ELEMENTARY TEACHERS' PERCEPTIONS OF ENGINEERING, ENGINEERING DESIGN, AND THEIR ABILITIES TO TEACH ENGINEERING: A MIXED METHODS STUDY

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Submitted to the Faculty of the
Graduate College of the
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in partial fulfillment of
the requirements for
the Degree of
DOCTOR OF PHILOSOPHY
May, 2016

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ACKNOWLEDGEMENTS

First, I would like to thank my dissertation committee members. Thank you to Dr. Julie Thomas for taking me on as a graduate student and mentoring me. My deepest appreciation goes to Dr. Toni Ivey, who took over as my dissertation chair when Dr. Thomas moved. Thank you for mentoring me, serving as a role model and friend, and providing a listening ear when I needed it most. Words cannot express my gratitude for the guidance and encouragement you have provided me over the years. Thank you to Dr. Juliana Utley for being an amazing teacher and for taking the time to sit with me and help me learn SPSS. To Dr. Pamela Brown, thank you for opening my eyes to the realities of the education system. I took away so much from your classes. To Dr. Steven Marks, thank you for agreeing to serve on my committee in my hour of need; I sincerely appreciate it. Finally, to Dr. Karen High, I want to thank you for introducing me to engineering all those years ago. I would not be where I am today if you had not taken me under your wing and provided me with the many professional development opportunities that helped fuel my passion for engineering education.

Thank you to the many faculty members in the College of Education whose courses helped shape me into a scholar. I also want to thank the faculty and staff who did not have me as a student, but still took the time to help me over the past six years. To my fellow graduate students, your comradery and support are greatly appreciated. I extend my gratitude to the CRSTL center, and especially to Drs. Ivey, Utley, and High for dropping everything to help me write a MSP grant and guiding me through that process. Your patience and flexibility have meant the world to me.

To my family and friends, thank you for your support, love, and encouragement during this very long and exhausting journey. The many hours I spent studying and writing, meant hours I was not spending time with you, and I cannot express how thankful I am for your understanding and willingness to share me with OSU. I could not have accomplished the things I have without your help.

Finally, I extend my gratitude to all the Oklahoma teachers who took the time to participate in this study and trusted me to report their views on engineering education.

Name: REBEKAH JANE HAMMACK

Date of Degree: MAY, 2016

Title of Study: ELEMENTARY TEACHERS' PERCEPTIONS OF ENGINEERING, ENGINEERING DESIGN, AND THEIR ABILITIES TO TEACH ENGINEERING: A MIXED METHODS STUDY

Major Field: EDUCATION

Abstract: This explanatory sequential mixed methods study explores elementary teachers' preparedness to teach engineering and engineering design as prescribed by the Next Generation Science Standards (NGSS). The data analyzed included the NGSS document, responses to an online survey that was completed by 542 Oklahoma K-5 teachers responsible for the science instruction of their students, and interview and focus group transcripts from a subset of survey participants. The results are organized into three distinct manuscripts, each devoted to a specific set of research questions. As a whole, the dissertation findings indicate that elementary teachers are not prepared to incorporate engineering practices into their classrooms. Study participants were found to have limited understanding of engineering and engineering design, as well as low engineering self-efficacy and engineering teaching efficacy related to pedagogical content knowledge. While participants recognized the benefits of including engineering activities in their classrooms, they reported that barriers such as lack of time, lack of training, lack of materials, and lack of support inhibited their abilities to infuse engineering into their curriculum.

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INTRODUCTION

The United States is becoming increasingly dependent upon technology in many areas including, but not limited to, economic stability, health care, national security, and energy usage. This dependence on technology has led to an increased demand for qualified workers in the areas of science, technology, engineering, and mathematics (STEM). According to the US Department of Commerce, Economics and Statistics Administration (2011), between 2008 and 2018, STEM occupations are projected to grow faster than non-STEM occupations. Furthermore, the United States is not producing enough STEM career ready college graduates to meet these projected demands. This points to a need to identify and funnel more American youth into the STEM pipeline.

While the lack of students entering and staying in the STEM pipeline is a major national concern, developing a mainline of STEM literate citizens is also of utmost importance to the nation's future. All American children need to leave high school with a basic understanding of the science, mathematical, and engineering practices used to develop today's technology. American citizens need to know how to make educated decisions about their health care needs and energy consumption choices. In addition, because voting citizens choose the politicians who enact policies related to STEM issues, it is imperative that all Americans know the types of questions to ask politicians and political candidates to ensure that they are scientifically and technologically literate in order to make informed political decisions (International Technology Education Association, ITEA, *2007).*

Background of the Problem

A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas (National Research Council, NRC, 2011) identified the key scientific and engineering ideas and practices that all students should learn during their K-12 education. Multiple experts in the fields of education and science developed the framework under the guidance of current research, personal expertise, and small teams of specialists. The *Framework* established two goals for K-12 education: 1) educate all students in science and engineering and 2) provide foundational knowledge for future scientists, technologists, engineers, and technicians (NRC, 2011).

The *Framework* served as the foundation for the development of the *Next Generation Science Standards (*NGSS; NGSS Lead States, 2013). Since the release of the final version of NGSS in April of 2013, the standards have been adopted by 15 states and the District of Columbia (NGSS Lead States, 2013), with additional states adopting standards that are similar to NGSS (e.g., Oklahoma, South Dakota). The Framework and NGSS are comprised of three dimensions: Science and Engineering Practices, Crosscutting Concepts, and Disciplinary Core Ideas. In NGSS, each of the standards is a performance expectation that incorporates all three dimensions. Table 1.1 presents the three dimensions of the Framework and NGSS as well as the components of each dimension. Table 1.2 presents the component ideas that make up Disciplinary Core Idea: Engineering, Technology, and Applications of Science. As evident from Tables 1.1 and 1.2, NGSS requires the infusion of engineering practices and core ideas within the science curriculum in all grade levels (NGSS Lead States, 2013; NRC, 2011).

Table 1.1

Dimensions of the Framework and Next Generation Science Standards

Science and Engineering Practices	• Asking questions (for science) and defining problems • Developing and using models (for engineering) • Planning and carrying out investigations • Analyzing and interpreting data • Using mathematics and computational thinking • Constructing explanations (for science) and designing solutions (for engineering) • Engaging in argument from evidence • Obtaining, evaluating, and communicating information
Crosscutting Concepts	• Patterns • Cause and effect • Scale, proportion, and quantity • Systems and system models • Energy and matter • Structure and function • Stability and change
Disciplinary Core Ideas	• Physical sciences • Life sciences • Earth and Space sciences • Engineering, Technology, and Applications of Science

Table 1.2

Core and Component Ideas in Engineering, Technology, and Applications of Science

Disciplinary Core Idea	Core Idea	Component Idea
Engineering, Technology, and Applications of Science	ETS1: Engineering Design	ETS1.A: Defining and Delimiting an Engineering Problem ETS1.B: Developing Possible Solutions ETS1.C: Optimizing the Design Solutions
	ETS2: Links Among Engineering, Technology, Science, and Society	ETS2.A: Interdependence of Science, Engineering, and Technology ETS2.B: Influence of Engineering, Technology, and Science on Society and the Natural World

The incorporation of engineering practices and core ideas within the science classroom requires science teachers of all grade levels to be knowledgeable of engineering and able to teach engineering practices and ideas to their students. The engineering practices and core ideas presented in Tables 1.1 and 1.2 can be used as a framework to identify the knowledge K-12 teachers must possess in order to successfully implement engineering instruction into their classrooms. Research in engineering education at the elementary level is in its infancy and relatively little is known about elementary teachers' abilities to effectively infuse engineering into their science curriculum. The research studies that are available suggest that elementary teachers (a) hold similar stereotypical misconceptions about engineers as their students (e.g. Cunningham, Lachapelle, & Lindgren-Streicher, 2006) and (b) feel unprepared to teach engineering to their students (e.g. Banilower, Smith, Weiss, Malzahn, Campbell, &Weis, 2013; Sargianis, Yang, and Cunningham, 2012). In fact, a national survey of science and mathematics teachers indicated that only 4% of elementary teachers reported feeling very well prepared to teach engineering compared to 39% for science and 77% for mathematics (Banilower et al., 2013).

Statement of the Problem

To meet the growing technological demands of the future, the United States must prepare the nation's children to become technologically literate adults (mainline), while providing the content knowledge and skills to those children who will enter the STEM workforce (pipeline). Pipeline and mainline concerns need to be addressed throughout the entire K-12 education system. *A Framework for K-12 Science Education* and *Next Generation Science Standards* were developed, in part, in response to the need for all K-12 students in the United States to engage in engineering practices. To accomplish this, all K-12 science teachers will need to integrate engineering into their classrooms. Most teacher preparation programs do not prepare elementary teachers to incorporate engineering practices into their classrooms, and engineering focused professional development opportunities for in-service elementary teachers are limited. Determining what perceptions elementary teachers hold about engineering and their ability to teach engineering practices will be required to ensure that in-service elementary teachers receive the training necessary to successfully implement engineering practices in their classrooms.

Purpose of the Study

The purpose of this study is to identify (a) the perceptions that in-service teachers hold about the nature of engineering and K-5 engineering education and (b) how these perceptions compare with the engineering practices put forth in *A Framework for K-12 Science Education* and *Next Generation Science Standards.* Furthermore, the study examines how in-service elementary teachers' perceive (a) their personal knowledge of engineering, (b) their abilities to teach engineering to children, and (c) barriers to teaching engineering at the K-5 level.

Significance of the Study

The NGSS require the infusion of engineering practices into K-5 classrooms, yet little is known about elementary teachers' knowledge or perceptions related to engineering. This study helps develop a baseline of current elementary teachers' perceptions of engineering, engineering design, and K-5 engineering education. This baseline is compared to the requirements put forth by NGSS and used to identify the gap between what teachers perceive they know about engineering and engineering design and what they are required to teach as a part of the standards. Additionally, this study examines elementary teachers' self-efficacy related to teaching engineering. The information resulting from this study can be used to help identify elementary teachers' needs in relation to engineering education and aid in the design of professional development experiences to meet those needs.

Research Questions

This dissertation consists of three independent studies. Study 1, entitled "Elementary Teachers' Perceptions of Engineering and Engineering Design," addressed the following questions:

1. How familiar are in-service elementary teachers with engineering and engineering design?
2. What perceptions do in-service elementary teachers hold about engineers and engineering design?
3. Are there differences in teachers' familiarity with engineering or perceptions of engineers between different demographic groups?
4. How do in-service elementary teachers' perceptions of engineering and engineering design compare with expectations set by K-5 engineering education standards?

Study 2, entitled "Examining Elementary Teachers' Engineering Self-efficacy and Engineering Teacher Efficacy," addressed the following questions:

1. How self-efficacious are in-service elementary teachers in their knowledge of engineering and engineering design and their abilities to teach engineering and engineering design?
2. Are there differences in teachers' engineering self-efficacy or engineering teaching efficacy between different demographic groups?
3. Is there a correlation between teachers' engineering self-efficacy and their familiarity with design/engineering/technology (DET)?

4. Is there a correlation between teachers' engineering teaching self-efficacy and their familiarity with design/engineering/technology (DET)?

Study 3, entitled "Elementary Teachers Perceptions of K-5 Engineering and Percieved Barriers," addressed the following questions:

1. What perceptions do in-service elementary teachers hold about K-5 engineering education?
2. What factors do in-service elementary teachers perceive as barriers to teaching engineering and engineering design?

Research Design

To address the research questions, this study employed an explanatory sequential mixed methods design (Creswell & Plano Clark, 2011). During Phase 1, the researcher employed a two-stage sampling plan to solicit responses from a sample of teachers who would be representative of the state of Oklahoma. The researcher distributed an online questionnaire to a population of K-5 teachers provided by an Oklahoma State Department of Education database. At the time of this study, the Oklahoma State Department of Education (OSDE) had divided the school districts in the state of Oklahoma into eight geographic regions, known as Reac^{3}h Regions (OSDE, 2014). During the first stage of the sampling plan, a questionnaire consisting of both quantitative questions (Likert, selected response) and open-ended qualitative questions was distributed via email to all K-5 teachers whose email addresses were on file with OSDE. During the second stage of the sampling plan, questionnaire responses were examined to determine the percentage of respondents that came from each Reac^{3}h Region. To ensure that the sample was representative of the Oklahoma elementary teacher population, targeted emails were sent to teachers in Reac^{3}h Regions that were underrepresented in the first stage responses. After administering the survey, qualitative data were coded and analyzed for emerging themes using descriptive coding methods. Quantitative data was imported into SPSS and analyzed to determine descriptive and frequency values. Concurrently, the NGSS document was analyzed to determine the engineering content K-5 teachers must implement as part of the standards. During Phase 2, qualitative data was collected in the form of individual and focus group interviews with a subset of Phase 1 participants using a data driven coding approach. Results from the survey analysis and NGSS document analysis were used to inform the development of interview protocols for Phase 2.

Theoretical Framework

According to Social Cognitive Theory (SCT), personal factors, such as learning and cognition, have a triadic reciprocal relationship (see Figure 1.1) with the environment (Bandura, 1989), meaning that there is a mutual influence between the environment and personal factors and their impact on human behavior. Furthermore, individual differences due to human physiological adaptations provide the possibility of different behavioral outcomes, but those biological differences do not dictate behavioral outcomes (Bussey & Bandura, 1999). While SCT recognizes that evolution and biology are important determinants of human behavior, it posits that sociocultural factors, in addition to biological factors, influence behavior.

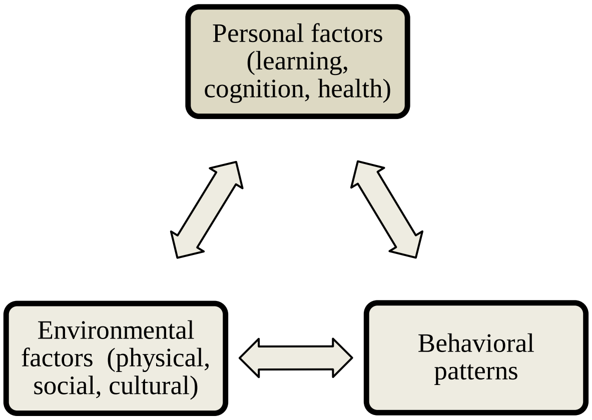

Figure 1.1. Reciprocal relationships in Bandura’s Social Cognitive Theory.

