, and they have to work together to figure it out. I think that's another part of it…I have some students talk about their parents being an engineer, and even, not to sound sexist but to have the girls see themselves as engineers and seeing engineering as a career path for them as well. Children that may not feel successful in a whole lot of other academic realms, finding success in this, is probably, one of the biggest bonuses that I've seen…I'm feeling like I don't need to really be in control of all that because sometimes the students are actually well more versed in it now than I am. I'm just kind of letting the students take over. It's been a learning for me. I've been able to like step back a little bit and not be so high strung about it…In terms of being a teacher of engineering, I always knew what engineering was. I understood the concept behind what engineering is but I never felt as though I was a teacher of engineering. I never felt like it was a fifth grade thing. With the Next Generation

> Science Standards and all of the STEM education that's coming down the pike, we really should be figuring out a way that we can embed this into our instruction. I actually feel a lot more confident now and competent in being able to bring engineering into my classroom and sharing it with my students as a result of this project.

That enhanced competence with instruction shared by Bea aligned with Nancy's educational philosophy for her work as an elementary teacher, and her beliefs about her responsibility for her students' competence in engineering. Nancy's level of effort in planning for and presenting lessons in engineering teaching were believed to lead to change in student achievement.

> I think one of our jobs as elementary school teachers is to create an excitement to learn, you know, providing opportunities. It's really an exposure, laying a foundation, and creating that excitement…So for me, it's like the aha moment was just being allowed to have the time to explore and to see the engagement. I need to do more stuff like this. I need to find a way to make it happen. It's not going to just happen, I need to drive it. I need to find a way to do it…That's going to help keep me focused on this as well because that piece is more the questioning and the discussion. I will be thinking about it and trying to find ways to incorporate it. I don't know what that is yet."

For Nancy in particular, the experience elevated her perceptions of engineering outcome-expectancy grounded in her efforts to learn the curriculum, and then present it to her students. "This process built that confidence and you know, through what the experiences that the children had gained, it just enhanced my experience. Their engagement has created my engagement that I would want to carry this forward and have a long-lasting effect for me as well as the knowledge for the kids." All three study participants did indicate that continued effective professional development will enhance their ability to integrate new subject matter necessary to enhance outcome expectancy in their classrooms. Study participants endorse the belief that they are responsible for their students' achievement in engineering, and their effectiveness in engineering teaching can influence the achievement of their students.

PART 2: Professional Development

During individual and focus group interviews with study participants, the concept of professional development was of central importance. Study participants expressed the importance of professional development to their work. That importance was grounded in the notion that professional development is vital to advancement efforts of the profession, and the learning needs of instructional staff as they seek to educate students. The comments shared by teachers reflect current research in best practices related to professional development: (1) active learning by participants; (2) coherence in professional development activities; (3) duration of contact time with professional development; and (4) collective participation in professional development activities (Yoon, Duncan, Lee, Scarloss, & Shapley, 2007; Guskey & Yoon, 2009; Guskey, 1986; Desimone, 2009; Darling-Hammond & McLaughlin, 1995; Singh & McMillan, 2002; Bowgren & Sever, 2010; Borko & Putnam, 1996; and Nadelson et al, 2012). Additionally, study participants shared a fifth theme not readily found in current research on professional development: focus on the instructional needs of teachers. The following sections will present findings of teacher responses that align with those themes.

Active Learning by Participants

The first theme gleaned from participant interviews was the belief that effective professional development is focused on providing authentic engagement of participants through active learning experiences. Active learning is defined as “an educational process where students become vigorously engaged in assimilating material being taught rather than absorbing it passively in a lecture format (Businessdictionary.com). Through active learning Bea was able to think like her students:

> it's been a long time since we've been ten years old. It's hard for us to sort of embed ourselves in their way of thinking and, and understand what they're struggling with so that we can better help them. I think any professional development like that where we're working together and doing exactly what we're expecting our students to do would benefit us and the students in the long run…We were doing hands-on stuff that we would expect our students to do. That kind of professional development I think is when I'm doing exactly what I would expect my students to do. How am I going to anticipate problems that they may have if I haven't necessarily had the chance to work through it on my own…I definitely think the best professional development is, I mean it's just me doing what I'm expecting my students to do…Having us construct the models. Having us follow the instructions as written. Having us sort of get a chance to anticipate maybe what struggles our students may have with the constructions. I found that to be incredibly helpful…In terms of making that a reality, is being given the time to play ourselves…I think anytime you can put yourselves in the shoes of someone else, you're going to learn something.

Similarly, active engagement through this study enabled Abby to play the role of student, which served to support her own learning style. She found value in being forced to complete similar tasks as those completed by her students during the professional development intervention experience.. Her experience enabled her to better consider the unique challenges and learning needs of her students during instruction, largely based on her own lived experience with the instructional materials.

> Just giving us the chance to build and try things out on our own to have ideas of what worked and what didn't work. Those specific management and visual things for the kids to look at were helpful…It made it more realistic to see someone teaching, to see someone doing the instruction that we were going to be doing. Being there to actually see what was happening, I think that's very powerful. If you are teaching something, going into someone else's room and seeing them instruct their kids. It's not a general vague overview that you're being taught, it is something you can see it in action. That is super meaningful for me to be able to take it into my own room or modify it in my own way to make it something that I can do…As we've all seen, being able to have time to learn from people who've done it -and experiment hands on has really helped us to integrate it into our own teaching and curriculum…So we were like the students getting that inquiry experience, and not really knowing what was going to happen or why. We could really do that ourselves, to really know what our kids are going to do and having that time to be able do that.

Being immersed in active learning was viewed as an opportunity to extend these concepts into other curriculum areas. “Just getting us actually, maybe it would be more appropriate to say kind of forcing us, into trying this out and learning something new has made it so that we can extend it into other things that we do."

Similarly, Nancy expressed the benefit achieved through hands on collaborative work with her colleagues during professional development. She related her own experience completing builds with her peers, given how she learns best. For Nancy, professional development that requires increased levels of participant participation is deemed most helpful to her own learning.

> You kind of need to work through it together. You can have all these great ideas but until you are in it, you don't know everything that is going to come up. You can try to anticipate but you can't…When you just sit and watch and you don't do. I need to do. I need to try. I need to explore. Just sitting and watching and just absorbing…I can't just absorb all this information. I need to think about it, play with it, sift through it, before I can apply it. Sometimes those are a little overwhelming. Try as you might to pay attention and take down all these notes and then you go and look at your notes a week later and they don't make any sense…I loved working with the LEGO's and I loved working with a partner to do that…You know, exploring together, having questions, trying to figure them out together. It's just been such good practice.

As shared by all three teachers, the presence of active learning during professional development enabled them to increase their confidence in their ability to teach engineering concepts within the classroom. The view that active learning experiences, utilizing materials similar to those used by their students, allowed for discourse with colleagues, and resulted in a firmer understanding and appreciation of the struggles that their students might experience.

Coherence in Professional Development Activities

The second theme shared by study participants was the importance of coherence in professional-development activities. Coherence concerns the ways in which such activities encourage professional communication among teachers who are engaged in efforts to reform their teaching in relatively similar ways. Coherence enables ongoing discussion among teachers who confront similar issues to facilitate change by encouraging the sharing of solutions to problems, as well as reinforcing the sense that, with time, improvement is possible (Garet et al, 2001). Participants shared that curriculum programs are routinely changed, and policy requirements in the form of mandatory training greatly impede professional-development efforts, as there is often little time to communicate with colleagues about practice. It was shared that an abundance of requirements have led to disjointed planning as teachers are commonly gearing up for the future at the expense of today. As shared by Abby, “Sometimes it's so far in advance, like it's something we are going to be doing or maybe something that may not apply to all grade levels or all kids that we work with…Things I don't see as feasible with either age level or with abilities of students. I think things that I know that my kids wouldn't enjoy.”

For Nancy, coherence in professional development has much to do with the creation of a structured feedback loop ,or time to debrief with colleagues, following completed professional development. An example of that structure was shared when Nancy and her colleagues returned to their classrooms and did “with our class and then we went back and discussed how it went and learned some new things…you know, problem solve together and try it again the next week…We want the kids to get more out of what we are teaching…Sometimes you just need to know where your resources are, or where to get those answers. As far as my colleagues, it's that beginning." The greatest challenge to coherence in professional development for Nancy is "just so many initiatives that there is only some much time in a day…You know you are at home and you are falling asleep and then you have these thoughts pop into your head…you are thinking about it constantly, but you are thinking about all these random things." Bea shared similar challenges with the coherence in professional development.

For Bea, the primary obstacle to coherence in professional development is the manner in which offerings are presented to teachers. She conveyed the feeling that "sometimes we feel like professional development is done to us, and not for us and with us. Just like they are asking us to engage our students, we should be asked to be engaged in the process as well. We can only give what we have. I think the more we buy into it, or the more experience we have, the better it is going to be for our students in the long run." To achieve increased "buy-in" on the part of teachers for new initiatives and associated professional development, teachers benefit from opportunities to work together. For Bea, "there was so much more power in having us all of us do it at the same time and we are trying to convey that in grant writing too…We sort of professionally feed off one another, but I also think it is beneficial for our students also…The more we buy into it or the more experience we have, the better it is going to be for our students in the long run."