Social Cognitive Career Theory (SCCT) is a conceptual framework for understanding the aspects involved in career development (Lent, Brown, & Hackett, 1994). SCCT draws from Albert Bandura’s Social Cognitive Theory and presents three building blocks of career development: self-efficacy, outcome expectations, and personal goals. Self-efficacy refers to an individual’s beliefs about his/her abilities to succeed. A person’s self-efficacy develops in four ways: through personal performance and mastery, social modeling (vicarious learning from others like you), social support from others, and improvement of psychological and physical well-being (Bussey & Bandura, 1999). Outcome expectations refer to a person’s beliefs about what will result from performing specific behaviors and might include things like monetary gains, social approval or disapproval, and self-satisfaction (Lent et al., 1994). Individuals set personal goals to guide their behavior and increase the likelihood of achieving desired outcomes.

According to SCCT, individuals choose careers based in part on their attitudes, values, and interests. Individuals are more likely to have positive attitudes towards and express interests in activities they feel confident in (high self-efficacy) and from which they expect positive outcomes. Additionally, increased interest in a particular activity is likely to result in an individual spending a greater amount of time participating in that activity. Increased participation or practice in a particular area can also result in improved skills which will lead to higher self-efficacy, thus reinforcing interest in the area (Lent et al., 1994). On the flip side of this, if individuals do not feel confident in certain activities (such as teaching engineering) they will be more likely to avoid participating in those activities.

Assumptions, Limitations, and Delimitations

It is assumed that all participants held a valid teaching certificate or license for teaching elementary students in Oklahoma and were employed as full time teachers in a K-5 classroom during the time they completed the questionnaire. Furthermore, it is assumed that all participants responded to the questionnaire honestly and to the best of their ability. The study is limited to the participants who volunteered to complete the questionnaire. Every effort was made to ensure that the sample population is an accurate representation of the general population; however, the researcher had no control over who chose to participate in the study. The study is delimited to grade K-5 teachers who are currently employed in a public school in Oklahoma and who are responsible for the science instruction of their students.

Definition of Terms

Engineering – “a systematic and often iterative approach to designing objects, processes, and systems to meet human needs and wants” (NRC, 2012, p. 202)

Engineering design – “an iterative process that begins with the identification of a problem and ends with a solution that takes into account the identified constraints and meets specifications for desired performance" (Committee on Standards for K-12 Engineering, 2010, p. 6-7)

Engineering self-efficacy – Self-efficacy refers to an individual's belief in his or her ability to produce a desired or intended outcome (Bandura, 1977). Engineering self-efficacy refers to an individual's belief in his or her ability to engage in engineering practices, specifically engineering design.

Engineering teaching self-efficacy – A teacher's belief in his or her ability to teach engineering to his or her students.

Familiarity with engineering and engineering design – Merriam Webster defines familiarity as the state of having knowledge about something (Familiarity, Def. 2). In this study, familiarity with engineering will refer to the extent to which an individual has knowledge or experience related to engineering and engineering design.

Perceptions of engineering – Perceptions can be defined as "a way of regarding, understanding, or interpreting something; a mental impression" (Perception, Def. 2). For the purposes of the current study, perceptions of engineering will refer to the way an individual regards, understands, or views engineering and engineering design practices.

Perceived barriers to teaching engineering – Any obstacle that a teacher views as inhibiting or preventing him or her from teaching engineering in the classroom.

Technology – "any modification of the natural world made to fulfill human needs or desires" (NRC, 2012, p. 202)

Technological literacy – "the ability to use, manage, assess, and understand technology" (ITEEA, 2007, p. 9)

Summary

This introductory chapter provides background information related to the current study, as well as the purpose and significance of the study. Chapter II presents a synthesis of literature related to elementary engineering education and the theoretical framework that guides the study. Chapters III, IV, and V are independent studies that investigate elementary teachers' perceptions of engineering, engineering design, and K-5 engineering education, as well as teachers' self-efficacy related to teaching engineering. Chapter VI provides a summary of the complete manuscript.

CHAPTER II

REVIEW OF LITERATURE

Over the past century, advances in technology have greatly impacted the way people live and interact, yet many Americans do not have a basic understanding of the fundamental nature of technology. The National Research Council (NRC) defines technology as “any modification of the natural world made to fulfill human needs or desires” (NRC, 2012, p. 202). However, technology is often misunderstood and its meaning is often restricted to a more narrow definition of objects requiring the use of electricity (Cunningham, Lachapelle, & Lindgren-Stricher, 2006). Further, NRC defines engineering as “a systematic and often iterative approach to designing objects, processes, and systems to meet human needs and wants” (NRC, 2012, p. 202). When examining the definitions of technology and engineering side by side, it is clear that engineers are involved in the development and innovation of technology. In order to ensure the technologically literate citizenry recommended by the International Technology and Engineering Educators Association (ITEEA) (ITEEA, 2007), K-12 students will need to develop a basic understand of engineering and how it is used to develop technology.

This paper reviews the professional literature related to elementary engineering education. First, an overview of the need for engineering education is presented, followed by a discussion of the characteristics and core concepts of engineering. Next, research related to the perceptions of engineering and engineering design in elementary schools is presented. Then, a body of work pertaining to self-efficacy, teacher efficacy, and teaching engineering efficacy is discussed. The paper concludes with a final summary of the literature and identification of the gaps that will be addressed.

Need for Engineering Education

Technology has changed the global economy and the world of work; and the quality of science, technology, engineering, and mathematics (STEM) education drives economic productivity (Drew, 2011). When examining the top 100 news stories of the twentieth century, Bybee (2011) noted that 40% of the stories were directly related to engineering and technology, demonstrating the importance of engineering in the United States. Engineers, through the application of mathematics and science, develop and improve technology, making them a vital part of the nation's STEM workforce. The STEM aptitude of the workforce directly relates to the nation's capacity for research and innovation in areas such as national security, energy usage, and biomedical sciences (Committee on Standards, 2010). Thus, to remain competitive on a global scale, the United States will need a well prepared STEM workforce that includes engineers.

In a 2011 report entitled *Successful K-12 STEM Education: Identifying Effective Approaches in Science, Technology, Engineering, and Mathematics*, the National Research Council described three goals for K-12 STEM education: 1) increase the number of students (including women and minorities) who pursue advanced degrees and careers in STEM fields, 2) increase the number of STEM-capable students (including women and minorities) who enter the workforce, and 3) increase STEM literacy for all students. Further, the Committee on K-12 Engineering Education (2009) described five potential benefits of including engineering education in K-12 classrooms: 1) improved learning and achievement in mathematics and science, 2) increased awareness of engineering, 3) increased interest in engineering as a possible career, 4) understanding of engineering and ability to engage in engineering design, and 5) enhanced technological literacy. These goals and potential benefits can be combined into three categories – student achievement, creating a STEM pipeline, and enhancing the STEM mainline.

Student Achievement. The Program for International Student Assessment (PISA) compares the learning outcomes for 15-year-old students from different countries. PISA measures students' abilities to apply mathematics, science, and reading literacy skills to real world contexts. Results of the 2012 PISA indicated that US students ranked 36th in mathematics literacy and 21st in science literacy, when compared with students from the 65 nations participating in the assessment (Kelly, Xia, Nord, Jenkins, Chan, & Kastberg, 2013). While some researchers caution against a reliance on PISA data when setting education policy due to biases in the data (Dohn, 2007), the PISA data do point to the need for programs that will improve American students' abilities to apply mathematics and science content to real-world contexts.

Engineering activities require students to apply mathematics and science knowledge in order to solve design challenges and are linked to mathematics and science achievement. Elementary students who participated in *Engineering is Elementary* curriculum programs showed an increased science content knowledge (Lachapelle & Cunningham, 2007). Similarly, elementary, middle, and high school students who participated in Engineering Our Future New Jersey saw increased math and science scores on state achievement tests (Hotaling et al., 2007). Additionally, students attending an engineering-focused elementary school showed significant gains in state mathematics and science test scores after completing the engineering curriculum (Parsons et al., 2007). Studies examining the impact of Project Lead the Way are very mixed in nature, with results ranging from no impact on local assessments (Tran & Nathan, 2010), to increased performance on math and science state assessments (Schenk, Rethwisch, Chapman, Laanan, Starobin, & Zhang, 2011), and increased math and science performance on the National Assessment of Educational Progress (NAEP) (Bottoms & Anthony, 2005). While the results vary with program and study, available research results suggest that students' math and/or science performance can be enhanced through engagement in engineering activities. Further, using engineering design to teach math and science could enhance students' communication and spatial reasoning skills, abilities to develop cognitive models of systems, synthesize information, and conduct experiments (Brophy, Klein, Portsmore, & Rogers, 2008).

Creating a STEM Pipeline. According to the Bureau of Labor Statistics, between 2012 and 2022, STEM occupations are expected to grow 13% while non-STEM occupations are only expected to grow 11%. Additionally, job growth in engineering fields such as biomedical, petroleum, civil, computer, and software engineering are each projected to grow over 20% between 2012 and 2022 (Vilorio, 2014). Currently, too few elementary and secondary students show an interest or high achievement in STEM (Drew, 2011), resulting in a projected shortage of qualified STEM graduates.

While this projected shortage in the STEM workforce has resulted in the US Department of Education and many businesses focusing efforts on STEM programs, the

“E” in STEM has largely remained silent. Engineering is the only one of the four STEM disciplines that does not have national stand-alone standards (Committee on K-12 Engineering Education, 2009). However, engineering standards are included in the *Standards for Technological Literacy* (ITEEA, 2007) and the *Next Generation Science Standards* (NGSS Lead States, 2013). It is estimated that since 1990, only 5 million of the 56 million K-12 students in the United States have experienced formal engineering curriculum (Committee on Standards, 2010), which is possibly due to the lack of national and state standards.

Many students capable of becoming engineers do not because they (a) do not understand what engineers do or (b) do not think they have the abilities needed to become an engineer; this is particularly common for underrepresented groups such as females and minorities (Committee on K-12 Engineering Education, 2009). Because students’ interests in (Hall, Dickerson, Batts, Kauffmann, & Bosse, 2011) and prior knowledge of a profession (Wyss, Heulskamp, & Siebert, 2012) have been reported to influence career choices, a lack of exposure to engineering in grades K-12 could limit the number of students pursuing engineering careers.

While limited, research does suggest that students who participate in engineering activities and classes may become more interested in engineering as a career and remain in the pipeline. Ferreira (2002) conducted a case study to determine the impact that an after school engineering program had on 18 African American middle school girls. Ferreira (2002) found a 25.7% increase in the number of girls who indicated they would like to become an engineer after participating in the biweekly afterschool engineering program. Likewise, Anderson, Gilbridge, and Bajaj (2005) reported that high school girls who attended a summer engineering program reported increased interest in engineering, Based on exit-survey data, Anderson et al. (2005) reported that over 80% of the 350 camp attendees reported that the camp increased their interest in engineering as a future career. Further, Anderson et al. (2005) conducted multiple follow-up surveys with campers after they graduated high school and found that approximately 30% of camp participants went on to pursue an engineering career. Furthermore, Taylor, Foster, and Ratcliff (2006) reported that engineering majors who participated in Project Lead The Way (PLTW) programs during high school were more likely to complete their engineering degrees than those who did not participate in PLTW.

Enhancing the STEM Mainline. An important goal of STEM education is to enhance the STEM knowledge of all students and create a technologically literate citizenry (mainline). Being able to recognize technology and the relationship between engineering and technology is a prerequisite of technological literacy (ITEEA, 2007). Students who are exposed to engineering instruction have improved their understanding of technology (Cunningham et al., 2006; Hammack, Ivey, Utley, & High, 2015; Hotaling et al, 2009), and thus enhanced their technological literacy. Further, technologically literate citizens understand how technology impacts society and can make informed decisions about issues impacting society (Committee on K-12 Engineering Education, 2009). Individuals need to know how to make informed decisions about what products they use, heath care options, and how to trouble shoot malfunctioning equipment, just to name a few. Citizens who do not understand technology or its impacts on society will leave these important decisions to guesswork, which could not only have negative impacts for them as individuals, but could also impact those around them. On a larger scale, the United States gives citizens the opportunity to elect the officials who create laws governing everything from scientific research to energy policy, making technological literacy an important aspect of being an informed voter.

In addition to being able to make personal and political decisions, citizens with STEM knowledge will be more prepared for the workforce of the future. According to the United States Census Bureau (2014), 74% of college graduates with a Bachelor's degree in a STEM field are employed in nonSTEM fields, suggesting that STEM skills can easily be applied in nonSTEM work settings. In addition, STEM graduates have lower unemployment rates than nonSTEM graduates, possibly because their education provided them with skills that are valued by a variety of employers.

K-12 Engineering Education Standards

To meet the growing demands for engineers and a technologically literate citizenry, students must be given the opportunity to explore their strengths and interests in engineering (ITEEA, 2007). National standards have a great influence over what is taught in public schools across the United States; therefore, national standards for engineering could greatly impact the exposure K-12 students have to engineering (Committee on Standards, 2010). Before engineering standards for K-12 education can be enacted, however, it will be necessary for educators to understand the nature of engineering and the core concepts it encompasses. When making recommendations about what should be included in engineering education, the Committee on Standards for K-12 Engineering (2010) put forward three general principles, stating that engineering education should (a) emphasize engineering design, (b) incorporate mathematics, science, and technology knowledge and skills, and (c) promote engineering habits of mind.

Identifying Core Concepts. Engineering is a very broad discipline, and the work of engineers can range from designing the fuselage of a Boeing 747 aircraft to developing a time release capsule surrounding a new blood pressure medication. The specific tasks associated with design projects in different engineering disciplines vary greatly, which can make it difficult to reach a consensus on the key concepts associated with engineering. After a thorough review of the literature and conducting focus groups with professional engineering educators, the Committee on Standards for K-12 Engineering (2010) identified 100 themes that were important to engineering education. The list was condensed to 14 core concepts that are appropriate for secondary level engineering education. Table 2.1 presents the 14 core concepts (Committee on Standards, 2010). There is overlap between many of the core concepts and most are encompassed within the engineering design process (design, modeling, constraints, innovation, optimization, experimentation, prototyping, trade-offs, analysis, problem solving, and visualization). Additionally, systems, functionality, and efficiency are all concepts engineers use while engaging in the design process.