This experience for Abby enhanced her conversations with colleagues about what is possible in their work. Teachers were engaged in ongoing discussion that enabled increased coherence in instruction across classrooms. “Now that we have had this experience. We’ve done this process. We have seen engineering work for our grade level. We have seen the kids’ engagement. Now I think it is easy to make that jump to how can we pose things in a different way to have the same kind of learning continue.” This sort of learning with colleagues led Abby to share that

> The power of confidence is crucial. Sometimes professional development is just a one shot deal and you are supposed to get everything figured out in that one time and are not necessarily told that it's going to be implemented right away. It is like this is professional development for next year thing that you are going to do. So, at the least for me, I say, I don't need to worry about next year right now, I need to worry about this year.

All three teachers expressed the belief that successful professional-development offerings are those that place value on the importance of communication among educators as they confront similar issues. Each teacher shared examples of relevant challenges educators face when professional development lacks coherence and opportunities for discussion about practice and implementation. The primary challenge to coherence in professional development as viewed by study participants is the sheer number of initiatives that they are being asked to implement.

Duration of Professional Development

The third theme shared by study participants was the value of professional development work that took place over an extended period of time, as opposed to one-hit workshops, or simply covering a topic based on using available time on scheduled workshop or early release days. Several research studies have found that there is significant variability in duration and intensity of professional-development activities provided to instructional staff (Yoon, Duncan, Lee, Scarloss, & Shapley, 2007; Guskey & Yoon, 2009; Guskey, 1986; Desimone, 2009; Darling-Hammond & McLaughlin, 1995; Singh & McMillan, 2002; Bowgren & Sever, 2010; Borko & Putnam, 1996; Nadelson et al, 2012). Those studies acknowledge that to realize the benefit of professional-development experiences, activities must take place over an extended period of time. The participants in this study indicated that they have participated in a varied assortment of experiences intended to improve their instructional practice, ranging in focus, quality, and duration. Abby shared that “Usually there's professional development days or half days with in-service kind of focusing on aspects of it…The least beneficial are things like I said that's kind of like one time. We are going to talk about it once. We are never going to talk about it again.” Similarly, Bea expressed a high degree of concern associated with the limited time devoted to deep learning on the part of instructional staff.

> Time is always just the biggest factor. When we do have professional-development days, there is usually already an agenda set for us, and there is very little flex for us to practice doing some experiments that we're going to eventually ask our students to do. I just think that is probably the biggest stumbling block that we would face at this point… I think the instructional time piece is huge. Finding the time or the platform for that to be successful could be a challenge.

The lack of time devoted to specific needs also resonated with Nancy. “To find the time to be able to discuss everything thoroughly. It's more, you know, there's just too much going on. I think we do have our conversations. We don't have the time to just sit down and talk about one thing at a time.”

The limitations associated with time needed for extended learning through instructional conversations about practice with colleagues was a frustration point for participants. Following workshops they found valuable, they rarely had time to deepen their connections with new learning with their peers immediately following the experience, given other demands placed on their time. As shared by Abby,

> I've been to great professional development, but there's not time to really digest it at that moment. Then it just ends up being something, I have on my to-do list, but I never get to it because there's so many other things. Spending time specifically talking and thinking with my colleagues about how we can use this and planning out is super beneficial. Having a chance to plan with it, and not just being thrown and say do this or do what you will with it… I would say the things that give you time to either talk about or plan out specifically how to use it in your classroom.

Time to digest and plan with colleagues was viewed as a remedy to those challenges. Each participant shared her perceptions of the value that was realized through this experience as they were provided uninterrupted time with colleagues both offsite and within their school to discuss curriculum, assessment, and instruction aligned with the renewable energy unit. Nancy summarized those thoughts as she shared,

> It's almost like you need time, like an offsite or something to just kind of go and think and talk with your friends or your fellow teachers to come up with a plan. I think that's the only way it's really going to happen…It's that time piece again. It's being mindful of the time and giving the time. It's hard being out of the classroom to attend these things. But then again, you can't do too much before school and after school because you need to be respectful that your teachers have their own

> personal lives. You can just take a day and go off site and call it good. I don't know where to find that time. I don't know what the answer is but to me, more focused time for us to sit and talk and maybe explore together.

All three participants expressed the belief that time is a critical component to effective professional development. They were in agreement that professional development that affords educators the ability to work together over an extended period of time has been beneficial to their work with children. Those professional development experiences, which provided ongoing dialogue with colleagues, were commonly viewed as most valuable to their work, and were seen as must-dos; procedural, or one-time events were collectively viewed as least helpful. Unique to this study, participants shared the value of completing work with colleagues and facilitators over a relatively extended period of time of suitable duration to support the acquisition of content knowledge in engineering.

Collective Participation in Professional-Development Activities

The fourth theme shared by study participants was the value added through collective participation in professional-development activities. Participants expressed support in favor of those activities that required high levels of collective participation and collaboration on the part of participants. Such collaboration enabled deeper levels of connections with one another, and with students. As shared by Abby, “I think it's made more of a collaborative environment with all this talking since we got to do what they are doing and can really identify with that.” Similarly, Nancy expressed her belief that “You need to kind of work through it together. You can have all these great ideas but until you're in it, you don't know everything that's going to come up. You can try to anticipate it, but you can't." This anticipation of the unanticipated was placed in check as each teacher had colleagues and professional development facilitators to turn to throughout the experience.

For Abby, collective participation provided a framework that strengthened the work being completed through active discourse.

> Starting with colleagues, I think it's helped us get kind of hit the ground running a little bit with planning in common. You know, like common experiences, sharing resources, kind of opening up that dialogue to work as a team together because we are all new to this. It's something we are all undertaking at the same, so that's created the feeling of you know, commonality. Let's share. Let's help each other out in the process. Some of that is with the supplies and then also what are we going to do to enrich this activity with our other curriculum areas with reading and the writing and that sort of a thing.

For Bea, "That collaboration piece, even though it may not have been embedded initially, I think it's just a really nice natural benefit that's coming out of this because just having that other professional that we can talk to about it. Likewise, I mean we can learn from each other. The synergy is exciting." Similarly for Nancy, the experience of working closely with colleagues was very eye opening.

> I just think that knowing that I was in this with the two of you, it was powerful. I knew I wasn't in it alone. I have people to go to and ask questions. Have you tried this yet? And knowing that you were experiencing the same things. It was huge for me. If you couldn't answer a question that I didn't know, I didn't feel quite so bad. There is always comfort in having a group, being part of that group. There is

> a safety in that, which I think allowed me to feel more comfortable exploring, trying and making errors. That it was okay, I didn't need to be perfect right from the get go… I found that was great because I got to try it. We'd talk about it. Discuss it. You know, problem solve together and then go back and try it again the next week. I really enjoyed that and just meeting with just the diversity of teachers. It was kind of nice to have that too when we're talking about the different levels and what they would encounter.

Conversations of that nature took time initially to evolve among Abby, Bea and Nancy. That was in part due to scheduling time for this work, as well as them not fully comprehending how best to work together. The challenges were short lived as students and staff began to realize the value of the unit. With increased buy-in, the need to plan for the future led to planning conversations. As shared by Bea,

> I think initially, we sort of had a hard time connecting collegially to discuss the process and the instruction. Just trying to be more cognizant of it, of late, to try to talk about it. Especially since we sat down last week to get some grant writing for the project, that led itself, to a conversation about what we've been doing, how we're feeling about it, and how we feel it's benefiting our students and us as teachers. Stretching our own thinking about STEM instruction.

Nancy summarized the professional development experience working with her colleagues and study facilitators detailing the value of collaboration, time, and hands-on learning.

> I thought it was well done. We had our agenda. I think having time to reflect is big. To discuss with your peers…I think both Mike and Stephanie were very

> approachable. I felt very comfortable if I wanted to ask a question. You know, I think that we put pressure on ourselves that we should know the answers to this stuff, but they made it perfectly comfortable when we didn't. I loved working with a partner to do that. I thought that was very helpful as well. We were all very excited on the way home…How powerful has this been to even make a connection with another elementary school? This is what you're doing, oh, my goodness. This is great. You know and then just to take that back, just even the idea back. You don't even know the amazing things that are out there that people are doing. Time to meet and to have more discussions and to build off each other. Just spreading the word, you know, that could be powerful.

Through such collective participation, study participants were able to collaborate with colleagues, enabling deeper levels of connections with one another and with students. Each participant spoke to the power of collective participation by their entire grade-level instructional team, and all fifth graders in their building. Through collective participation, they were able to leverage the interests of students across their grade level who were discussing beyond their classroom walls with fellow students and caregivers. Those conversations were also present on the part of staff members with one another, with building and district level colleagues, and also with caregivers.

Instructional Needs of Teachers

The fifth theme gleaned from participant interviews was the belief that effective professional development is keenly focused on the instructional needs of teachers. Initial comments from study participants were heavily devoted to the perceived lack of focus on the professional needs of teachers present in much of the staff development they have participated in during their professional careers. For Nancy, professional development "is something that is not always done well. We don't have a lot of time to explore before we have to implement with children. That's kind of always been my feeling. Kind of like, okay, just give me the materials and let me muddle through" with minimal focus. That negative perception of the professional development held by study participants was born from the belief that professional development is commonly viewed as a task that school leaders simply need to check off a list, not one that addresses current realities impacting the work of teachers. For study participants, the need for focused professional development has been the exception rather than the rule. As shared by Abby, "Being able to really say, this information we're going to use in this way. We are going to put time into it because it's important. Not just talk about it for a couple hours and then never come back to it again. That repeated exposure to the same content is really important as well." Similarly, for Bea, professional development if often misaligned with the needs of teachers.