Table 2.1

Core Engineering Concepts and Descriptors

Concept	Descriptors
Design	Iterative, technological, analysis based, experimental, ergonomic, universal
Modeling	Mathematical, computer-based, sketching, technical drawing, physical
Constraints	Criteria, specifications, limitations, requirements
Innovation	Creativity, improvement, refinement, invention
Systems	Input/output, process, feedback, component design and interaction, subsystems
Optimization	Improvement, refinement, balancing, decision heuristics
Experimentation	Testing, test development, trial and error
Prototyping	Physical and process modeling and evaluation, preliminary
Trade-offs	Conflicting constraints, negotiation, competing requirements or criteria
Analysis	Risk, cost/benefit, life-cycle, failure, mathematical, decision, functional, economic
Problem solving	Description of need, solution generation, troubleshooting, invention, design
Functionality	Key engineering goal, usefulness, practicality
Visualization	Imagery, spatial and abstract representation, sketching
Efficiency	Key engineering goal, guiding principle

Table 2.2 presents the engineering disciplinary core ideas that are presented in *A Framework for K-12 Science Education* (NRC, 2012) and *Next Generation Science Standards* (NGSS) (NGSS Lead States, 2013). There are clear connections between the

engineering core concepts presented in Table 2.2 and the core idea of engineering design presented in Table 2.1, with the most prominent commonality between the two tables being engineering design. It is important to note that the core concepts presented in Table 2.1 were recommended for secondary level students, while those presented in Table 2.2 were meant to be used across all K-12 grade levels, which may explain some of the differences between the core concepts and ideas presented in the two tables.

Table 2.2

Core and Component Ideas in Engineering, Technology, and Applications of Science

Disciplinary Core Idea	Core Idea	Component Idea
Engineering, Technology, and Applications of Science	ETS1: Engineering Design	ETS1.A: Defining and Delimiting an Engineering Problem ETS1.B: Developing Possible Solutions ETS1.C: Optimizing the Design Solutions
	ETS2: Links Among Engineering, Technology, Science, and Society	ETS2.A: Interdependence of Science, Engineering, and Technology ETS2.B: Influence of Engineering, Technology, and Science on Society and the Natural World

The Committee on Standards for K-12 Engineering described the engineering design process as iterative; open to many different possible design solutions; a meaningful context for applying math, science, and technological knowledge; and a way to stimulate modeling, analysis, and systems thinking. Providing students with opportunities to apply math, science, and technological knowledge while engaging in engineering design challenges is an important aspect of NGSS. In addition, it is important to promote the habits of mind associated with engineering, which include systems thinking, a desire to encourage and support effective teamwork, and a concern for the societal and environmental impacts of technology (Committee on Standards, 2010).

The Case Against Stand-alone Engineering Standards. In their 2010 report, the Committee on Standards for K-12 Engineering did not recommend the development of national stand-alone standards for engineering education. While they determined that it was possible to develop such standards, they believed it would be very difficult to ensure that the standards would be effective. One reason the committee gave for not developing stand-alone engineering standards was the lack of teachers who are qualified to teach engineering. The United States employs 276,000 math teachers, 247,000 science teachers, and 25,000-35,000 technology teachers; however, only 18,000 US teachers have received pre- or in-service training that would prepare them to teach engineering (Committee of Standards, 2010).

Infusion, the second approach recommended by the committee, involves including standards for engineering within the standards for another discipline. The *Standards for Technological Literacy* (ITEEA, 2007) and the *Next Generation Science Standards* (NGSS Lead States, 2013) are examples of engineering infusion. Infusion is advantageous because if engineering standards are incorporated within science, mathematics, and technology standards, the link between the STEM disciplines becomes very clear to teachers and students. Additionally, infusion would result in engineering content being included on science, mathematics, and technology assessments.

Rather than develop stand-alone engineering standards, the Committee on Standards for K-12 Engineering suggested the use of mapping and infusion as ways to integrate engineering into already established content standards. Mapping involves the dissection of current content standards to determine where engineering would fit within those standards. For example, national math standards would be examined to find areas in which engineering might easily fit within the already established and enacted standards. Once the fit was determined, math teachers could incorporate engineering activities into their lessons when teaching the mapped standards. Mapping could help teachers draw attention to engineering and engage students in engineering activities while teaching their mandated content standards.

Engineering in elementary schools

With the current high-stakes testing system in place, teachers are under immense pressure to teach an already jam packed curriculum, so it is unlikely that most American teachers will add engineering to their curriculum unless it has been incorporated within the education standards for the subject and grade level they teach. With the recent incorporation of engineering standards in NGSS, the nation should see an increase in the implementation of engineering curriculum across the country; however, there is concern about how prepared teachers are to teach engineering to their students.

Developmental appropriateness of K-5 engineering. Children are born with a natural desire to figure out how things work and design their own creations (Cunningham, 2009). The fundamental activity of engineering is design, which naturally permeates children's lives (Petroski, 2003), and children are capable of successfully working through the design process (Brophy, Klein, Portsmore, & Rogers, 2008). Berrett (2006) reported that while some engineering concepts may be more challenging for children to understand, such as optimization and robust design, elementary students do have the ability and interest to benefit from engineering curriculum. Further, Perrin (2004) reported that K-4 students are able to question and investigate the world around them, and have the motor skills needed to use measurement tools and complete engineering activities.

If presented in a fitting way, with the correct support structures, engineering is developmentally appropriate for children, and they can engage in sophisticated design challenges well before young adulthood (Schunn, 2009). Cunningham (2009) reported that students who participated in *Engineering is Elementary* curriculum developed by the Boston Museum of Science had an improved understanding of engineering, technology, and science as a result of their engagement in engineering activities. Further, using design to teach mathematics and science can enhance children's communication and spatial reasoning skills, and their abilities to develop cognitive models of systems, synthesize information, and conduct experiments (Brophy et al., 2008). In fact, the engineering-focused Douglas L. Johnson Jr. Elementary School has seen significant gains in state reading and math scores and a decrease in discipline issues by using an all engineering-focused curriculum (Barger, Gilbert, Poth, & Little, 2006). It is important to note, however, that this program is still young and the results should not be heavily relied upon until further data is collected.

Perceptions of engineering. Many Americans do not understand what engineering is and often confuse the work of engineers with the work of scientists, construction workers, or mechanics (Oware, Capobianco, & Diefes-Dux, 2007). This lack of understanding leads to misconceptions that could prevent talented adolescents form entering the engineering pipeline. Studies employing the Draw-an-Engineer (DAE) instrument (Knight & Cunningham, 2004) highlight the stereotypical misconceptions that children hold about engineering. Children often perceive engineers as people who build and fix things and are much more likely to create drawings of white, male engineers who are working alone than drawings of women, minorities, or people working in groups (Fralick, Kearn, Thompson, & Lyons, 2009; Hammack & High, 2014; Karatas, Micklos, & Bodner, 2011).

Karatas and colleagues (2011) conducted a phenomenographic study of 20 sixth graders from a small Midwestern town, during which they conducted individual 45-minute-long interviews with students after completing the DAE instrument. During the interviews, students were asked questions about their drawings, were shown pictures associated with artifacts (electronics, roads, roller coasters), and asked questions about how engineers may have been involved in developing the products. Students were also asked to define engineering, describe the differences between science and engineering, and explain how engineering is related to society. Karatas et al. (2011) reported that students tended to characterize engineers as people who build or fix things; however, they did mention aspects of design as well. These finding are similar to the results of Hammack and High (2014) and Fralick et al. (2009) who also reported drawings associated with building and fixing things. When asked about their drawings, students' perceptions of engineers were fragile and tended to change throughout an interview, with students contradicting themselves about engineers, suggesting that students have unclear perceptions of engineering (Karatas et al., 2011). This was also seen in the interview responses to different pictures. Based on the product they were shown, students had different responses to how engineers were involved in product development, indicating that they did not have a firm grasp on what engineers do. Most attributed work done by other professions as engineering (e.g. architects, construction workers, scientists, and mechanics). When asked to differentiate between scientists and engineers, most students described scientists as studying life, possibly because their previous science studies were limited to life science (Karatas et al., 2011).

Only one drawing in the Karatas et al. (2011) study depicted a female engineer, yet when the students were asked if engineering was a man's job, they all answered no. Similarly, Fralick and colleagues (2009) reported that only 13% of the 744 DAE drawings analyzed in their study depicted female engineers. Hammack and High (2014), however, reported a higher percentage of students depicting female engineers in their drawings (17.6% female, 16.7% male, 65.7% undetermined). All participants in the Hammack and High study were 6th and 7th grade females who self-selected into a girls' engineering club and all club instructors were female, suggesting that the larger proportion of female drawings could have been due to self-identification. The DAE studies suggest that while students believe that women can be engineers, the field is predominately characterized as male.

Adults are prone to similar preconceptions about the nature of engineering (Liu, Carr, & Strobel, 2009). In fact, kindergarten through twelfth grade teachers are more likely to believe that engineers are the people constructing a building than the ones supervising the construction (Cunningham et al., 2006). Additionally, when asked to describe engineering, few pre-Kindergarten through 6th grade teachers described engineering as being linked to science and mathematics, involving teamwork and communication, or being creative (Lambert, Diefes-Dux, Beck, Duncam, Oware, & Nemeth, 2007), all of which are related to the three general principles of engineering education put forth by the Committee on Standards for K-12 Engineering (2010).

Teachers' perceptions toward science influence students' perceptions toward science, and likewise, it is expected that teachers' perceptions of engineering will influence students' perceptions of engineering (Lambert et al., 2007). Teachers' perceptions of engineering are affected by their limited understanding of engineering (Yasar, Baker, Kurpius-Robinson, Krause, & Roberts, 2006a; Yasar, Baker, Kurpius-Robinson, Krause, & Roberts, 2006b) which can be passed on to their students. Due to a limited understanding of engineering, elementary teachers often do not view engineering as an appropriate career choice for all students (Brophy et al., 2008), believing that only "super smart" teachers and students can learn engineering concepts (Cunningham, 2009), and place less value on teaching engineering design than secondary teachers do (Yasar et al., 2006a, 2006b). This may result in teachers focusing their efforts on content they feel will benefit all students and not just the few who they view as capable of becoming engineers (Brophy, Klein, Portsmore, & Rogers, 2008). Additionally, teachers who have a narrow view of engineering might misrepresent engineering careers to their students, thus missing the opportunity to encourage students to enter the STEM pipeline (Yasar et al., 2006a).

Teaching engineering design. Teachers are uncomfortable teaching what they do not know or are unfamiliar with (Brophy et al., 2008). The familiarity with engineering construct is not well developed in the research literature and studies are limited to those using an instrument developed by Yasar and colleagues. Yasar et al. (2006a, 2006b) used a Likert scale instrument to measure K-12 teachers' familiarity with engineering, engineering design, and technology (DET). Most teachers in the study had low familiarity with DET, which they attributed to lack of knowledge, lack of administrative support, lack of training, and lack of time for learning about DET. Subsequent studies using the instrument developed by Yasar et al. (2006a, 2006b) reported similar findings (Hsu, Purzer, & Cardella, 2011; Hsu, Cardella, Purzer, & Diaz, 2010).

Many pre-kindergarten through eighth grade teachers have limited STEM content knowledge (Brophy et al., 2008) which may result in the avoidance of teaching engineering. While working with teachers in Scotland, Harlen and Holroyd (1997) determined that elementary teachers employed coping strategies when they did not feel confident in their abilities to teach science content. Examples of the coping strategies included: (a) placing as little of the content as possible in the weekly lesson plans so the content could be the first item removed if the class is behind schedule; (b) compensating for low confidence areas (e.g. physical science) by teaching more high confidence content (e.g. life science); (c) relying heavily on worksheets or kits that have step-by-step instructions; (d) emphasizing teacher-centered instruction with little opportunity for student questions or discussions; (e) only using the simplest science equipment and activities (e.g. using hand lenses rather than microscopes); and (f) seeking help from colleagues and experts (Harlen & Holroyd, 1997). It is expected that teachers would employ similar coping strategies when faced with teaching engineering content with which they are unfamiliar.

Regardless of subject or grade level taught, effective classroom instruction requires the teacher to possess subject matter content knowledge (SMCK), curricular knowledge (CK), and pedagogical content knowledge (PCK) (Shulman, 1986). SMCK refers to knowledge of the component facts and concepts of a subject as well as the ways in which the facts and concepts are arranged and validated. CK refers to a knowledge of the instructional resources available for teaching a subject. Shulman (1986) defined PCK as "the ways of representing and formulating the subject that make it comprehensible to others" (p. 9). PCK includes an understanding of what makes particular concepts difficult to understand and the preconceptions and misconceptions students have about a subject.

Design is the fundamental activity of engineering (Petroski, 2003) and teaching engineering design requires SMCK, CK, and PCK. Teachers who are unfamiliar with the nature of engineering design will be unable to address engineering design standards or identify ways to infuse engineering into their curriculum (Baker, Yasar-Purzer, Kurpius, Krause, & Roberts, 2007). The open-ended nature of engineering design means that design challenges do not have a single solution. Teachers must assess engineering design activities not only by how well the developed design solution solves the problem, but also by the processes the students went through to develop the solution (Brophy et al., 2009). Teachers with greater PCK are better able to determine children's understandings by observing their behaviors and performances, and use that information to modify class instruction (Bischoff, 2006). Many elementary teachers have never taught using open-ended problems that do not have a single “correct” answer (Cunningham, 2009) and may lack the PCK to effectively teach using open-ended engineering design challenges.

SMCK and PCK are required for teachers to understand real-world applications of content and to design effective instruction (Davis, 2003). Engineering design is an iterative process (Schunn, 2009; Silk & Schunn, 2008), and when students are given the opportunity to redesign, they develop a more complete understanding of the related engineering concepts (Schunn, 2009). Short duration exposures to engineering are not likely to lead to meaningful learning (Schunn, 2009) because they do not provide students with the opportunity to learn from their mistakes. In order to facilitate redesign activities, however, teachers must possess appropriate knowledge to help students identify the weaknesses in their original designs and ways to improve upon those designs. Additionally, it is critical that design lessons require the application of math and science and are situated within real-world contexts (Guzey, Tank, Wang, Roehrig, & Moore, 2014) which require teachers to possess SCMC, CK, and PCK related to engineering.

Self-efficacy

There are several theoretical approaches to examining self-efficacy. The theoretical approach informing this study is based on Albert Bandura’s (1977, 1988, 1989) Social Cognitive Theory (SCT). According to Bandura, “what people think, believe, and feel affects how they behave” (Bandura, 1992, p. 2-3). SCT posits a triadic reciprocal relationship between human behavior, environmental influences, and personal factors, with each factor interacting with and influencing the other two. The amount of influence exerted by each of the three factors varies for different people and during different activities. People can reflect on these factors and have some influence over their behaviors by considering different alternatives, foreseeing and weighing consequences, and evaluating their perceived abilities to succeed in the possible situations they have considered (Bandura, 1986).