> Well I don't care what you've been doing this is what you are doing now…
> Like it had already been determined that this was our new program and then they said, oh, well here's something. We just didn't feel like there was enough of a 360 support around that…Sometimes I feel, and I don't want to speak for you, but I feel like there's a date on the calendar like oh, we have an early release day on January whatever, what are we going to do? Oh let's just do this, because we got to fill that time. I feel like sometimes, they are really not thinking about what our professional needs are, let alone differentiation. We are expected to teach in a certain way, but yet our professional development looks different. If we are

> talking about differentiation for our students we should, at the very least, be talking about differentiation for our staff as well because our professional development is not one size fits all.

For Nancy, focus on professional development is about “the needs of the teacher or the person. It needs to be immediate. It needs to be timely…more focused time for us to sit and talk and explore together.” That focus on professional development was also viewed by Nancy as a powerful tool in supporting embedded work within the classroom. “If we can do it in our class, with our kids or during the normal part of our day somehow. I think anytime that it's extra, it's still valuable, but it becomes a little more of a burden because there are other things that you have to do as part of your day duty.” Limitations with focus and the needs of teachers was also shared by Abby as she conveyed her preferred delivery method of professional development intended to support her professional work:

> I need to worry about right now and that kind of stuff isn't always useful because it's not repeated practice, repeated exposure to build that confidence. Whereas in this case, all right we're doing this today you're starting tomorrow and this is the chance for you to learn for the next few weeks. This is what you're going to be expected to do, which, you know, that timeline and having it be immediate. I think for me helped me kind of focus in. Repeating what I did and we learned every day for a few weeks, that all, it built the confidence.

Comments of that nature reflect the lived experiences of all three study participants. They each expressed the importance of providing professional development experiences that align with the instructional needs of staff. The findings of this study reflect that for these particular teachers, professional development has been viewed as a "one size fits all." The findings of this study suggest the importance of aligning professional development intended to improve instruction with the instructional needs of teachers.

Summary

This chapter examined notable findings that were considered in the context of this study. The results of the study revealed the level of teacher perceptions of self-efficacy and the impact that a professional development experience had on those perceptions. All three study participants reported gains in all six sections of the Teaching Engineering Self-Efficacy Scale. Pre- and post-TESS survey results reflect teacher-perceptions of measureable improvement in their engineering pedagogical-content knowledge, following a professional-development experience and subsequent presentation of an instructional unit in engineering. Those gains were consistent with findings from interviews with study participants that reflect perceived gains in confidence in their abilities to teach engineering concepts in their grade-five classrooms. Chapter Five discusses the relationship between study participants' teaching engineering self-efficacy ratings and completed professional development and instructional unit completion in further detail.

Chapter Five

Conclusions and Implications

The purpose of this mixed-methods research study was to address the following research questions following intervention professional development: (1) How do teacher perceptions of engineering self-efficacy evolve during implementation of an instructional unit in engineering? and (2) What is the relationship between a professional-development intervention in engineering on teacher perceptions of their content knowledge and pedagogical-content knowledge in engineering? Data to answer the above research questions were gathered through teacher interviews, focus-group interviews, and pre- and post-intervention survey results from the Teaching Engineering Self-Efficacy (TESS) protocol developed by Yoon, Evans, & Strobel (2012). Review of qualitative interview data revealed five themes associated with teachers perceptions of professional development: (1) the benefit of active learning for participants; (2) the importance of coherence in professional development activities; (3) the value added when professional-development activities occur over an extended period of time; (4) the importance of collective participation with peers; and (5) focus on the instructional needs of teachers. Additionally, quantitative TESS Survey data revealed teachers reported gains in:

- Engineering Pedagogical-content knowledge Self-Efficacy
- Motivational Self-Efficacy
- Instructional Self-Efficacy
- Engagement Self-Efficacy
- Disciplinary Self-Efficacy
- Outcome Expectancy

This chapter provides a discussion of the findings associated with these questions as presented in Chapter 4. This chapter summarizes the findings of this study, connects those findings to existing literature, and then identifies the limitations of the research, and how this study may inform the direction of future research. Finally, it concludes with a discussion of the implications of this work on the design and implementation of engineering curriculum at the elementary level. This study supports the notion that when teachers participate in professional-development offerings that embed the aforementioned components into the PD experience, teachers report gains in perceived self-efficacy. The study questioned whether: (1) Teacher practice can change in a relatively limited time through structured professional development?; (2) Leading teachers through a structured curriculum that requires collaboration and reflection with colleagues alters their perceptions of self-efficacy; (3) The manner in which content is delivered to teachers through professional development can increase their perceptions of gains in content knowledge? Conclusions related to those questions are discussed in greater detail in the following sections. The conclusions are followed by discussion of implications on educational policy, instructional practice, and future research.

Research Question 1

How do teacher perceptions of engineering self-efficacy evolve during implementation of an instructional unit in engineering?

As described in chapter 2, previous research completed on teacher self-efficacy suggests that teacher reports of increased levels of self-efficacy have been found to be associated with improved instructional practice (Bandura, 1993; Yoon et al, 2012). Findings of this study reflect that teachers reported gains in all six sections of the

Teaching Engineering Self-Efficacy Survey (TESS), and reported through interviews that their personal levels of engineering pedagogical content knowledge grew throughout the duration of the study. Teachers attributed increased confidence and ability to teach engineering in their classrooms to interactions they were having with one another and facilitators of the professional development they attended. Teachers reported self-efficacy was associated with their individual and collective willingness to let student ideas diverge from a predetermined path during instruction with the renewable energy materials. Teachers shared that their initial focus on students' following specific instructions supported the reality that they initially lacked confidence in how each model build should look. As time progressed, teachers shared that they were more inclined to allow students' ideas to evolve as they provided guidance during instruction.

With added experience, teachers applied an incremental view of engineering within their classrooms. Each teacher emphasized the importance of refining the design activities being completed. As teachers gained comfort, they were no longer asking their students to follow instructions as a means of coming up with solutions. They simply provided prompts and guidance necessary to encourage their students to evaluate their builds. The teachers also supported their students as they made design changes based on their own appraisals of these builds. Evidence from the intervention observations and interviews show that self-efficacy and engineering-design knowledge evolve over time, and may be connected to their influence on teaching approaches. Initial survey results may reflect the challenge of integrating engineering into elementary grade-levels where teachers have a greater responsibility to provide instruction in a wide array of curriculum areas.

All three teachers reported that they were invested in listening to their students' ideas, employing active demonstrations, and were actively helping their students connect with engineering content. All three teachers shared the belief that their expanded knowledge and understanding of teaching engineering concepts contributed to their abilities to view tasks through the eyes of their students. As they supported their students, they expressed their abilities to assess their own knowledge and understanding of engineering concepts. That process enabled each teacher to learn and deepen her knowledge of engineering content while teaching, as their students presented new and unanticipated ideas that required them to check their own understandings.

At the conclusion of the study, teachers reported that they not only enjoyed the experience, but also had increased their levels of confidence in their abilities to expand their instructional practices following the unit of instruction. They openly acknowledged that they lacked formal training or knowledge of elementary-level engineering prior to participating in this study. During the final focus-group conversation they shared that it was very beneficial working so closely with colleagues for an extended period of time. They also reported that ongoing support from one another and professional development facilitators allowed them to take greater risks with instruction, which served to increase their confidence and reduce fears of failure. Those assertions from study participants suggest gains in engineering self-efficacy. Though gains were found in all six subsections of the TESS survey, teacher gains varied among the sections, and by individual. By looking closer at the six sections of the TESS survey, a few assumptions may be drawn.

Teacher responses on the TESS survey found that they had gains in all areas of engineering self-efficacy, with a few notable areas of considerable gain. Collected qualitative and quantitative data indicate that study participants expressed the beliefs that their self-efficacy and confidence in engineering pedagogical-content knowledge, self-efficacy, and instructional self-efficacy exhibited the greatest measureable gains. The researcher believes that those findings may be in large part due to limited prior knowledge of elementary engineering, and no previous instructional practice associated with elementary-level engineering. Through the course of this study, all three teachers reported that they better understood the curriculum, were better prepared to deliver instruction, and were able to assess student learning while teaching engineering. This researcher anticipated that these two areas of engineering self-efficacy would realize the greatest gains. Conversely, participants reported the least degree of engineering self-efficacy evolution in the area of disciplinary self-efficacy. This researcher believes that those data reflect the reality that they were three experienced educators who possess a wealth of experience managing student behavior in their daily work. The results were anticipated by this researcher for the aforementioned reason.

Research Question 2

What is the relationship between a professional development intervention in engineering on teacher perceptions of their content knowledge and pedagogical-content knowledge in engineering?

This study suggests that teachers can develop approaches to teaching engineering concepts in their own classrooms. As engineering in K-12 education evolves in public schools, additional research is needed to better understand what professional-development experiences will be most effective in supporting teacher development necessary to implement engineering instruction at that level. A change will necessitate the need for professional development that aligns with science and engineering frameworks (NRC, 2012) and a commitment to teaching engineering content at the elementary level (NGSS, 2013). As provided in chapter 2, research is very consistent when it comes to quality professional development intended to elevate professional practice within the classroom setting. Whether one looks to Guskey (2002), Desimone (2009), Darling-Hammond et al (2009), Yoon et al (2007) or other researchers cited in this research and beyond, elements of active learning, coherence, duration, and collective participation are commonly viewed as cornerstones of effective professional development.

Conclusion Related to Theme #1: Active Learning for Participants

Each study participant expressed the importance of, and value added to, professional development that required them to authentically engage with the materials they would be using in their own practice with students. Through active engagement, they shared how this experience enabled them to grasp concepts that prepared them to teach their students problem solving and engineering through-real world applications that they themselves worked through during training. All three teachers believed that participation in hands-on learning activities provided them tools and strategies that supported their efforts in connecting engineering educational theories with instructional practices.

The benefit of active learning for study participants was grounded in the initial work with study facilitators. That facilitation of learning required all three teachers to assume the role of student during professional development. The teachers thought that experience armed them with first-hand experience, which enabled them to encourage students to discover on their own, similar to the teachers' own training with colleagues. .

Research participants reported that the subsequent shift from student to facilitator allowed them to realize learning gains for their students, while also gaining meaning from the experience themselves.

Teachers shared that they gained experience through exposure to the materials that prepared them to pin-point, analyze, and communicate design flaws through a guiding hand with their students. Through active participation with materials, teachers expressed the belief that they were able to readily observe a variety of possible solutions for design- and build-problems, whereas initially they seemed to fixate on one solution they thought would solve the problem being investigated.

Conclusion Related to Theme 2: Coherence in Professional Development Activities

As cited in the research, there is value in coherence in professional-development activities (Desimone, 2010). Data from individual and focus group interviews indicate that teachers felt that much of the professional development they received was misaligned with their daily work with students and colleagues. Area of greatest concern shared by all three teachers was the belief that a great deal of professional development can be fit into the category of needs-improvement. Through ongoing conversations they each shared that their own experience with professional development lacked sustained focus and cohesion. Each teacher expressed concern associated with professional-development initiatives that were commonly viewed as one-size-fits-all or flavor-of-the-day offerings. Similarly, they each spoke about how the scope and sequence of professional development often lacked direction, as reform efforts brought with them continual change in curriculum and instructional programs. Each teacher shared her beliefs on the beneficial impact of increased and sustained conversation with colleagues, which in turn increases coherence in professional-development activities.

Conclusion Related to Theme 3: Duration of Professional Development Experience

Research on effective professional development clearly indicates that professional development that takes place over an extended period of time achieves greater results than that which provides a lesser degree of contact time for and among participants (Desimone, 2010; Guskey, 1986; Guskey, 2002; Guskey, 2003; Guskey & Yoon, 2009). The findings of this research are consistent with previous research. All three participants found their experiences beneficial to their professional growth as they worked along their peers over an extended period of time. As supported by research, and conveyed during individual and focus group conversations, time to “muddle” through together and learn together was viewed as a critical ingredient for success by each participant of the study.

Conclusion Related to Theme 4: Collective Participation with Peers

Current research suggests that when staff development provides collective participation by participants, acquisition of new knowledge and conceptual understanding is increased (Guskey & Yoon, 2009; Guskey, 1986; Desimone, 2009; and Darling-Hammond & McLaughlin, 1995). As found in this research, study participants expressed how valuable their time spent working with their colleagues was to their learning. They reported that they were able to learn effective strategies and techniques through a shared experience alongside peers. Working collaboratively through constructive critique, feedback, and reflection, was reported as helpful to their work in learning engineering content. All three teachers shared that they were turning to one another for support when they encountered challenges when completing instruction with students. Through collective participation, teachers shared that they were willing to take greater risks as working with colleagues increased their confidence. Though they did not specifically use the words "self-efficacy," self-described gains in confidence likely resulted in reported gains in each teacher's self-efficacy beliefs in teaching engineering concepts. Collegiality among staff members at the building level was cited as a major support for continued learning among teachers. Findings from this research study suggest that collective participation in professional development with peers leads to greater outcomes of professional development activities.

Conclusion Related to Theme 5: Focus on Instructional Needs of Teachers

The results of this study indicate that professional development that is keenly focused on the instructional needs of teachers most beneficial to the work of research participants. All three teachers shared during individual and focus group conversations that many of the professional-development activities provided to them neglect to consider their unique needs, or those of their colleagues. They each reported frustration with the planning and implementation process of professional development. In sharing their perceptions of good and bad professional development, the critical component to "good" was the focus on teachers' needs achieved through "differentiation" in offerings. This research recommends that an accurate appraisal of staff needs be completed prior to scheduling and implementing professional development intended to support teacher learning.

Implications

Though this study was completed with a small group of elementary teachers, the results of the research are promising for the introduction of engineering at the elementary level. The introduction of engineering at the elementary level will require system-level changes in the manner in which we provide professional development in engineering content to teachers (Rogers & Portsmore, 2004). Survey and interview data indicate that the participants, who initially exhibited relatively low levels of self-efficacy beliefs about teaching engineering in their classrooms, evolved considerably over the duration of this study. No participant had ever formally tried teaching engineering concepts prior to the study. They willingly participated in the study, given the realization of increased pressure on elementary public school teachers to integrate engineering in their classrooms. Time spent with colleagues, engagement of students, and available resources were reported to be the most crucial factor in the development of positive self-efficacy beliefs and approaches to teaching engineering cited by study participants. That openness to learn enabled them to create activities and lead instruction with students in unfamiliar content, which they deemed successful

This researcher found that many variables can potentially impact a teacher's self-efficacy in teaching engineering, knowledge of engineering, and approaches to teaching engineering. This study provides a glimpse into the dynamics that impact professional-development activities intended to support teachers attempting to integrate elements of engineering in their classrooms. The recent push to infuse engineering in K-12 education requires a clear focus on the instructional needs of teachers, and time for them to work with colleagues. As found in this research, time and focus were reported as essential to the evolution of these teachers' engineering self-efficacy. An active and ongoing investment in the form of time and resources necessary to prepare teachers is essential to effectively provide quality instruction in engineering. This study suggests that elementary engineering-instruction can be achieved if teachers are provided professional-development activities that result in a deeper understanding of engineering content-knowledge and pedagogy. That deeper understanding will likely lead to gains in teachers' engineering-self-efficacy as they gain confidence in their abilities to teach such content. Professional development should be viewed as the driver of educational reform efforts because it may have an impact on how teachers' knowledge of engineering design evolves along with their strategies to present engineering-design instruction.

Recommendations

As shared in chapter 1, policy decisions are quickly changing the landscape of K-12 education. Many policymakers are keenly interested in STEM education, and the addition of engineering at the elementary level. Given that objective, efforts are currently underway in many states to prepare teachers to integrate engineering in their classrooms: as a stand-alone subject or embedded within existing science and technology standards. By assessing teachers' engineering self-efficacy, educators, researchers, and policymakers may attain a better understanding of teachers' beliefs about engineering instruction, professional-development needs, and their abilities to teach engineering. That information can be used to inform professional development and staff support to best meet the needs of teachers, and the reform efforts so vitally needed to succeed in a rapidly changing world. Teachers will endorse different levels of engineering self-efficacy, informing professional-development efforts that are more closely aligned with those relative needs. To plan for a preferred future with respect to elementary level engineering, the following recommendations are offered for policymakers and educators.

Recommendations for policy

1. Establish provisions for professional development and required coursework for pre-service and in-service teachers that support the introduction of engineering-curriculum content at the elementary level.
2. Establish provisions that ensure sufficient time embedded within a teacher's workday for specific mentoring and follow-up learning activities aligned with professional development and coursework in engineering.
3. Require that all elementary-teacher preparatory programs require completion of a three-credit course in K-12 engineering design.
4. Establish state and regional support systems that serve as a resource and instructional clearinghouse for engineering and associated STEM curricula.

Recommendations for Practice/Professional Development

1. Provide ongoing engineering professional-development workshops based on theoretical frameworks and methodologies in elementary engineering.
2. Provide engineering professional-development workshops that include engineering-design challenges that include active participation on the part of teachers using similar materials as those to be used by their students.
3. Incorporate the characteristics of creativity, innovation, and fun, into professional development to be carried forward into elementary-engineering instruction.
4. Design professional development that is focused on teachers' learning needs and experiences.

Recommendations for Future Study

The purpose of this study was to examine the influence of professional development to support educators in the integration of engineering in STEM (science technology, engineering, and mathematics) education at the elementary level. Particular consideration focused on the evolution of teachers' perceptions of engineering self-efficacy following engagement in professional development intended to support the introduction of an inquiry-based science unit aligned with the *Next Generation Science Standards* and the National Research Council's *A Framework for K-12 Science Education* in selected grade-five classrooms. The findings of this research suggest a number of possible research studies to inform integration efforts in elementary-school engineering.

1. The completion of research that examines the types of professional-development activities that are considered most useful by teachers to understand the practices of engineers, and relative applications at the elementary level.
2. The completion of research that examines the role of facilitators in intervention professional-development.
3. The completion of research in the form of a meta-analysis of effective practices in elementary-engineering professional development.
4. The completion of similar research using participants from other Maine districts to compare with the results of this study. That would realize a larger sample size, and allow the research to better inform generalizability.