Self-efficacy refers to an individual's belief in his or her ability to produce a desired or intended outcome. Self-efficacy, as described by Albert Bandura (1977), consists of two dimensions – outcome expectancy and efficacy expectation. Bandura (1977) defines outcome expectancy as "a person's estimate that a given behavior will lead to certain outcomes" (p. 193) and efficacy expectation as "the conviction that one can successfully execute the behavior required to produce outcomes" (p. 193). Individuals' behaviors are impacted by both outcome expectancy and efficacy expectations; however, efficacy is a better predictor of behavior than expected outcomes (Bandura, 1986). For example, individuals might believe that a specific action will have a particular outcome that they desire (outcome expectancy); however, if they do not feel they can successfully complete the required behavior (efficacy expectations) then they may choose to refrain from engaging in the required behavior even though it is thought to bring about desired outcomes. Additionally, self-efficacy is task specific and individuals with high self-efficacy in one area may have low self-efficacy in a different area (Bandura, 1977).

A person's self-efficacy develops through four sources of information: performance accomplishments, vicarious experiences, verbal persuasion, and emotional arousal (Bandura, 1977, 1989; Pajares, 2002). Personal accomplishments are mastery experiences and are the most powerful of the four sources of self-efficacy (Bandura, 1988). If a person experiences success in an area, then his or her self-efficacy related to that area tends to improve. Likewise, if the person fails at a task then his or her self-efficacy in that area tends to decrease. As the number of mastery experiences in an area increases, so does the impact on self-efficacy. The same is true for the number of failures in an area, with increased failures resulting in a greater negative effect on self-efficacy The timing of the success or failure is also important to the development of self-efficacy (Bandura, 1977, 1988). Once a person has become secure in his or her successes, he or she will be able to manage setbacks (failure). In fact, occasional failures followed by success due to sustained effort can increase self-efficacy. However, if a person encounters many failures despite putting forth effort, or only experiences success after exerting a very large amount of effort, his or her self-efficacy may decrease.

Individuals may also develop self-efficacy through vicarious experiences (Bandura, 1977, 1988, 1989; Pajares, 2002). Individuals make judgments about their own abilities based on the experiences of others who they view to be similar to themselves. If an individual witnesses a peer successfully complete a task, the individual may also think that he or she will do well on a similar task. However, if an individual witnesses a peer fail, it may weaken an individual’s view of his or her own abilities. The level of success achieved and the amount of effort put forth also impact vicarious experiences. For example, witnessing a peer have great success with minor effort would have a greater impact on enhancing self-efficacy than witnessing lesser success with greater effort.

Individuals may also be persuaded into believing that they are able to successfully engage in behaviors they have previously avoided (Bandura, 1977; Pajares, 2002). The impact of verbal persuasion may depend on the credibility of the persuader and the individual's ability to successfully engage in a task. If the persuader is not trustworthy or credible, then verbal persuasion will likely be ineffective. Similarly, if an individual is persuaded to engage in a task and then fails at the task, self-efficacy would be reduced. However, if a trustworthy individual provides realistic encouragement that results in a successful mastery experience, self-efficacy can be increased (Bandura, 1988).

The final source of information impacting self-efficacy is emotional arousal or physiological state (Bandura, 1977, 1988; Pajares, 2002). People often view their emotional responses to a situation as signs of their performance abilities (Bandura, 1988). When a person is met with negative emotions (e.g. fear, anxiety), his or her performance may suffer, leading to negative thoughts about his or her abilities, which can lead to even higher levels of fear and anxiety. This can lead to a person avoiding a behavior all together. Conversely, positive emotional arousal (e.g. excitement) or a lessoning of negative emotional arousal can reduce the desire to avoid a behavior.

Self-judged capabilities influence the career options people consider, how much interest they show in a career, and the job paths they ultimately follow (Bandura, 1992; Lent et al., 1994). According to Social Cognitive Career Theory, individuals choose career paths based on their interests, attitudes, and values (Lent et al., 1994). Because people spend more time participating in activities they have high self-efficacy in, they are likely to enhance their skills related to those activities, and thus enhance their self-efficacy. Individuals can then choose career paths based upon these developed skills they feel confident in. Conversely, if individuals have low self-efficacy in an area (such as teaching engineering), they may avoid participating in activities that could enhance their skills related to that area.

Teacher efficacy

Teacher efficacy was first conceptualized by the RAND organization (Armor et al., 1976) and can be defined as a teacher's belief that he or she can influence how well students learn, even if the students are unmotivated (Guskey & Passaro, 1994). The RAND studies of teacher efficacy were grounded in Rotter's social learning theory (Rotter, 1966) and consisted of two statements: 1) "When it comes right down to it, a teacher really can't do much because most of a student's motivation and performance depends on his or her home environment," and 2) "If I really try hard, I can get through to even the most difficult or unmotivated students" (Armor et al., 1976). Teachers who strongly agree with the first question tend to believe that external factors (outside of the classroom) have a greater impact on student learning than teachers do. These beliefs have been labeled *general teaching efficacy*. Teachers who strongly agree with the second question tend to believe that good teachers can bring about student learning despite external factors that may be working against them. These beliefs have been labeled *personal teaching efficacy* (Gibson & Dembo, 1984).

A second strand of teacher efficacy research was grounded in Bandura's social cognitive theory (Bandura, 1977). Gibson and Dembo (1984) explained that the two RAND questions represented the two dimensions of self-efficacy described by Bandura (1977) – outcome expectancy and efficacy expectation. In 1984, Gibson and Dembo introduced the Teaching Efficacy Scale (TES), which they developed by applying the concepts of Bandura's self-efficacy while expanding on the two RAND questions. TES is commonly used to determine an individual’s self-efficacy related to teaching and consists of two scales – General Teaching Efficacy (GTE), corresponding to RAND question 1, and Personal Teaching Efficacy (PTE), corresponding to RAND question 2. GTE is a teacher’s belief that external factors limit his or her ability to elicit student learning. PTE is a teacher’s belief that he or she has the ability to bring about student learning. Higher scores on the GTE and PTE indicate higher teacher efficacy.

Research studies employing TES have reported that high teacher efficacy is associated with greater teaching effort and persistence in difficult situations, as well as higher student achievement (Tschannen-Moran, Woolfolk Hoy, & Hoy, 1998). High PTE has been linked to a willingness to implement new and/or innovative teaching methods (Allinder, 1994) and willingness to work longer with academically struggling students (Gibson & Dembo, 1984) before referring them for special education services (Allinder, 1994). Additionally, teachers with high teacher efficacy are more likely to use small group instruction as opposed to whole class lecture and less likely to criticize students who give incorrect responses to discussion questions (Gibson & Dembo, 1984).

Like self-efficacy, teacher efficacy is situation specific (Tschannen-Moran et al., 1998). Teacher efficacy is impacted by subject area, grade level, and student characteristics (e.g, socio economic status, special education, English language learners). Because teaching efficacy is subject specific, Riggs and Enochs (1990) developed the Science Teaching Efficacy Belief Instrument (STEBI) to better measure teacher efficacy related to science teaching. Like TES, STEBI consists of two scales aligned with Bandura’s two dimensions of self-efficacy, one measuring teaching efficacy (Personal Science Teaching Efficacy) and one measuring outcome expectancy (Science Teaching

Outcome Expectancy). Different variants of the STEBI have been developed for application in specific content areas (Enochs, Riggs, & Ellis, 1993; Enochs, Smith & Huinker, 2000). Studies employing STEBI and its derivatives have reported that science teachers with low self-efficacy rely more on textbook-based, teacher centered instruction (Cakiroglu, Capa-Aydin, & Woolfolk Hoy, 2012; Enochs, Scharmann, & Riggs, 1995). Additionally, elementary teachers with low science teacher efficacy spend less time teaching science than more efficacious teachers or may completely avoid science teaching (Cakiroglu, Capa-Aydin, & Woolfolk Hoy, 2012).

Teaching efficacy is dependent upon teachers' content knowledge and pedagogical content knowledge (Committee on Integrated STEM Education, 2014). Science teacher efficacy is higher for teachers who took greater numbers of high school science courses (Mulholland, Dorman, & Odgers, 2004) and college science courses (Cantrell, Young, & Moore, 2003). This could be because teachers who know the science content well are able to select appropriate pedagogical strategies that lead to more success in the classroom, which enhances self-efficacy (Yilmaz-Tuzun, 2008). It is estimated that few elementary teachers have high school or college coursework in engineering (Committee on Standards, 2010). This suggests that elementary teachers may lack the required background knowledge to teach engineering, which could result in low engineering teaching self-efficacy.

Engineering standards are now incorporated in the national science standards (NGSS), and engineering will be taught in science classrooms across the country. The way in which teachers approach engineering instruction in their classrooms will be impacted by their engineering teaching self-efficacy. Just as a teacher with high teaching self-efficacy for high school chemistry may have low teaching self-efficacy for middle school life science (Tschannen-Moran et al., 1998), teachers who have high teaching self-efficacy in the science content area they regularly teach may not have high engineering teaching self-efficacy.

Extensive research has been conducted on science teaching self-efficacy, however there is a dearth of research related to engineering teaching self-efficacy. In fact, the Teaching Engineering Self-Efficacy Scale (TESS) developed by Yoon, Evans, and Strobel (2014) was the first validated instrument for measuring K-12 engineering teacher efficacy to surface in the literature. However, published studies employing TESS are absent in the literature due to the newness of the instrument.

Teacher efficacy is a strong indicator of a teacher's ability to be successful in the classroom (Cakiroglu et al., 2012). Self-efficacy scales are widely used to measure teacher efficacy, however they may have limited reliability due to the nature of self-report measures. Teachers tend to avoid ranking themselves at the lowest scale levels, especially if they are responding to a scale as part of a post-intervention (Cakiroglu et al., 2012). Continued analysis and refinement of teacher efficacy instruments in needed to ensure the quality of the data collected. In addition, employing a variety of research methods when studying teacher efficacy can enhance the quality of information collected and offset some of the weaknesses associate with self-reported measures (Tschannen-Moran et al., 1998).

Summary

K-12 engineering education, and more specifically K-5 engineering education, is a relatively new field of study. The need to create both a STEM pipeline and STEM mainline make the incorporation of engineering into the elementary classroom an urgent need. The infusion of engineering standards within the *Next Generation Science Standards* should lead to the incorporation of engineering within all K-5 science curricula. This leads to concerns about how prepared elementary teachers are to successfully implement the new NGSS engineering standards.

Figure 2.1 depicts factors within the scope of this study that impact elementary engineering education. Teacher efficacy is related to content knowledge (Harlen & Holroyd, 1997) and both teacher knowledge and efficacy, in addition to engineering content, are expected to have great impacts on elementary engineering education (as shown in Figure 2.1). The subject matter content taught in schools is driven by the standards for the content area, which are developed based on the agreed upon purposes for teaching the subject in schools (Committee on Standards, 2010) and developmentally appropriate practices. In the case of engineering education, addressing common misconceptions and negative perceptions of engineering is directly linked to the purpose of developing a STEM pipeline. In addition, perceptions of engineering impact teacher efficacy, because if a teacher believes that only “super smart” people can understand engineering he or she may doubt his or her ability to teach engineering.

Teachers are likely to spend less time teaching in a content area that they have low efficacy in (Appleton, 2003; Harlen & Holroyd, 1997). Because teachers learn and grow with teaching practice, avoiding teaching experiences due to low efficacy can result in teachers missing valuable learning opportunities that could enhance their SMCK, CK, and PKC (Appleton, 2003), which will, in turn, impact the quality of elementary engineering education.

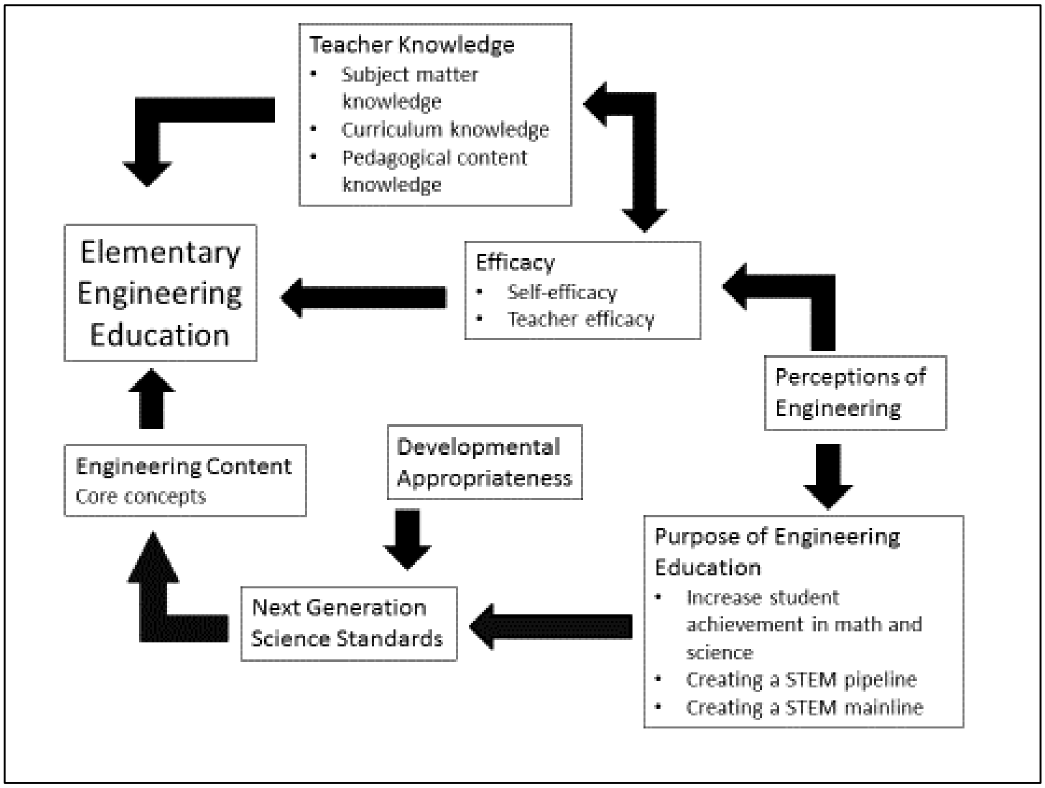

Figure 2.1. Factors impacting how engineering is taught at the elementary level.

The interrelated constructs in Figure 2.1 form the conceptual framework for this study. Literature devoted to K-5 educators' knowledge and perceptions of engineering and engineering design are far from complete, with a dearth of studies being devoted to elementary engineering education and engineering teaching self-efficacy. The current study helps address the gaps in the literature related to elementary engineering education by uncovering elementary teachers' understandings and perceptions of engineering and their perceived engineering teacher efficacy. This study also identifies factors elementary teachers perceive as barriers to teaching K-5 engineering, which will aid in the design of professional development programs to enhance engineering SMCK, CK, and PCK.