5. The completion of a mixed-methods research study to determine the professional-development opportunities educators received that were considered appropriate for teaching engineering at the elementary level, so as to better inform engineering integration into existing curriculum frameworks, and provide focus on the instructional needs of teachers.
6. The completion of a mixed-methods research study to determine how a teacher's engineering self-efficacy impacts measureable gains in student achievement.
7. The completion of a larger quantitative analysis of teacher professional development, and reported changes in teacher self-efficacy could expand and clarify the results of this study.
8. The completion of further study to determine if increases in teachers' engineering self-efficacy is transferrable to student learning within the classroom, and if so, what is the effect on their students' attitudes, aspirations, and understanding of engineering?

Limitations

It is important to note the possible limitations of the results of this study, given the fact that all survey results show positive gains, and teacher-reported responses during interview were consistent with one another. Nevertheless, the study yielded positive reactions based on reported gains in self-efficacy across all questions for all three study participants gleaned from pre- and post-intervention survey submissions.

The findings of this study are based on a one-time snapshot of a small group of teachers. A larger quantitative analysis of teacher professional development and reported changes in teacher self-efficacy could expand and clarify the results of this study. Although this study used one model for initiating professional development to support gains in teacher self-efficacy in teaching engineering concepts, expanded opportunities for teachers to explore engineering in their classroom may enhance how teachers perceive their instruction of engineering concepts. The types of experiences that build positive self-efficacy beliefs in teaching engineering design, and the type of support that can relieve teachers from the pressure of being engineering and design experts, is an area for future research.

Conclusion

As stated at the outset of this study, the United States is faced with the realization that it is not currently preparing a sufficient number of engineers necessary to keep pace with other nations in a rapidly changing world. As a means of addressing that challenge, policymakers have emphasized the importance of STEM education through active legislation efforts that require the introduction of engineering within K-12 classrooms. The significance of this study rests in the reality that as interest in K-12 engineering grows, reform efforts necessary to support the professional development and instructional needs of educators must too grow. Through efforts directed at enhancing teacher professional development and increased levels of self-efficacy, the ultimate goal of strengthening the United States' position as a global leader of innovation and design may be achieved.

This study about integrating engineering education into elementary schools suggests that elementary teachers with minimal, if any, formal academic preparation in engineering curriculum, assessment, and instruction can indeed integrate engineering concepts into their teaching. Therefore teachers should be encouraged to introduce engineering at the K-12 level. Through interactions with students, colleagues, and professional development interventionists, teachers developed increased levels of teaching engineering self-efficacy through intervention professional development. This study suggests that professional-development experiences that require participants to experience and present hands-on and student-centered engineering tasks, learn engineering concepts as they teach them. Teachers can learn engineering practices alongside colleagues and experts who are resources to check their understandings of engineering This study indicates that it is possible for teachers to learn and develop effective instructional approaches for teaching engineering at the elementary level. One contribution of this study to the literature is underlining the fact that the ultimate goal of teachers' professional-development experiences should not be simply preparing highly efficacious teachers, but preparing highly efficacious teachers who have solid engineering-content knowledge.

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Appendix A

Teaching Engineering Self- Efficacy Scale (TESS) for K-12 Teachers

Yoon, Y.S., Evans, M.G. & Strobel, J. (2012)

1 strongly disagree
2 moderately disagree
3 disagree slightly more than agree
4 agree slightly more than disagree
5 moderately agree
6 strongly agree

Engineering Pedagogical-content knowledge Self-efficacy

1. I can explain the different aspects of the engineering design process.	1 2 3 4 5 6
2. I can discuss how given criteria affect the outcome of an engineering design project.	1 2 3 4 5 6
3. I can explain engineering concepts well enough to be effective in teaching engineering.	1 2 3 4 5 6
4. I can assess my students' engineering design products.	1 2 3 4 5 6
5. I know how to teach engineering concepts effectively.	1 2 3 4 5 6
6. I can teach engineering as well as I do most subjects.	1 2 3 4 5 6
7. I can craft good questions about engineering for my students.	1 2 3 4 5 6
8. I can employ engineering activities in my classroom effectively.	1 2 3 4 5 6
9. I can discuss how engineering is connected to my daily life.	1 2 3 4 5 6
10. I can spend the time necessary to plan engineering lessons for my class.	1 2 3 4 5 6
11. I can explain the ways that engineering is used in the world.	1 2 3 4 5 6
12. I can describe the process of engineering design.	1 2 3 4 5 6
13. I can select appropriate materials for engineering activities.	1 2 3 4 5 6
14. I can create engineering activities at the appropriate level for my students.	1 2 3 4 5 6
15. I can stay current in my knowledge of engineering.	1 2 3 4 5 6
16. I can recognize and appreciate the engineering concepts in all subject areas.	1 2 3 4 5 6
17. I can guide my students' solution development with the engineering design process.	1 2 3 4 5 6

Motivational Self-efficacy

18. I can motivate students who show low interest in learning engineering. 1 2 3 4 5 6

19. I can increase students' interest in learning engineering. 1 2 3 4 5 6

20. Through engineering activities, I can make students enjoy the class more. 1 2 3 4 5 6

Instructional Self-efficacy

21. I can use a variety of assessment strategies for teaching engineering. 1 2 3 4 5 6

22. I can adequately assign my students to work at group activities like engineering design. 1 2 3 4 5 6

23. I can plan engineering lessons based on each student's learning level. 1 2 3 4 5 6

24. I can gauge student comprehension of the engineering materials that I have taught. 1 2 3 4 5 6

25. I can help my students apply their engineering knowledge to real world situations. 1 2 3 4 5 6

Engagement Self-efficacy

26. I can promote a positive attitude toward engineering learning in my students. 1 2 3 4 5 6

27. I can encourage my students to think creatively during engineering activities and lessons. 1 2 3 4 5 6

28. I can encourage my students to think critically when practicing engineering. 1 2 3 4 5 6

29. I can encourage my students to interact with each other when participating engineering activities. 1 2 3 4 5 6

Disciplinary Self-efficacy

30. I can control disruptive behavior in my classroom during engineering activities. 1 2 3 4 5 6

31. I can keep a few problem students from ruining an entire engineering lesson. 1 2 3 4 5 6

32. I can redirect defiant students during engineering lessons. 1 2 3 4 5 6

33. I can calm a student who is disruptive or noisy during engineering activities. 1 2 3 4 5 6

34. I can get through to students with behavior problems while teaching engineering. 1 2 3 4 5 6

35. I can establish a classroom management system for engineering activities. 1 2 3 4 5 6

Outcome Expectancy

36.	I am generally responsible for my students' achievements in engineering.	1	2	3	4	5	6
37.	When my students do better than usual in engineering, it is often because I exerted a little extra effort.	1	2	3	4	5	6
38.	My effectiveness in engineering teaching can influence the achievement of students with low motivation.	1	2	3	4	5	6
39.	When a student gets a better grade in engineering than he/she usually gets, it is often because I found better ways of teaching that student.	1	2	3	4	5	6
40.	If I increase my effort in engineering teaching, I see significant change in students' engineering achievement.	1	2	3	4	5	6
41.	I am responsible for my students' competence in engineering.	1	2	3	4	5	6

Appendix B

TESS Respondent Data
Degree of Change on 6 Point Scale
Pre vs. Post Survey Submission

	Teacher 1	Teacher 2	Teacher 3	Teacher Average
Pedagogical-content knowledge (Items 1-17)	2.76	2.53	3.65	2.98
Motivational Self-Efficacy (Items 18-20)	2.67	2.0	2.0	2.22
Instructional Self-Efficacy (Items 21-25)	3.0	2.6	2.8	2.8
Engagement Self-Efficacy (Items 26-29)	2.75	2.0	1.75	2.17
Disciplinary Self-Efficacy (Items 30-35)	2.0	1.33	.67	1.33
Outcome Expectancy (Items 36-41)	1.83	2.17	2.17	2.06
Total (Items 1-41)	2.54	2.20	2.59	2.45

Rank Ordered Change

Strongest Change	Pedagogical-content knowledge
	Instructional Self-Efficacy
	Motivational Self-Efficacy
	Engagement Self-Efficacy
	Outcome Expectancy
Least Change	Disciplinary Self-Efficacy

Appendix B

TESS Respondent Data
Post Survey 6 Point Scale

	Teacher 1	Teacher 2	Teacher 3	Teacher Average
Pedagogical-content knowledge (Items 1-17)	5.0	**4.82**	5.24	5.02
Motivational Self-Efficacy (Items 18-20)	5.0	5.67	**4.67**	5.11
Instructional Self-Efficacy (Items 21-25)	5.0	5.4	5.0	5.13
Engagement Self-Efficacy (Items 26-29)	5.0	6.0	5.0	5.33
Disciplinary Self-Efficacy (Items 30-35)	5.0	5.17	**4.67**	4.94
Outcome Expectancy (Items 36-41)	**4.83**	5.0	5.17	5.0
Total (Items 1-41)	4.98	5.15	5.05	5.06

Strongest Assertion	Engagement Self-Efficacy
	Instructional Self-Efficacy
	Motivational Self-Efficacy
	Engineering Pedagogical-content knowledge
	Outcome Expectancy
Weakest Assertion	Disciplinary Self-Efficacy

Appendix B
TESS Respondent Data
Degree of Change on 6 Point Scale By Item and Cluster

	Least Change Item	Greatest Change Item	
Pedagogical-content knowledge (1-17)	9	12	
9. I can discuss how engineering is connected to my daily life. *Highest start. Tied highest finish.*			+2.0
12. I can describe the process of engineering design. *Tied lowest start. Tied highest finish*			+3.67
Motivational Self-Efficacy (18-20)	20	18	
20. Through engineering activities, I can make students enjoy the class more. *Highest start. Lowest finish.*			+1.67
18. I can motivate students who show low interest in learning engineering. *Lowest start. Highest finish.*			+3.0
Instructional Self-Efficacy (21-25)	21	25	
21. I can use a variety of assessment strategies for teaching engineering. *Lowest finish.*			+2.0
25. I can help my students apply their engineering knowledge to real world situations. *Tied lowest start.*			+3.33
Engagement Self-Efficacy (26-29)	26	28	
26. I can promote a positive attitude toward engineering learning in my students. *Highest start. Lowest finish.*			+1.33
28. I can encourage my students to think critically when practicing engineering. *Lowest start.*			+3.0
Disciplinary Self-Efficacy (30-35)	34	30	
34. I can get through to students with behavior problems while teaching engineering. *Highest start. Lowest finish.*			+1.0
30. I can control disruptive behavior in my classroom during engineering activities. *Highest start. Highest finish.*			+1.67

TESS Respondent Data
Degree of Change on 6 Point Scale By Item and Cluster

		Least Change Item	Greatest Change Item
Outcome Expectancy	**(36-41)**	37/40	36

37. When my students do better than usual in engineering, it is often because I exerted a little extra effort. +1.67
    Highest start.
40. If I increase my effort in engineering teaching, I see a significant change in students' engineering achievement. +1.67
    Lowest finish.
36. I am generally responsible for my students' achievement in engineering. +2.67
    Lowest Start. Lowest finish.

Appendix C

<u>School Demographics and Goals</u>

This study will be conducted with three faculty members from a K-5 elementary school in southern Maine. Participants were selected for the study given similarities to the researcher's school and area of interest. The researcher currently serves as an elementary school principal, and is interested in investigating teacher change with individuals who participate in professional development intended to support the integration of engineering and design within existing science instruction.

School Department total enrollment K-12 of 2,666 (as of 10/1/13)
Selected School (K-5) Enrollment 427 Elementary student/teacher ratio 21:1

Focus Area: Improving Academic Performance

Rationale: The members of XXX School recognize that society needs educated, active citizens who can communicate clearly, employ technology, have a bank of knowledge and skills, and can use higher order thinking. It demands consistency and high quality in curriculum, instruction, and assessment across classrooms, as well as across the district. Given this, it is our mission to develop curriculum, instruction, and assessment that enable high quality, continuous progress for all students.

Focus Area: Adult Development

Rationale: This focus area attends to the art and technology of teaching and learning. It enables the adults in our school community to keep "learning about learning." We are committed to enriching our school environment by supporting adult learning in a focused manner. It is believed that the more we know, the greater benefit it is to our students. Adults engage in ways to gain knowledge and understanding about theory content and practice. Given this, it is our mission to enable and encourage on-going professional development.

Appendix D

Student Recording Packet as provided at initial onsite training.

Energy, Engineering and DesignScience Unit

Name: ________________________________

Date: _____________

Potential and Kinetic Energy

Definitions:

Potential Energy- Stored energy due to an object's relative position and mass.

Kinetic Energy- Energy associated with motion.

Observations:

What difference do you notice when extra mass is added to the cart?

What difference do you notice when the incline of the ramp is increased?

Scenario:

A friend challenges you to a sled race. You are able to design your own sled and choose the location. Based on what you know about how you can alter potential energy, explain what decisions you would make in designing your sled and choosing your location. (If you can think of any other alterations you could make to increase your chances, please add them.)

Storing and Using Energy (Hand Crank)

Definitions:

Joule (J)- a unit of measure for energy.

Setting Up:

1.) Break into groups of four. Two students will be responsible for building the Joule Jeep. The other two will be responsible for building the hand crank, as shown in the instruction manuals.

2.) Set your Joule Jeep on the floor with a direct path in front of it. Mark a starting line on the floor with a piece of masking tape.

3.) Hook the hand crank up to the Joule Jeep using the wires given and make sure the Energy Meter is reset to 0 joules.

Making Predictions and Collecting Data:

1.) On the table below, write your prediction as to how many joules you think you will accumulate within ten seconds of turning the hand crank.

2.) Turn the hand crank for ten seconds. On the table below, write down the joules collected.

3.) Compare your prediction to your findings. Based on what you found, make predictions for the amount of joules that will be collected after 20, 30, 40, 50 and 60 seconds.

4.) Turn the crank five more times, ten seconds each. Write the total amount of joules that have been collected at the end of each ten second period.

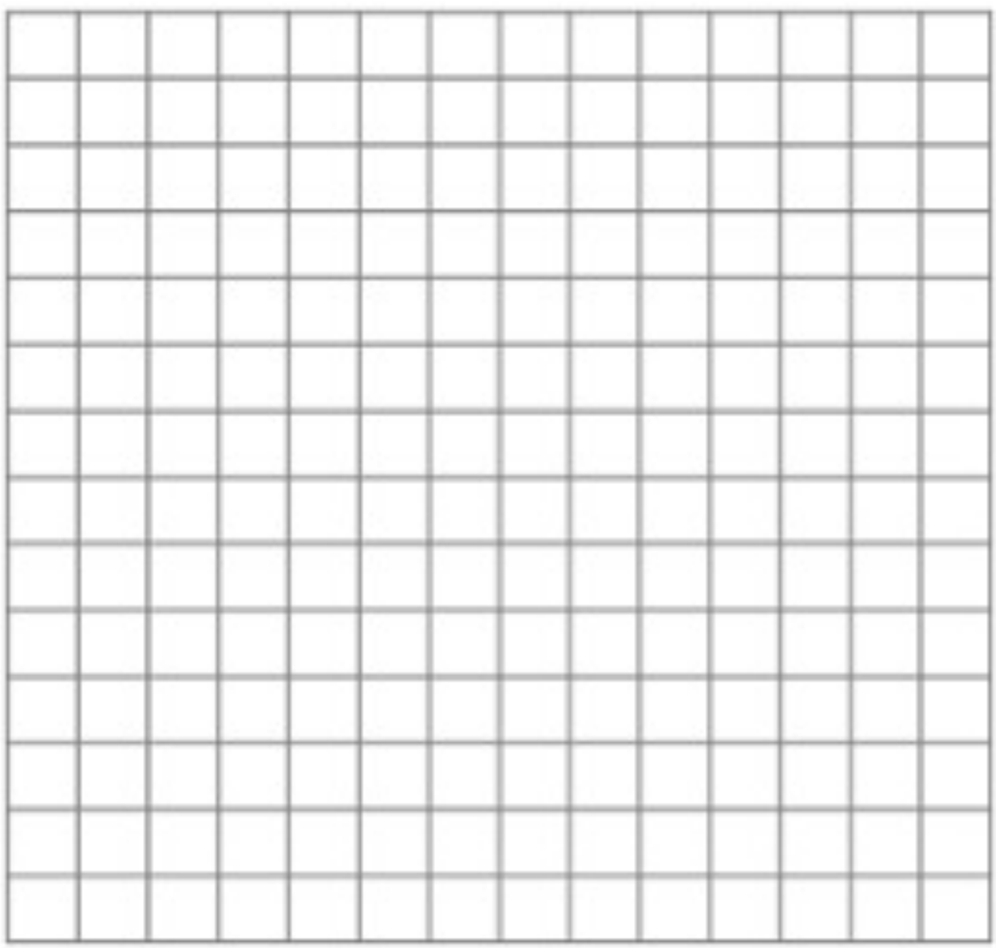
	10 Seconds	20 Seconds	30 Seconds	40 Seconds	50 Seconds	60 Seconds
My Prediction						
My Findings						

5.) Using the amount of joules collected over 60 seconds, see how far your Joule Jeep can travel. How many feet did your jeep travel? ____________

Displaying Data:

My Predictions and Findings

Using the data collected on the previous page, create a line graph showing one line for your predictions and one line for your findings. Use different colors for each line and label them.



Creating a More Efficient Design

Definitions:

Efficient- Achieving maximum productivity with minimum wasted effort or expense.

Directions:

1.) Based off discussions with your group, begin making alterations to your hand crank.

2.) Hooking your newly designed hand crank up to your joule jeep, test how many joules you can generate over 10, 20, 30, 40, 50, and 60 seconds. Compare this data with that collected in the previous experiment.

3.) If more joules are *not* generated, continue discussion with group and redesign until data shows improvement in the hand crank's efficiency.

Describe any changes you made that resulted in an increase in joule generation.

____

____

____

____

____

Show data collected from improved hand crank.