CHAPTER III

ELEMENTARY TEACHERS' PERCEPTIONS OF ENGINEERING AND ENGINEERING DESIGN

Target Journals: A. Journal of Engineering Education

B. International Journal of STEM Education

Authors: Rebekah Hammack, Toni Ivey

Abstract:

Background: The Next Generation Science Standards (NGSS) call for the infusion of engineering practices beginning in Kindergarten, yet little is known about how prepared elementary teachers are to incorporate these standards.

Purpose: The purpose of this study was to identify (a) the perceptions that in-service teachers hold about the nature of engineering and engineering design and (b) how these perceptions compare with the engineering practices put forth in NGSS.

Design/Method: This study employed an explanatory sequential mixed methods design. During Phase 1, participants completed an online questionnaire, the results of which were used to finalize interview protocols for Phase 2. During Phase 2 follow-up focus groups and interviews were conducted with a subset of Phase 1 participants.

Results: Findings indicate that participants were unfamiliar with engineering or engineering design and held stereotypical views of engineers. Many participants reported having little experience teaching engineering and were not able to distinguish between examples of science and engineering activities.

Conclusion: Elementary teachers are unfamiliar with engineering and are not prepared to incorporate the engineering practices prescribed by NGSS into their classrooms. Ongoing training will be required to provide elementary teachers with the tools necessary to effectively teach engineering.

Keywords: elementary, engineering education, teacher perceptions, NGSS

Introduction

As the United States becomes increasingly dependent on technology, the nation's demand for workers in the areas of science technology, engineering, and mathematics (STEM) has increased (International Technology Education Association, ITEA, 2007). To help address these demands, the National Research Council (NRC, 2012) released *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* in which they identified key scientific and engineering practices that all students should learn during K-12 education. The *Next Generation Science Standards* (NGSS) (NGSS Lead States, 2013) were developed based on the practices identified in the *Framework.* The NGSS call for the infusion of engineering practices into K-12 science classrooms; however, little is known about the preparedness of elementary teachers to incorporate these engineering standards. Available research suggests that elementary teachers feel unprepared to teach engineering practices (Banilower, Smith, Weiss, Malzahn, Campbell, &Weis, 2013; Sargianis, Yang, and Cunningham, 2012). One national survey indicated that only 4% of elementary teachers felt very well prepared to teach engineering to their students. This is considerably lower than the 39% who felt very well prepared to teach science and 77% for mathematics (Banilower et al., 2013).

Most teacher preparation programs do not prepare elementary teachers to incorporate engineering concepts and practices into their teaching, and in-service programs focused on engineering for elementary teachers are limited. Determining the perceptions that elementary teachers have of engineering, as well as their understanding of engineering design, will be vital to ensuring that teachers receive the proper professional development to successfully implement engineering concepts and practices in their classrooms. The development of such programs should be rooted in the research literature related to elementary engineering education; however, that body of literature is far from complete. The current study helps address the gaps in the research literature by describing elementary teachers' perceptions of engineering and engineering design.

Purpose of the Study

The purpose of this study was to identify (a) the perceptions that in-service teachers hold about the nature of engineering and engineering design and (b) how these perceptions compare with the engineering practices put forth in *A Framework for K-12 Science Education* and *Next Generation Science Standards.* Specifically, the study sought to answer the following research questions:

1. How familiar are in-service elementary teachers with engineering and engineering design?
2. What perceptions do in-service elementary teachers hold about engineers and engineering design?
3. Are there differences in teachers' familiarity with engineering or perceptions of engineers between different demographic groups?
4. How do in-service elementary teachers' perceptions of engineering and engineering design compare with expectations set by K-5 engineering education standards?

Related Literature

Many Americans do not understand what engineering is and often confuse the work of engineers with the work of scientists, construction workers, or mechanics (Oware, Capobianco, & Diefes-Dux, 2007). This lack of understanding leads to misconceptions that could prevent talented adolescents form entering the engineering pipeline. Studies employing the Draw-an-Engineer (DAE) instrument (Knight & Cunningham, 2004) highlight the stereotypical misconceptions that children hold about engineering. Children often perceive engineers as people who build and fix things and are much more likely to create drawings of white, male engineers who are working alone than drawings of women, minorities, or people working in groups (Fralick, Kearn, Thompson, & Lyons, 2009; Hammack & High, 2014; Karatas, Micklos, & Bodner, 2011).

Karatas and colleagues (2011) conducted a phenomenographic study of 20 sixth graders from a small Midwestern town, during which they conducted individual 45-minute-long interviews with students after completing the DAE instrument. During the interviews, students were asked questions about their drawings, were shown pictures associated with artifacts (electronics, roads, roller coasters), and asked questions about how engineers may have been involved in developing the artifacts. Students were also asked to define engineering, describe the differences between science and engineering, and explain how engineering is related to society. Karatas et al. (2011) reported that students tended to characterize engineers as people who build or fix things, however, they did mentioned aspects of design as well. These finding are similar to the results of Hammack and High (2014) and Fralick et al. (2009) who also reported drawings associated with building and fixing things. When asked about their drawings, students' perceptions of engineers were fragile and tended to change throughout an interview, with students contradicting themselves about engineers, suggesting that students have unclear perceptions of engineering (Karatas et al., 2011). This was also seen in the interview responses to different pictures. Based on the artifact they were shown, students had different responses to how engineers were involved in artifact (product) development, indicating that they did not have a firm grasp on what engineers do. Most attributed work done by other professions as engineering (e.g. architects, construction workers, scientists, and mechanics). When asked to differentiate between scientists and engineers, most students described scientists as those who only study life, possibly because their previous science studies were limited to the life sciences (Karatas et al., 2011).

Only one drawing in the Karatas et al. (2011) study depicted a female engineer, yet when the students were asked if engineering was a man's job, they all answered no. Similarly, Fralick and colleagues (2009) reported that only 13% of the 744 DAE drawings analyzed in their study depicted female engineers. Hammack and High (2014), however, reported a slightly higher percentage of students depicting female engineers in their drawings (17.6% female, 16.7% male, 65.7% undetermined). These participants were 6th and 7th grade females who self-selected into a girls' engineering club and all club instructors were female. Findings from the study suggest that the larger proportion of female drawings could have been due to participant self-identification. The DAE studies suggest that while students believe that women can be engineers, they primarily view engineering as a male field. Traditionally, the field of engineering has been predominately male. It is not clear if the perceptions revealed by DAE are an indication that participants viewed engineering as more appropriate for men than women or if it was simply a manifestation of the actual demographic make-up of the profession.

Adults are prone to similar preconceptions about the nature of engineering (Liu, Carr, & Strobel, 2009). In fact, K-12 teachers are more likely to believe that engineers are the people constructing a building than the ones supervising the construction (Cunningham, Lachapele, & Lindgren-Stricher, 2006). Additionally, when asked to describe engineering, few K-6 grade teachers described engineering as being linked to science and mathematics, involving teamwork and communication, or being creative (Lambert, Diefes-Dux, Beck, Duncam, Oware, & Nemeth, 2007), all of which are related to the three general principles of engineering education put forth by the Committee on Standards for K-12 Engineering (2010).

Research findings indicate that teachers’ perceptions toward science influence students’ perceptions toward science, and likewise, it is expected that teachers’ perceptions of engineering will influence students’ perceptions of engineering (Lambert et al., 2007). Teachers’ limited understanding of engineering impacts their perceptions of engineering (Yasar, Baker, Kurpius-Robinson, Krause, & Roberts, 2006a; Yasar, Baker, Kurpius-Robinson, Krause, & Roberts, 2006b) which can be passed on to their students. Due to a limited understanding of engineering, elementary teachers often do not view engineering as an appropriate career choice for all students (Brophy et al., 2008), believing that only “super smart” teachers and students can learn engineering concepts (Cunningham, 2009), and place less value on teaching engineering design than secondary teachers do (Yasar et al., 2006a, 2006b). This may result in teachers focusing their efforts on content they feel will benefit all students and not just the few who they view as capable of becoming engineers (Brophy, Klein, Portsmore, & Rogers, 2008). Additionally, teachers who have a narrow view of engineering might misrepresent engineering careers to their students, thus missing the opportunity to encourage students to enter the STEM pipeline (Yasar et al., 2006a).

Next Generation Science Standards (NGSS)

The NGSS are comprised of three dimensions: Science and Engineering Practices, Crosscutting Concepts, and Disciplinary Core Ideas. In NGSS, each of the standards is a performance expectation that incorporates all three dimensions. Table 3.1 presents the three dimensions of the Framework and NGSS as well as the components of each dimension. Table 3.2 presents the component ideas that make up Disciplinary Core Idea: Engineering, Technology, and Applications of Science (NGSS Lead States, 2013). The information presented in Tables 3.1 and 3.2 can be used as a framework to determine the knowledge K-12 teachers will need in order to implement engineering concepts and practices into their classrooms.

Table 3.1

Dimensions of the Framework and NGSS

Science and Engineering Practices	• Asking questions (for science) and defining problems • Developing and using models (for engineering) • Planning and carrying out investigations • Analyzing and interpreting data • Using mathematics and computational thinking • Constructing explanations (for science) and designing solutions (for engineering) • Engaging in argument from evidence • Obtaining, evaluating, and communicating information
Crosscutting Concepts	• Patterns • Cause and effect • Scale, proportion, and quantity • Systems and system models • Energy and matter • Structure and function • Stability and change
Disciplinary Core Ideas	• Physical sciences • Life sciences • Earth and Space sciences • Engineering, Technology, and Applications of Science

Table 3.2

Core and Component Ideas in Engineering, Technology, and Applications of Science

Disciplinary Core Idea	Core Idea	Component Idea
Engineering, Technology, and Applications of Science	ETS1: Engineering Design	ETS1.A: Defining and Delimiting an Engineering Problem ETS1.B: Developing Possible Solutions ETS1.C: Optimizing the Design Solutions
	ETS2: Links Among Engineering, Technology, Science, and Society	ETS2.A: Interdependence of Science, Engineering ,and Technology ETS2.B: Influence of Engineering, Technology, and Science on Society and the Natural World

Method

The current study is part of a larger mixed methods research study. Mixed methods research refers to any study that involves the collection, analysis, and interpretation of both qualitative and quantitative data (Creswell & Plano Clark, 2011). Both quantitative and qualitative data were used to compare the results from different phases of the study and provide greater insight into the problem being studied than by using a single method.

During the first phase, the *Next Generation Science Standards* document was analyzed to determine the knowledge required for elementary teachers to implement the engineering components required by the standards. Concurrently, participants completed an online questionnaire containing both open and closed-ended questions. The results from Phase 1 were used to finalize the interview protocols used during the individual and focus group sessions that took place during Phase 2 of the study. The interview protocols for the individual and focus group sessions are included in Appendices B and C, respectively. Data from both phases were merged to answer the research questions related to teachers' perceptions of engineering and engineering design and how these perceptions compare with the expectations set forth in NGSS.

Measures

Because the researcher was unable to identify a validated instrument that would fully answer each of the proposed research questions in the full study, subscales from existing validated instruments were combined (see Appendix A). Only those subscale questions which were pertinent to answering the current research questions are included in this study. The questions addressed in the current study consist of the *Familiarity with Design Engineering and Technology* and *Stereotypical Characteristics of Engineers* subscales from the Design Engineering and Technology Survey (DET) developed by Hong, Purzer, & Cardelal (2011), and the two researcher-generated open-ended questions "What words or phrases would you use to describe the characteristics of a typical engineer?" and "What do engineers do as part of their work?"

Design Engineering and Technology Survey (DET). The DET was originally developed by Yasar, Baker, Robinson-Kurpius, Krause, and Roberts (2006a, 2006b) and later re-evaluated and revised by Hong et al. (2011). The DET contains 40 items on a five point Likert scale, and is used to measure teachers' perceptions of engineering and familiarity with teaching engineering, engineering design, and technology. Exploratory factor analysis using a new sample of 405 participant teachers resulted in a 40-item four-factor instrument with an overall Cronbach's $\alpha = 0.88$. The resulting factors were *Importance of DET* (19 items, $\alpha = 0.91$), *Familiarity with DET* (8 items, $\alpha = 0.81$), *Stereotypical Characteristics of Engineers* (7 items, $\alpha = 0.77$), and *Barriers to Integrating DET* (6 items, $\alpha = 0.68$). The *Familiarity with DET* subscale and *Stereotypical Characteristics of Engineers* subscale were the only DET subscales included in the current study.

Participants

A link to the questionnaire was emailed to all Oklahoma K-5 public school teachers (n=16,546) whose information was on file with the Oklahoma State Department of Education, however 1,008 emails were returned undeliverable. The questionnaire was completed by 542 participants resulting in a 3.5% response rate. Tables 3.3 and 3.4 present demographic information for the sample. Oklahoma encompasses a large geographic region with both urban and rural populations, and the researcher wanted to ensure that the sample was representative of the geographic distribution of the state population. The Oklahoma State Department of Education has assigned all school districts in the state to one of eight geographic regions, which were used to evaluate the geographic distribution of the sample. The data in Table 3.3 reveal that the sample was representative of the state population of elementary teachers with regard to geographic distribution of teachers, gender, education level, grade level taught, and years of work experience.

Table 3.3.

Demographics of Oklahoma K-5 Teacher Population and Study Sample

		Population		Sample	
		Number	Percentage	Number	Percentage
Oklahoma Reac^{3}h Region[1]					
	1	670	4.03	26	4.80
	2	1181	7.10	48	8.86
	3	3538	21.28	159	29.34
	4	2180	13.11	55	10.15
	5	1049	6.31	18	3.32
	6	1384	8.32	37	6.83
	7	1058	6.36	30	5.54
	8	5567	33.48	169	31.18
Gender					
	M	698	4.20	16	3.00
	F	15929	95.80	526	97.00
Highest Education Level					
	Bachelor's	13090	78.73	381	70.30
	Master's/Education Specialist	3498	21.04	157	28.97
	Doctorate	36	0.22	4	0.74
	N/A	3	0.01	0	0.00
Teaching Experience					
(Years)	1 to 5	4926	29.63	163	30.07
	6 to 10	3501	21.06	111	20.48
	11 to 15	2506	15.07	85	15.68
	16 to 20	2224	13.38	69	12.73
	21 to 25	1613	9.70	48	8.86
	26 to 30	912	5.49	38	7.01
	31 to 35	534	3.21	15	2.77
	36-40	323	1.94	10	1.85
	over 40	88	0.53	3	0.55
Teacher Certification Type					
	Traditional	15951	95.93	491	90.59
	Nontraditional	676	4.07	51	9.41
Grade Level Taught					
	K	3176	19.10	91	16.79
	1	3638	21.88	98	18.08
	2	3601	21.66	102	18.82
	3	3658	22.00	112	20.67
	4	3370	20.27	120	22.14
	5	3527	21.21	98	18.08

[1] The Oklahoma Reac^{3}h regions were used to determine the geographical representation of the state. A map of the Reac^{3}h regions can be found at http://ok.gov/sde/reac3h-network.