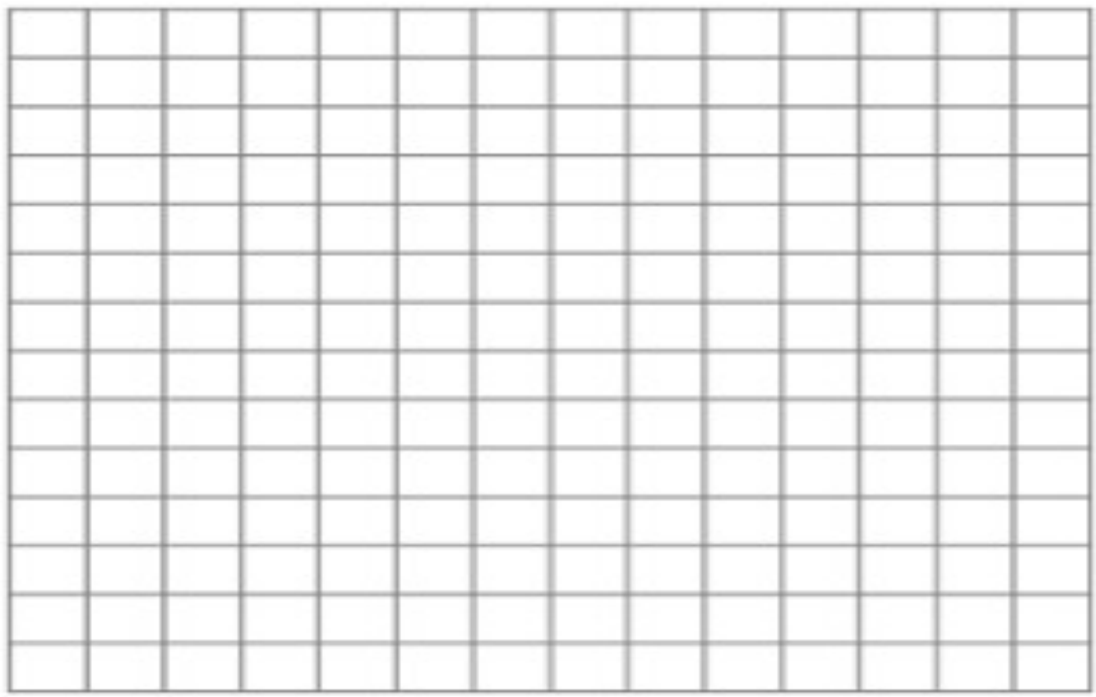
	10 Seconds	20 Seconds	30 Seconds	40 Seconds	50 Seconds	60 Seconds
My Findings						

Using the amount of joules collected over 60 seconds using the new and improved hand crank, see how far your Joule Jeep can travel. How many feet did your jeep travel?

____

Displaying Data:

Create a line graph with a line displaying your findings in the first experiment using the original hand crank and a second line displaying your findings using the new and improved hand crank.



Hand Crank First Trial And Second Trial

What

does this line graph show us?

____

____

____

<u>**Storing and Using Energy (Wind Turbine)**</u>

Definitions:

<u>**Wattage**</u>: A measure of electrical power in watts.

Setting Up:

1.) Break up into groups of four. Two students will be responsible for building the stand portion of the turbine from pg. 35 of Book A . The other two will be responsible for building the propeller section of the turbine from Book B. Once completed, connect the two pieces.

2.) Make sure the energy meter is securely hooked up to the turbine and is set back to 0 joules. Measure a distance of 12 inches the fan to the turbine. Before turning on the fan, make a prediction as to what average voltage and wattage will be generated by the turbine and write it below.

3.) Turn the fan on to its lowest setting and once the numbers have settled, record your findings.

4.) Move the fan 6 inches closer to the turbine and repeat.

Six Bladed Turbine	**12 Inches From Fan**		**6 Inches From Fan**	
My Predictions	(V)	(W)	(V)	(W)
My Average Findings	(V)	(W)	(V)	(W)

5.) If you remove three of the six blades, as shown on the back of book B, do you think the turbine will generate a higher or lower average voltage and wattage? WHY?

____

____

____

6.) Remove the three blades and repeat the same steps you completed when there were six blades. Record your data below.

Three Bladed Turbine	12 Inches From Fan		6 Inches From Fan	
My Predictions	(V)	(W)	(V)	(W)
My Average Findings	(V)	(W)	(V)	(W)

7.) What did you discover?

____

____

____

____

8.) If you had the resources and you wanted to build a wind turbine to power your house, what are three decisions that you would make that could affect the efficiency of your turbine?

____

____

____

____

Storing and Using Energy (Solar Station)

Definitions:

Variable: An element, feature, or factor that is liable to vary or change.

Voltage: An electromotive force. (V)

Current: The flow of Energy through a conductor, measured in Amps (A)

Setting Up:

1.) Make sure that your wind turbine is dismantled.

2.) Discuss with your group what you know about solar panels and how you have seen them set up or positioned before.

Crane Building:

1.) Break your group into two small groups. Using books A and B, create bother upper and lower portions of the Lego Crane.

2.) Connect the two pieces together.

3.) Connect the energy meter input to the solar panel.

Initial Findings:

Hold your connected solar panel up to a light source for 30 seconds. Turn the dial on your energy meter and see if you can lift the crane's load all the way to the pulley with the energy you've collected.

Q: What are three variables that you think might affect the ability of the solar panels to collect solar energy?

1.) ____

2.) ____

3.) ____

Solar Station Readings

Predict and Test the amperage your meter reads when the solar panel is placed in the positions below.

	Horizontal	**Diagonal**	**Vertical**
Predictions for Current (A)			
Findings for Current (A)			

Variable Changes:

1.) Which position showed the maximum current? ______________________

2.) Based on the variables you listed before and any new ones you've considered since then, try and change some of these variables so that the solar panel will collect more solar energy.

3.) Discuss any of the successful changes you've made below:

____

____

____

____

____

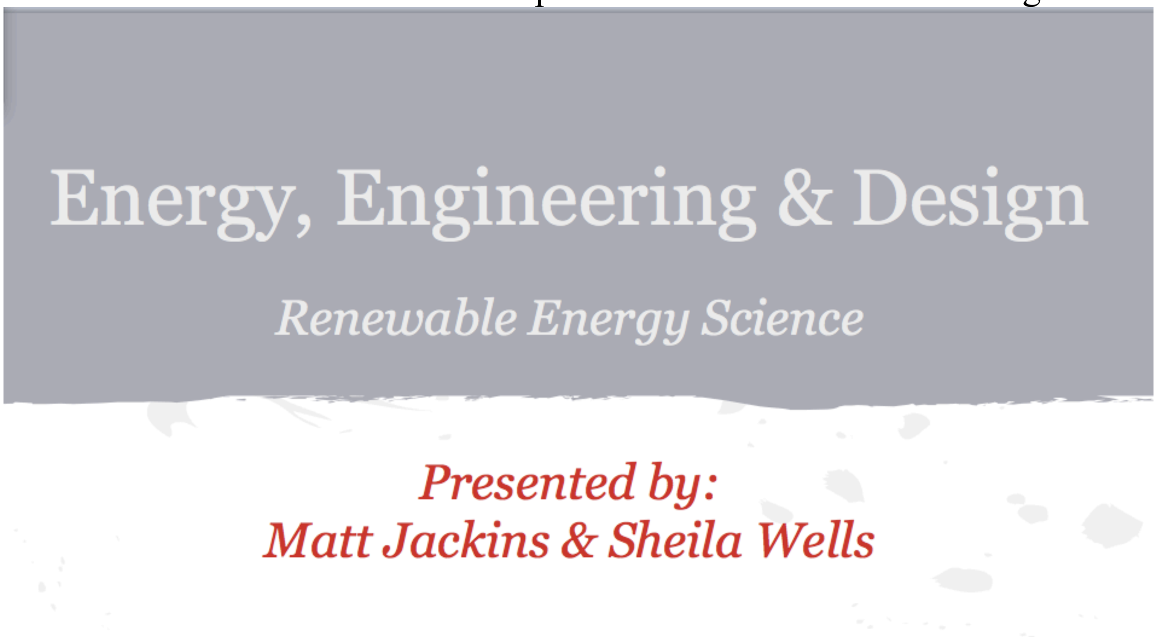
____

Maximum Amperage Recorded: ____________

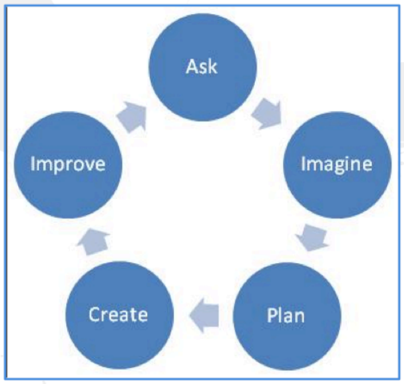
Challenge! With the changes you've made, see if you can lift the load any farther now with the energy you've collected over 30 seconds.

Appendix E

Presentation Power Point as presented at initial offsite training



What is Engineering?