Table 3.4.

Ethnicity and Title I school status of study participants.

	Number	Percentage
Do you teach in a Title I school?		
Yes	432	79.70
No	84	15.50
Don't Know	26	4.80
Ethnicity		
African American	5	0.92
American Indian or Alaskan Native	42	7.75
Hispanic	13	2.40
Asian or Pacific Islander	4	0.74
White	453	83.58
More than one	16	2.95
Other	8	1.48

Data Analysis

Quantitative data from the questionnaire, qualitative data from the questionnaire, and the NGSS document were analyzed separately and then merged to look for convergence or divergence of findings (Creswell & Plano Clark, 2011). Additionally, the qualitative data from the interviews and focus group sessions collected during Phase 2 were analyzed independently of the other data and then merged with the Phase 1 data to further explain and expand the analysis from Phase 1.

Quantitative Data Analysis. Participant responses for the DET questions were transferred to SPSS and analyzed. Cronbach's α was computed to determine the internal consistency of each DET subscale. The researcher analyzed the DET subscale data to yield frequencies of respondents choosing each response category. Box and whiskers plots were created to visually display DET subscale data. The esearcher used one-way ANOVA to determine if any significant differences existed on subscale scores of different demographic groups including grade level taught, gender, pathway to certification, ethnicity, grade level taught, education attainment level, geographic region, and years of teaching experience. ANOVA assumes equality of variance, therefore, the Levene's test for equality of variance was run before interpreting the results of the one-way ANOVA. When the assumption of equal variances was violated (Levene's test less than .05), the Welch test, which does not assume equal variances, was used.

Qualitative Data Analysis. Qualitative data included the NGSS document, open-ended questionnaire responses, and focus group and interview transcripts.

NGSS coding. First, the researcher completed an initial read through of the entire *NGSS* document to familiarize herself with the content of the document. Next, the researcher applied descriptive coding techniques (Saldana, 2013) to all K-5 standards. The descriptive coding led to an inventory of topics associated with each standard. The researcher placed each standard found to be associated with engineering content on a note card. Next, the researcher matched the Science and Engineering Practices, Disciplinary Core Ideas, and Crosscutting Concepts associated with each engineering standard on the card. Then, the researcher analyzed these associated items and developed topics in order to identify the most frequent codes, eliminate redundant codes, and organize codes into categories and subcategories.

Open-ended questionnaire responses. Responses to the two open-ended questions "What words or phrases would you use to describe the characteristics of a typical engineer?" and "What do engineers do as part of their work?" were printed onto cards which were used during the coding process (Creswell, 2007). First, attribute coding was used to log essential demographic information about the participants for future reference (Saldana, 2013). Each card was coded with the participant's gender, ethnicity, years of teaching experience, education attainment level, geographic region, pathway to certification, and grade level taught. Next, a word cloud (www.wordle.net) was created for each open-ended question and used to create an initial visual representation of the data and identify the most salient words to use as initial codes. In a word cloud, words that appear more frequently in the data set are displayed using a larger font. This provides a quick visual representation of the frequency with which different words are used. However, word clouds are impacted by spelling, punctuation, and conjugates of words, which impact the visual display. For example, problem solver and problem solving would not be grouped together because they are not exact matches. McNaught and Lam (2010) found that word clouds are useful tools for preliminary qualitative data analysis, however they should not be used as the only method of analysis due to the way in which the word clouds are generated. To help clean up the data prior to entering it into the word cloud generator, the researcher changed all capital letters to lowercase letters.

After generating word clouds, the researcher used the initial code list to complete a round of descriptive coding as described by Saldana (2013). During this first round of descriptive coding, additional codes were generated and added to the initial code list and code frequencies were determined. As suggested by Namey, Guest, Thairu, and Johnson (2008), the frequencies with which each code appeared in the data were based on the number of participants who used a particular code, not the number of times that the code appeared.

Focus groups and interviews. Upon completion of the online questionnaire, participants were redirected to an unlinked survey where they could provide contact information if they wished to participate in a follow-up interview or focus group. Based on individual availability, three focus groups were scheduled in two different large cities in the state, with seven to ten individuals scheduled for each session. Actual focus group attendance was low, with four individuals participating in the first focus group and the last two focus group sessions becoming individual interviews. A total of 11 individual interviews were conducted, two in person, and nine over the phone. The researcher wrote field notes during each session, reviewed the notes immediately following each follow-up session, and used the field notes to write a reflection over the session. Demographic information for focus group and interview participants is presented in Table 3.5.

Table 3.5

Demographic information of interview and focus group participants.

	Number		Number
Oklahoma Reac^{3}h Region[1]		*Teaching Experience (Years)*	
1	1	1 to 3	6
2	1	4 to 6	1
3	6	7 to 10	2
4	1	11 to 15	0
5	1	16 to 20	3
6	0	21 to 25	1
7	1	over 25	2
8	3	*Teacher Certification Type*	
Gender		Traditional	12
F	15	Nontraditional	3
M	0	*Grade Level Taught*	
Highest Education Level		K	4
Bachelor's	10	1	2
Master's/Education Specialist	5	2	4
Doctorate	0	3	1
Ethnicity		4	5
Asian or Pacific Islander	1	5	1
Hispanic	2	*Do you teach in a Title I school?*	
Native American or Alaskan Native	1	Yes	13
White	11	No	2

[1] The Oklahoma Reac^{3}h regions were used to determine the geographical representation of the state. A map of the Reac^{3}h regions can be found at http://ok.gov/sde/reac3h-network.

All focus group and interview sessions were audio recorded and transcribed verbatim by the researcher who conducted the interview (Oliver, Serovich, & Mason, 2005). To ensure that the findings remained true to the participants' perspectives, each participant was provided with a copy of the transcript to allow for member checking. Changes were made to the transcripts based on participants' feedback. During transcript analysis, the researcher did not force the data into predetermined categories. Rather, the researcher inductively coded the individual transcripts using a data-driven approach (Brinkmann, 2013) during which she developed codes as she read over the raw data transcripts. Later, focused coding was used to organize the initial data into categories and compare the codes across participants' transcripts (Saldana, 2013).

Trustworthiness and Credibility

Creswell (2007) identified eight validation strategies for qualitative research – prolonged engagement in the field; triangulation; peer review; negative case analysis; clarifying researcher bias at the beginning of the study; member checking; rich, thick descriptions; and external audits – and recommend the use of at least two of them in every qualitative study. In the current study, the researcher was candid with participants about the nature of the study and provided participants with the opportunity to review the researcher's written description and interpretation of the interviews and focus group sessions. The themes emerging from the interview and focus group sessions were compared with the information obtained from the questionnaire responses and NGSS document analysis to allow for triangulation (Gall, Gall, & Borg, 2003). The researcher also established inter-rater reliability by having additional scholars independently analyze the transcripts and compare the resulting codes.

Results

When answering the research questions, the researcher first analyzed the qualitative and quantitative data separately and then merged the two to come to a deeper understanding of the underlying phenomena. The findings are presented in a similar manner, with the qualitative and quantitative findings reported separately in the results section and then merged and described in the discussion section.

Quantitative data

During Phase 1, the *Familiarity with DET* and *Stereotypical Characteristics of Engineers* subscales were analyzed. Prior to data analysis, the internal consistency of each DET subscale was determine using Cronbach's α. Computed values for *Familiarity with DET* ($\alpha = .90$) and *Stereotypical Characteristics of Engineers* ($\alpha = .85$) were higher than those reported by Hong et al. (2011). Figure 3.1 provides box and whiskers plots of DET subscale data. Seventy-five percent of participants had a mean subscale score at or below 2.5 on the *Familiarity with DET* subscale. This, combined with the overall mean score of 1.99 on the *Familiarity with DET* subscale, suggests that participants were not very familiar with design, engineering, and technology. The mean score on the *Stereotypical Characteristics of Engineers* was 4.30 and 95% of participants scored at least 3.0, indicating that participants held stereotypical views of engineers. Pearson correlation reveals that *Familiarity with DET* and *Stereotypical Characteristics of Engineers* were significantly correlated with each other ($r = .13$, $p = .002$), however the small r value may indicate low practical significance. ANOVA revealed that male participants had significantly higher *Familiarity with DET* than female participants, $F(1, 541) = 9.828$, $p = .002$, $\eta^2 = .01$. No other significant differences were found between demographic groups.

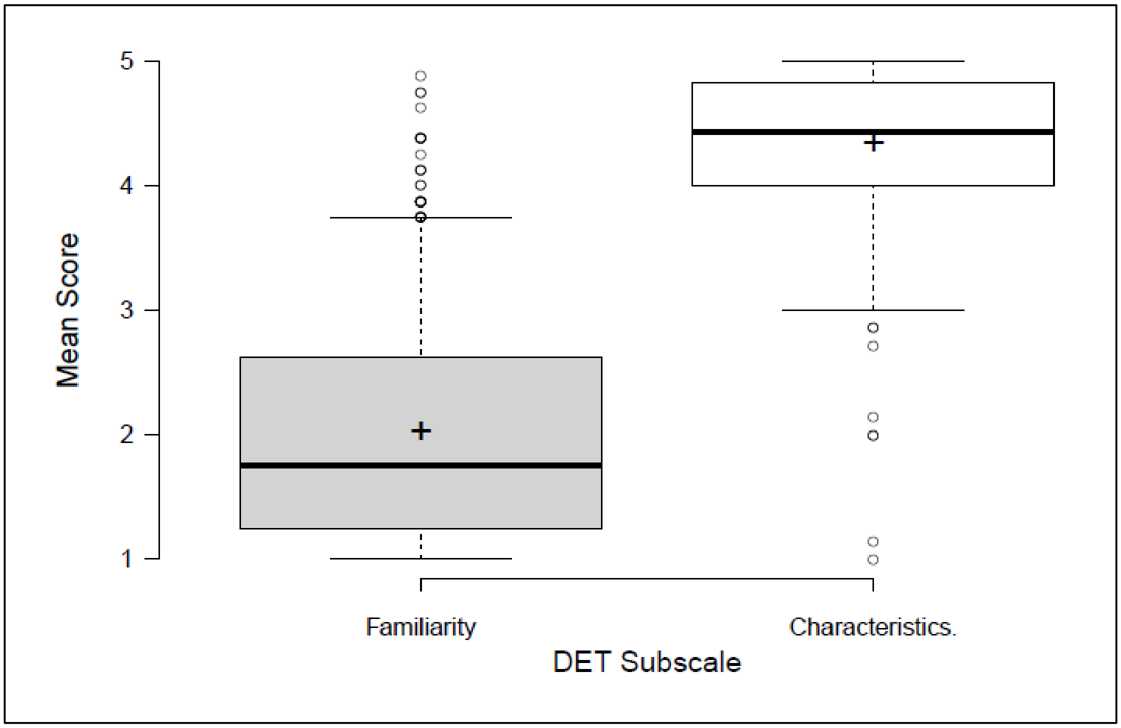

Figure 3.1. Mean Design/Engineering/Technology (DET) subscale data. The whiskers extend from the 5th to 95th percentile scores and the "+" represents the mean.

Figure 3.2 provides a breakdown of participant responses by Likert level for each of the questions on the *Familiarity with DET* subscale. Please refer to Appendix D for a full list of subscale questions. The responses clearly illustrate that the majority of participants did not have preservice coursework for DET and left their preservice curriculum not feeling prepared to teach engineering. The majority of participants also rated their DET confidence low, reported that they did not use DET activities in their classrooms, and did not have a support system at school to help them implement DET activities.

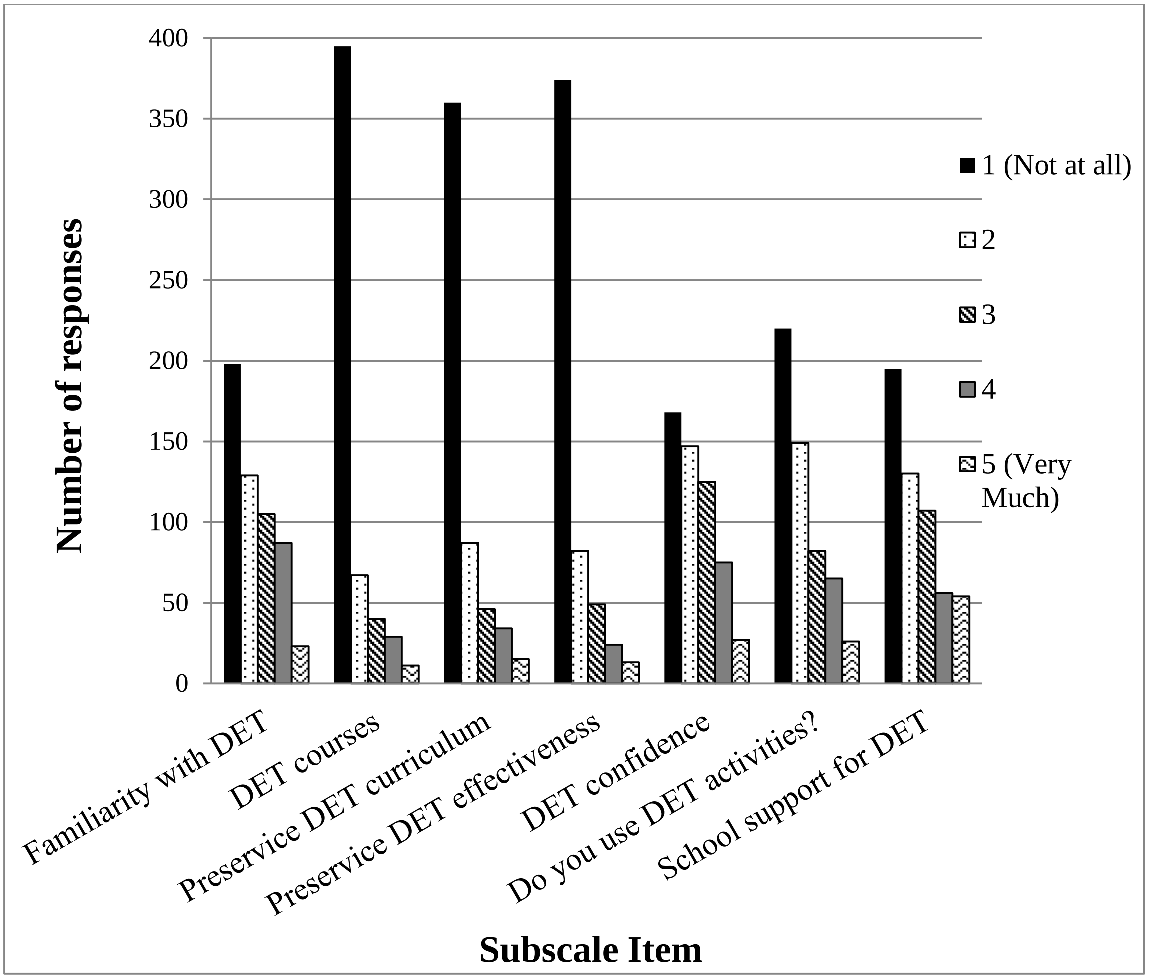

Figure 3.2. Participant responses for each item on the *Familiarity with Design/Engineering/Technology* subscale.