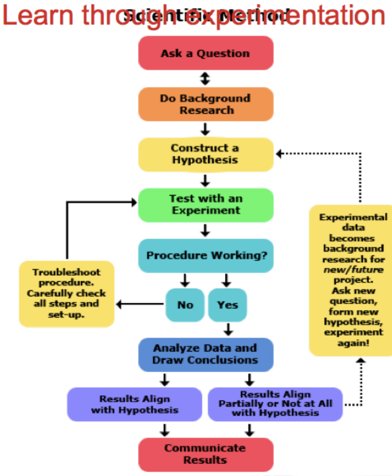


http://www.teachengineering.org/engrdesignprocess.php

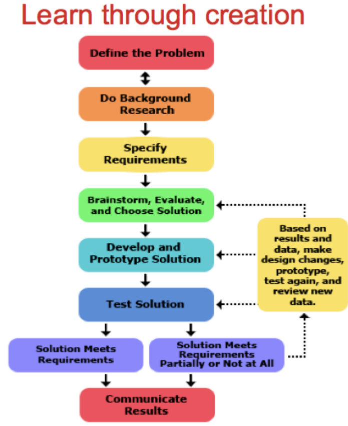
Engineering is the branch of science and technology concerned with the design, building, and use of engines, machines, and structures. **Engineering** combines the fields of science and math to solve real world problems that improve the world around us. (http://whatisengineering.com/)

Scientific Method vs. Engineering

Learn through experimentation



Learn through creation

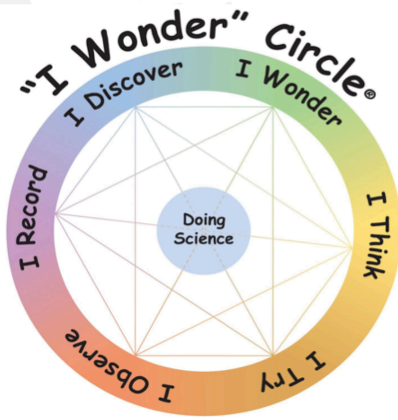


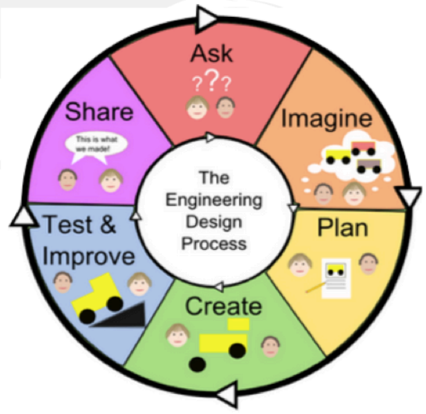
Next Generation Science Standards

Science & Engineering Practices:

1. Asking questions (for science) and defining problems (for engineering)
2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematics and computational thinking
6. Constructing explanations (science) and designing solutions (engineering)
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information

Elementary Engineering





www.sciencecompanion.co
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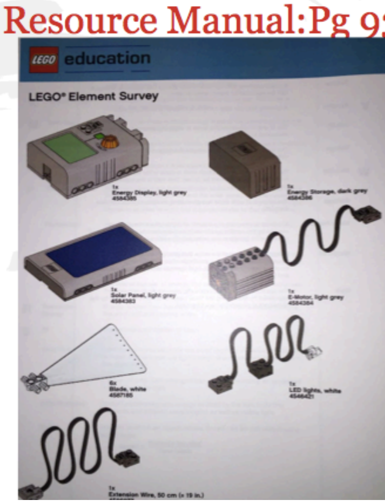
Grades 3-5

At the upper elementary grades, engineering design engages students in more formalized problem solving. Students define a problem using criteria for success and constraints or limits of possible solutions. Students research and consider multiple possible solutions to a given problem. Generating and testing solutions also becomes more rigorous as the students learn to optimize solutions by revising them several times to obtain the best possible design.

Engineering Design in the NGSS

Renewable Energy Kit

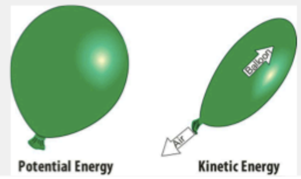
Resource Manual:Pg 93



Potential/Kinetic Energy
Build & Demo

Resource Manual: Pg 34-40
Book 1i pg 3

Student Video



Hand Generator

Resource Manual Pg 34

Book 1A pg 3
Book 1B pg 3

Online Timer

Creating a More Efficient Design

Bike Gears Explained

Wind Energy Basics

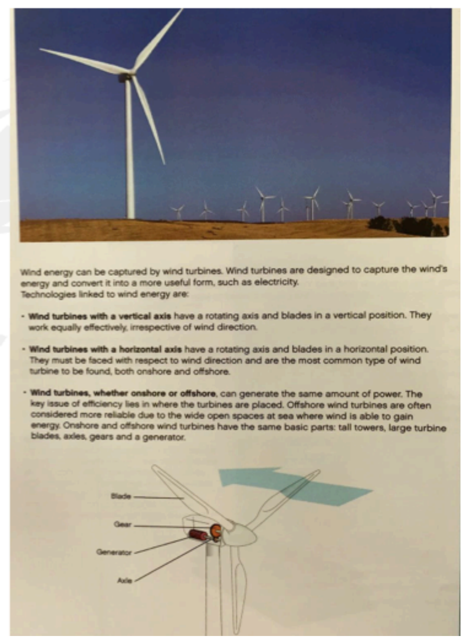
[Wind Energy Info]

Wind Turbine Build

[Resource Manual Pg. 48]

Build Book 3A pg 35
Book 3B pg 31

[CMP Power Source]



Wind energy can be captured by wind turbines. Wind turbines are designed to capture the wind's energy and convert it into a more useful form, such as electricity.
Technologies linked to wind energy are:

- **Wind turbines with a vertical axis** have a rotating axis and blades in a vertical position. They work equally effectively, irrespective of wind direction.
- **Wind turbines with a horizontal axis** have a rotating axis and blades in a horizontal position. They must be faced with respect to wind direction and are the most common type of wind turbine to be found, both onshore and offshore.
- **Wind turbines, whether onshore or offshore**, can generate the same amount of power. The key issue of efficiency lies in where the turbines are placed. Offshore wind turbines are often considered more reliable due to the wide open spaces at sea where wind is able to gain energy. Onshore and offshore wind turbines have the same basic parts: tall towers, large turbine blades, axles, gears and a generator.

Solar Energy

Resource Manual Pg. 41

Resource Manual Pg. 76(Boat Pulley)
Book 6A pg 29
Book 6B pg 45

Solar Energy

Solar energy can be captured, for example, by solar cells. Many solar cells assembled together are called solar panels. Solar panels are designed to capture the suns energy and convert it to more exploitable forms, such as heat or electricity. Technologies linked to solar energy are:

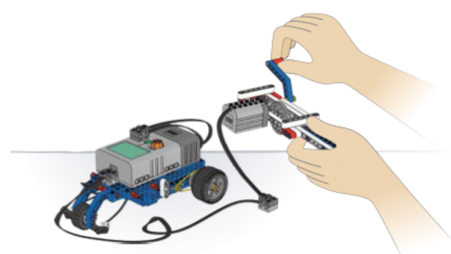
- **Passive solar energy**, in which the energy in sunlight is used for light and heat. In passive solar building design the Sun's energy contribution is fully optimized.
- **Active solar water heating systems**, in which the Sun's heat energy is transferred to special fluids held in solar collectors. This fluid is pumped through pipes in water tanks and the heat energy transferred to the water.
- **Photovoltaics**, in which the energy in visible light from the Sun is converted directly into an electric current by means of solar cells. Using the photoelectric effect, loose electrons in the upper layer of the solar cell are caused to move, thus creating an electric current that can be used to operate an electrical device.

Appendix F

Professional Development Intervention Shared Resources.

You Tube –Introduction to Renewable Energy Curriculum. (3:55)
http://www.youtube.com/watch?v=xwLjR6xGEAo

Hand Generator (1:30) http://www.youtube.com/watch?v=k7Kyzy_JCec



Wind Turbine (2:58) http://www.youtube.com/watch?v=yl-qdw4Vhzo

Additionally, Clean Line Energy's website provided resources to supplement the LEGO Renewable Energy curriculum.

http://www.cleanlineenergy.com/learn/teachers

Appendix G

Parent Letter sent home by study participants.

Dear Parents,

As you may have heard from your child, we have been learning about renewable energy using LEGO Education materials. These materials are aligned with The National Research Council's *A Framework for K-12 Science Education: Practices, Cross Cutting Concepts, and Core Ideas* for engineering and Next Generation Science Standards. The core tenets contained within these standards serve as the foundation on which inquiry based learning utilizing LEGO's Renewable Energy Curriculum is built. This curriculum allows students to better understand science and engineering practices as they design and build models and systems based in real life applications.

The world is full of energy, which we all use on a daily basis. As with many things, we often take energy for granted, not understanding the processes that go into making it available or the continued efforts being made to find new, more efficient ways to attain it.

Through the use of Lego Renewable Energy Kits, students are learning how energy takes many forms and how it can be converted from one form to another. With many hands on building experiences, students will have a chance to create and test generators of electrical energy, using kinetic and solar power. They will question, design, test, evaluate, and retest so as to create more efficient generators. Students will also learn terminology for energy measurement, how to use graphs to compare results, and gain interest and appreciation for one of the world's fastest growing careers.

Over the next several weeks, we encourage you to talk with your children about the work they are doing in the classroom involving this engineering program and ask that you share with us any of these exciting conversations. The world is rapidly evolving and it's these types of experiences and discussions that help prepare our youth to take their place in it.

We encourage you to have your child share their new learning with you. You may start this conversation by asking them about how the are developing and using models, planning and carrying out investigations, analyzing and interpreting data, constructing and designing solutions, and obtaining, evaluating, and communicating information.

Biography of Author

Stephen D. Marquis was born and raised in Old Town, Maine. He received a bachelor of science degree in education and secondary social studies from the University of Maine at Orono in 1992. He later earned a master of science degree in educational leadership from the University of Southern Maine. Additional coursework and experiences have allowed him to hold seven Maine educator certifications. He has been an educator for nearly twenty-five years, beginning as a special education teacher. He is currently serving as an elementary school principal.

He has worked with fellow school leaders in a variety of capacities including the Maine ASCD Board of Directors, the York County Superintendents Association, the York County Administrative Certification Collaborative, and the Maine Principals Association. He is also a member of the University of Southern Maine’s first doctoral cohort in educational leadership and policy.