Figure 3.3 provides a breakdown of participant responses for each item on the *Stereotypical Characteristics of Engineering* subscale of the DET instrument. Visual inspection of the individual items in Figure 3.3 reveals that participants viewed engineers as people who have good math and science skills, earn good money, and like to fix things. However, fewer participants strongly agreed that engineers work well with other people and have good communication skills (verbal and written).

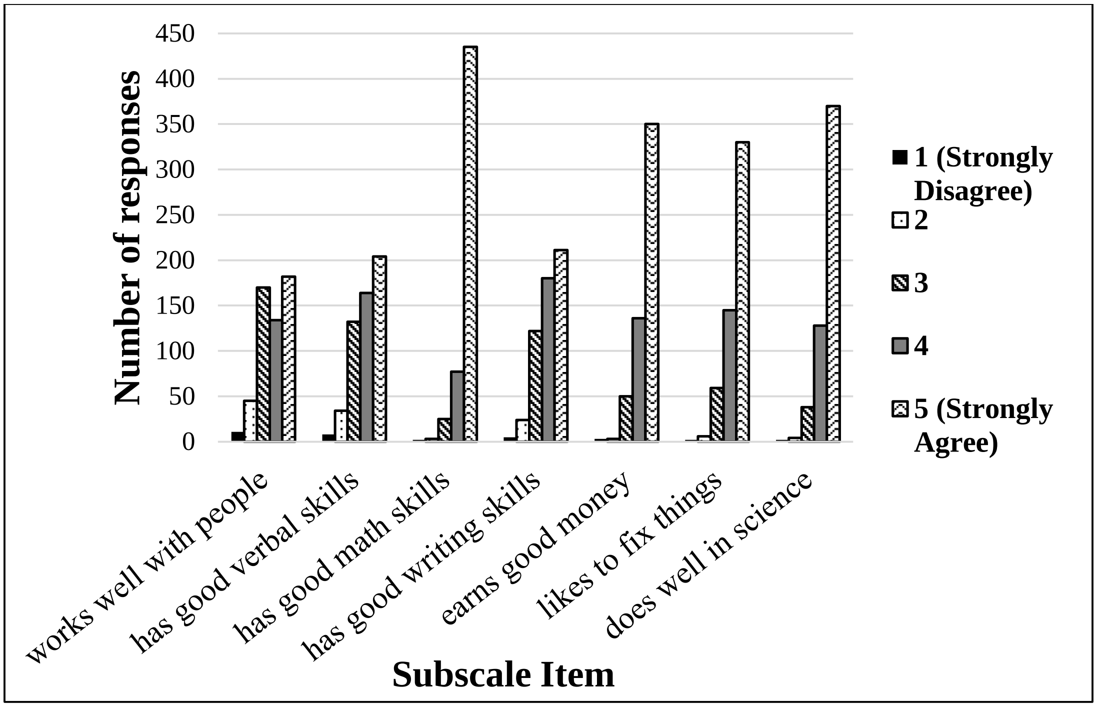

Figure 3.3. Participant responses for each item on the *Stereotypical Characteristics of Engineers* subscale.

Qualitative data

NGSS document. The results of the NGSS document analysis identified the content knowledge that K-5 teachers must possess in order to implement the suggested engineering standards into their classrooms. The analysis resulted in three categories of required topics to be covered by K-5 teachers: Engineering Design, Influences of Engineering and Technology on Society and Nature (IET), and Disciplinary Core Ideas. The NGSS are written such that each standard that incorporates engineering practices is also associated with core science content (life, earth, or physical). This ensures that the engineering standards are taught within a meaningful context and explains the appearance of the Disciplinary Core Ideas topic (DCI) within our analysis. Because the DCI topics of earth, physical, and life science are taught throughout the NGSS and are not specific to the teaching of engineering standards, they are not included within the current analysis. Figures 3.4 and 3.5 present the subcomponents of the Engineering Design and IET categories that are embedded within NGSS.

K-2 Engineering Design

Define a design problem
- Ask questions based on observations
- Obtain information from appropriate resources
- People have questions about the natural world
- Clearly understand a problem before beginning

Developing possible solutions
- Communicate solutions
    - Drawings
    - Sketches
    - Models
- Use tools to design and build a solution

Comparing different solutions
- Analyze and interpret data
- Cause and effect
    - Test ideas about causes
        - Design test
        - Gather evidence
        - Evaluate ideas based on evidence
    - Causes result in effects with observable patterns

3-5 Engineering Design

Define a design problem
- Identify criteria
- Identify constraints

Developing possible solutions
- Research before designing a solution
- Generate multiple solutions

Communicate ideas

Improving designs
- Plan and conduct controlled tests
- Test until failure
- Compare multiple design solutions
- Defend design ideas with evidence
- Identify aspects to improve (redesign)

Figure 3.4. Engineering design topics embedded within the *Next Generation Science Standards* for grades K-2 and 3-5.

Influence of Engineering and Technology on Society and Nature

K-2
- Humans can reduce their impacts on the natural world
- Technology impacts nature
- Problems can be solved through engineering
- Manmade products require application of scientific knowledge
- People depend on technology
- People use a variety of devices to communicate

3-5
- Scientific discoveries can lead to inventions and innovations
- Technologies are developed through engineering design
- Engineers invent an innovate to meet societal demands
- Demands for technology can change over time with people’s needs and wants
- Engineers work as teams
- Scientific knowledge is important in engineering

Figure 3.5. Topics embedded within the *Next Generation Science Standards* related to the influence of engineering and technology on society and nature.

Open-ended responses. Most participant responses to the open-ended questions fell within one or more of the following nine categories – Engineers as Thinkers, Engineers as Creators, Engineers as Doers, Engineers as Managers, Engineers are Motivated, Engineers are Tech Savvy, Engineers as Social Beings, Types of Engineers, and Uncertainty. It was common for a participants’ responses to fall into multiple categories. Table 3.6 presents a description of each category and examples of representative codes that fell within each category. Table 3.6 is arranged such that the categories are listed in order by frequency of occurrence, with the most frequently occurring category listed at the top of the table. Figures 3.6 and 3.7 display the word clouds that were generated from the participants’ responses to the open-ended survey responses.

Table 3.6.

Category descriptors and illustrative codes for open-ended responses

Category	Description	Codes (and frequencies) in category
Engineers as Thinkers	Response focuses on the use or application of knowledge	problem solver (n = 307), math (n = 222), intelligent (n = 127), research (n = 109), science (n = 79), analytical (n = 52), logical (n = 37), critical thinker (n = 23), optimize (n = 22), curious or inquisitive (n = 21), spatial reasoning (n = 20), thinking outside of the box (n = 17), high level of education (n = 14), methodical (n = 6), reasoning abilities (n = 5), intuitive (n = 4), systematic thinkers (n = 3), pragmatic (n = 2)
Engineers as Creators	Response focuses on creative processes	designer (n = 273), creative (n = 249), innovative (n = 81), inventive (n = 46), develop ideas (n = 7), visual and artistic (n = 6)
Engineers as Managers	Response describes engineers as those who oversee work OR describe qualities needed to manage	planner (n = 73), detail oriented (n = 43), leads/oversees (n = 31), organized (n = 27), safety (n = 12)
Engineers as Doers	Response describes the engagement in hands-on or physical work	work on structures (n = 55), Construct/make/build (n = 22), maintain/repair/fix things (n = 20), mechanically inclined (n = 20), work with hands (n = 15), use tools (n = 3)
Types of Engineers	Response describe work done by different types of engineers OR mentions there are different types of engineers	types of engineers (n = 63)
Engineers are Tech Savvy	Response refers to the development or use of computers or other high tech gadgets	Computers (n = 28), technology (n = 19)
Engineers as Social Beings	Response describes engineers as either working with or communicating with others OR describes personality traits	team work (n = 31), communication (n = 7), nerdy (n = 2), anti-social behaviors (n = 2), corky (n = 1), introverted (n = 1), out of touch (n = 1), shy (n = 1), geek (n = 1)
Engineers are Motivated	Response describes engineers as being hard workers	Hardworking (n = 22), motivated/determined (n = 16)
Uncertainty	Response demonstrates that participant does not know how to respond OR questions the response	I don’t know (n = 9), questions own answer (n = 4)

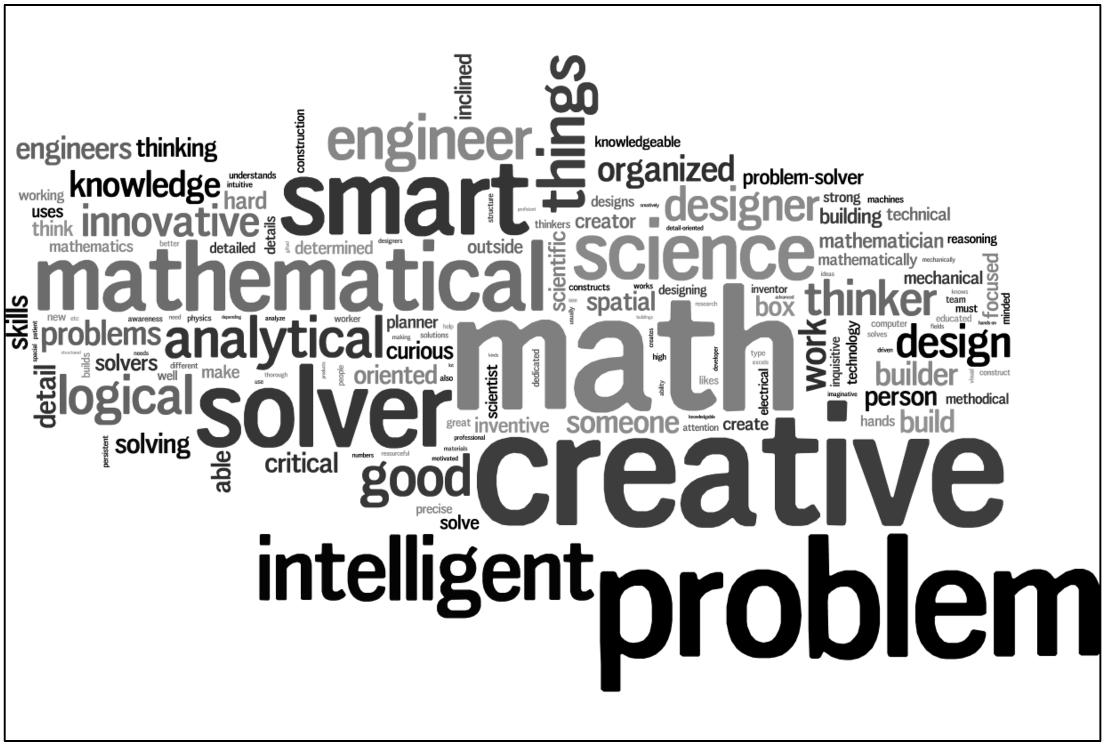

Figure 3.6. Word cloud generated from participant responses to the survey question “What words or phrases would you use to describe the characteristics of a typical engineer?”

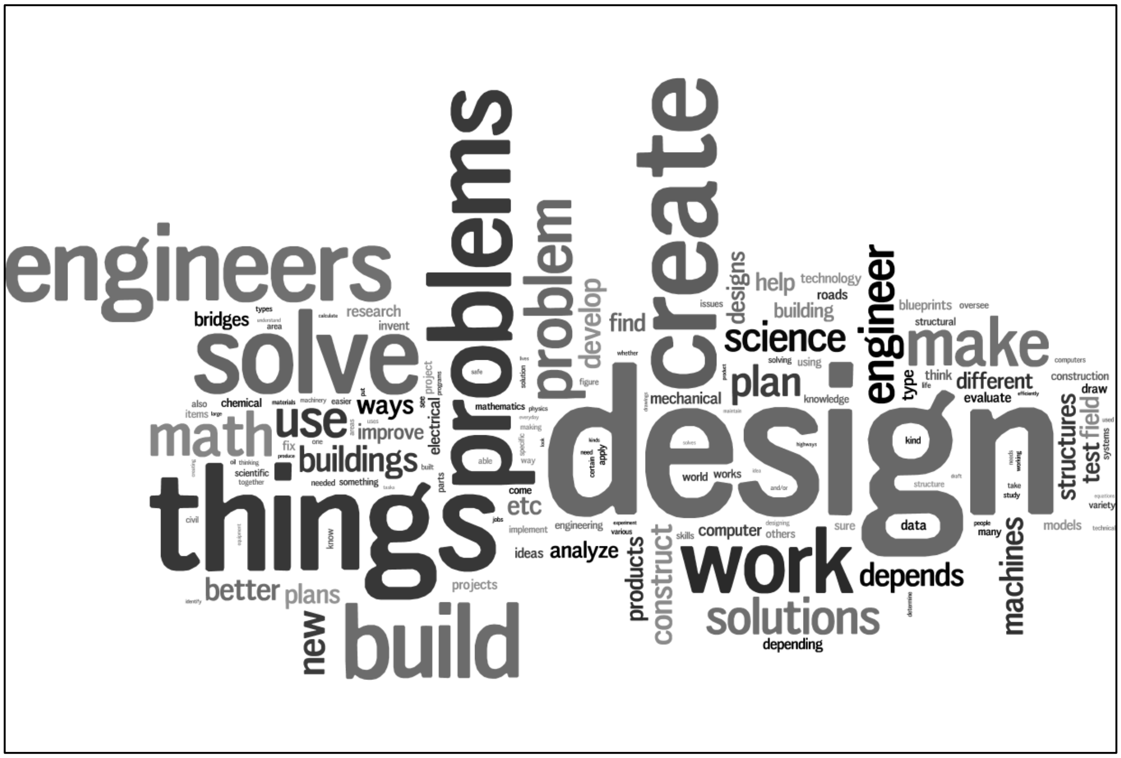

Figure 3.7. Word cloud generated from participant responses to "What do engineers do as part of their work?"

Engineers as Thinkers. Words or phrases falling under the category of engineers as thinkers occurred 1,070 times. Participants described engineers as intelligent and mentioned engineers' abilities to use scientific knowledge. More than half of the participants described engineers as needing to know and use mathematics, writing things such as "Mathematical-minded; intelligent; likes to figure things out (a thinker!)" and "applying mathematical formulas to help solve problems." Engineers were frequently described as problem solvers, often in conjunction with the application of mathematics or science knowledge. Additional illustrative quotes were:

"An engineer is an individual who uses science and math to develop new technologies and products. An engineer must be well-educated in these fields in order to adequately design new equipment or materials. An engineer must be able to think creatively to come up with new innovations for old problems."

"A typical engineer applies scientific knowledge and math to creatively solve technical, commercial (ie infrastructure/bridges) and societal problems (Human engineering)."

"An engineer is a scientist who can build and solve problems. He/she is someone that works with numbers and science daily."

Engineers as Creators. The majority of responses in this category were single word answers or very short phrases that described engineers as being creative, designers, and inventors. Participants wrote statements such as "Create and design buildings," "Engineers are creators," "A person who creates things," "An engineer has creativity," and "Innovative."

Engineers as Doers. Responses in this category focused on physical or mechanical aspects of engineers' work. Many participants described engineers as people who construct, make, or build things; work on structures; or maintain and repair things. Example responses included "Engineers like to build things," "Build things and if it breaks, figures out a way to fix it," and "A person who builds engines."

Engineers as Managers. Engineers were also described as overseeing projects or as possessing the skills required to manage projects (i.e. organization, safety). Participants responses included "They are responsible for designing projects and overseeing their completion," "To be in charge and to manage or direct a group," and "Oversee that the project is going as planned."

Engineers are Motivated. Engineers were also described as hard working, determined, and motivated. Responses in this category were often single words or very short phrases, such as "Self-motivated," "Determined and a hard worker," and "The ability to scrap it and start again."

Engineers are Technologically Savvy. Engineers were described as being able to program or work with computers and good with technology. For example, engineers "Use computers to analyze and produce designs," "Develop computer programs," and "Have excellent computer skills to produce and analyze designs."

Engineers as Social Beings. This category included words or phrases that describe perceived personality traits or the ways that engineers interact with others. The perceived personality traits were often negative stereotypes, such as "Nerdy," "Anti-social behaviors," "Introverted," and "Out of touch." However, engineers were also described as “Team players” and “A team member who must communicate and listen accurately.”

Types of Engineers. Sixty three participants mentioned that there are different types of engineers and their jobs vary depending on the type of engineer they are. Example responses in this category include:

“It depends. They can be an engineer for the railroad, armed services, or robotics.”

“It completely depends on the type of engineer. For a generalization I would say they come up with ‘things’ (depending on the type of engineer) and they test them. They have to be able to solve technical problems.”

“I would imagine that an engineer would be in charge of chemical testing, design, instruction, and implementation of design. It would all depend on the field of study ie chemical, mechanical, or petroleum engineer.”

“Engineer can mean many different things, depending on the field the engineer works in. A civil engineer and a chemical engineer do different tasks, but I believe both are focused on mathematics, science, and problem-solving.”

“There are different types of engineers: some who design/create, some technical (who implement).”

Uncertainty. Some participants did not know how to describe engineers or the work they perform, making statements such as “Not really sure” and “I honestly do not know.” Others gave responses but questioned their own statements, such as “Change things and make them better? I really don’t know” and “Science and math calculations????” One participant quoted a TV character, “’Engineers are the oompah loompahs of the science world.' – Sheldon Cooper." Another participant indicated that his/her participation in the study was due to a lack of understanding of engineering, "The term engineer is not clearly defined. That is why I decided to participate in this survey. I think that engineer is replacing the title of scientist, but I am not sure. Other teachers are not sure."

Follow-up sessions

Qualitative data from follow-up focus groups and interviews are presented below. For ease of reading, follow-up data are presented by the question being answered.

What comes to mind when you think of an engineer? Responses to this question fell within the same categories as the open-ended survey questions, with most responses falling within multiple categories. One participant's response fell within Engineers as Thinkers, Engineers as Doers, Engineers as Social Beings, Engineers are Tech Savvy, and Types of Engineers, "Kind of nerdy but in a good way. I have some friends who are engineers. Really smart, building things, like civil engineers involved with water and dams and other types of engineers who build buildings and those types of things but again I have a friend who is a computer engineer and does computer stuff, so just kind of a whole lot of things." During the focus group, one participant mentioned that engineers are problem solvers, and another participant followed up with, "I had only heard that an engineer was a problem solver at a conference that I had been to, and I had never even thought of it in that way until you said that [referring to another focus group member] and then you think of all the different lines of engineering and that is the one thing that is in common is problem solving and so that kind of opened my eyes up too. That's been kind of a process for me to think about it in that way because you think about it more as building things, making things, or testing things, whether or not it’s going to work before you actually do something.” This participant’s response indicates that her understanding of engineering has changed as a result of professional development experiences.

How would you describe your understanding of engineering? When asked to describe their personal understanding of engineering, most participants described their understanding as limited or developing, “Fairly limited. I’ve not taken any upper science. That’s not something I took in my education or even my college years, so I would say it would be limited.” One participant rated her knowledge on a scale, “On a scale from like 1 to 10, I would say I’m about a 5. I’m familiar with it. I can’t tell you in depth about it.” Two participants said their personal understanding of engineering was enhanced because their spouses were engineers, “Probably broader than most kindergarten teachers and early childhood teachers because of my husband. He comes home and talks about work.”

Do you use engineering activities in your classroom? To gain a better understanding of how familiar participants were with engineering, they were asked to describe any engineering activities they use in their classrooms. Most participants said they did not use any engineering activities with their students, other than using building blocks during centers. One participant described a unit on weights and measures as engineering, while another described a lab over phase changes as being engineering. One participant described an egg drop project she used. When asked if she talked about engineering during the egg drop project she responded, “I don’t know that I have actually used the term engineering. We’ve talked about the science elements of what we are doing, like the energy side of it and building a structure that will withstand the forces you are trying to put on it, but I don’t know that I have ever really used the term engineering with them.”

What do you know about the engineering design process? Most participants said that they knew very little or nothing at all about the design process. One participant stated, “I know nothing. I read it over and over again on the science standards and say okay engineering means that you find out that you need something, you need to design it, you need to create it, you need to find out what the flaws are, you need to redesign, but I don’t know how to do that. I can say it but how do you put it into practice.” Others were unsure of what the design process was and asked if it were similar to a scientific process, “Probably not a lot because I’m not familiar with what that is. Is it maybe kind of like a science process?” Another participant stated, “The scientific method is that what you’re talking about? If it is different from the scientific method, then, I don’t know.” A few participants said that they felt they understood what the design process was but that they did not have the terminology required to teach it to their students. “I feel like I have enough knowledge…I think that a lot of the knowledge I need to teach it isn’t specific enough. I need more help with the specific vocabulary…I feel like I have an understanding of the process they go through but to actually walk you through the steps and know what they are called, no.” Another participant stated that the standards did not clearly describe what the design process was, “I probably do it and don’t know it…I think terminology is the big issue. You know when I read through the standards last year when they started throwing them up my first reaction was ‘What are they even talking about.’ They wrote the standards for a Kindergarten teacher as if they were talking to PhD engineers. No, no, no, use the terminology that we are going to use and incorporate with our kids because otherwise you just scare and intimidate everybody." These participants' responses clearly demonstrate that they are making an effort to be knowledgeable of the standards but they are limited in their abilities to do that because they do not possess the background knowledge or training necessary to understand how to put the standards into practice.

Discussion and Conclusions

As previously stated, the purpose of this study was to (a) identify the perceptions that in-service elementary teachers hold about engineering and engineering design and (b) how those perceptions compare with the engineering practices described in NGSS. Findings are organized by research question.

Research Question 1: How familiar are in-service elementary teachers with engineering and engineering design?

Overall, K-5 teachers are unfamiliar with engineering or engineering design. Teachers reported their own knowledge of engineering as limited and scores on the *Familiarity with DET* subscale showed that participants had little previous coursework or training in engineering. Further, most participants said they were unfamiliar with engineering design. Additionally, very few teachers reported using DET activities in their classrooms. This was also seen in follow-up sessions when participants described the engineering activities they used in their classrooms. Of the few follow-up session participants who reported using engineering activities, most described activities that were actually science activities (e.g. weights and measures, phase changes) or described building with blocks. Building with blocks could fall under engineering if the teachers provided students with a problem they had to solve using the blocks, but none of the teachers who talked about blocks mentioned anything other than “building.” Collectively, these results indicate that many K-5 teachers are not using engineering activities in the classroom and are not familiar enough with engineering to properly identify examples of engineering activities. This is not unexpected given that a previous national study only reported that 4% of elementary teachers felt prepared to teach engineering (Banilower et al., 2013). Further, because teachers are not comfortable teaching what they are unfamiliar with (Brophy et al., 2008) it is not surprising that few teachers in the study used engineering activities.

Research Question 2: What perceptions do in-service elementary teachers hold about engineers and engineering design?

Overall, elementary teachers in this study held stereotypical views about engineering as indicated by their responses on the DET, the open-ended questionnaire responses, and the follow-up sessions. Teachers often viewed engineers as being super smart with great math and science skills. Arguably, many engineers are intelligent and do well in math and science, however, it is interesting to note that fewer teachers identified engineers as having good communication skills and some mentioned negative social stereotypes such as “nerdy.” When describing the work of engineers, many participants mentioned that engineers design or create, but it was also common for teachers to focus on physical aspects such as building and fixing machines. Likewise, Cunningham et al. (2006) found that K-6 teachers often viewed engineers as builders. Further, many teachers questioned their own understanding or stated that they did not know what engineers did for their work. Elementary teachers have limited understanding of engineering design. Most of the follow-up participants stated that they did not know what engineering design was or they confused it with the scientific method. Others stated that they had read the standards but didn't understand what they meant or how to enact them.

Together, these findings indicate that many elementary teachers hold misconceptions about engineers, engineering, and engineering design.

Research Question 3: Are there differences in teachers' familiarity with engineering or perceptions of engineers between different demographic groups?

ANOVA results for the *Familiarity with DET* and *Stereotypical Characteristics of Engineering* subscales were used to answer this question. The only significant difference for *Familiarity with DET* was gender, with males being more familiar with DET than females. While there was a large difference in sample sizes between males and females, the sample sizes were representative of the population and thought to be reliable. The significant difference found between males and females was not surprising, as previous research indicates that gender role socialization leads to boys having more STEM experiences than girls. Many family members, peers, teachers, and counselors reinforce masculine stereotypes of science (Ashbacher et al., 2010) and technology and encourage girls to pursue more feminine activities (Farmer, 2008). Counselors often steer girls into career paths that are more traditionally female and do not encourage as many girls to take advanced math, science, and technology courses (Farmer, 2008).

There were no significant differences between demographic groups for perceptions of engineers, as measured by the *Stereotypical Characteristics of Engineering* subscale, indicating that teachers in this study held the same misconceptions about engineers regardless of demographic group. This suggests that stereotypical misconceptions of engineers are widespread and need to be addressed across all demographic groups.

Research Question 4: How do in-service elementary teachers' perceptions of engineers and engineering design compare with expectations set by K-5 engineering education standards?

NGSS analysis revealed that the engineering standards to be taught in K-5 classrooms fall under the topics of engineering design and engineers' impact on society. In order to teach these standards, teachers must understand engineering design as well as pedagogical strategies for implementing design activities into the classroom. They must also have a basic understanding of how the work of engineers impacts society. Participants' responses on the questionnaire and follow-up sessions revealed that elementary teachers hold misconceptions about engineering which may impact the way they view the work of engineers and impact the way they teach engineering to their students. Teachers also have a limited understanding of engineering design, as well as limited experiences using engineering design with their students. Having fewer experiences using engineering design activities limits teachers' opportunities to build the pedagogical strategies required to successfully implement the standards related to engineering.

Strengths and Limitations

One strength of this study was that sampling strategy resulted in a sample that closely mirrored the state K-5 teacher population with regard to geographic region, gender, teaching experience, education level, pathway to certification, and grade level taught. Additionally, the use of both quantitative and qualitative methods helped to offset the weaknesses associated with using either method individually. The study does however have certain limitations. First, data was limited to the population members who chose to participate, and the data was self-reported which can be associated with response bias. Additionally, only public school teachers in Oklahoma were included in the study, which could limit the generalizability to teachers from other states. However, the researcher speculates that these findings may be common amongst most elementary teachers.

Implications and future research

Findings form this study indicate that elementary teachers are not prepared to incorporate engineering practices in their classrooms as prescribed by NGSS. Teachers are unfamiliar with the work of engineers and the engineering design process and have little experience teaching engineering design. Before teachers can successfully incorporate engineering practices into their classrooms they will need training in how to distinguish between science and engineering practices, as well as how to infuse engineering design elements into developmentally appropriate lessons that also incorporate science content, knowledge of engineers, and career awareness. Further research is needed to determine the ways to best deliver engineering focused professional development to elementary teachers. In the meantime, teacher preparation programs and providers of professional development need to identify current engineering education training programs that are available for teachers as well as work to develop and pilot programs that target these areas of need. Further, administrators need to be aware of these findings and work to identify available resources for their teachers as well as ways to fund needed training.

With the release of the NGSS it is imperative that elementary teachers receive proper training in order to successfully implement engineering content and practices into their classrooms. This will require quality ongoing training that addresses what engineering is and how to differentiate between science and engineering activities, as well as provide teachers with the tools to incorporate engineering into their classrooms and go beyond teaching engineering as building with blocks.

CHAPTER IV

EXAMINING ELEMENTARY TEACHERS' ENGINEERING SELF-EFFICACY AND ENGINEERING TEACHER EFFICACY

Target Journals: A. School Science and Mathematics

B. Journal of Research in STEM Education

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Abstract:

Research indicates that teacher efficacy influences student achievement and is situation specific. With the NGSS calling for the incorporation of engineering practices into K-12 classrooms, it is important to identify teachers' engineering teaching efficacy. A study of K-5 teachers' engineering self-efficacy and engineering teaching efficacy revealed that that they have low engineering self-efficacy and low teacher efficacy related to engineering pedagogical content knowledge. Additionally, significant differences existed in self-efficacy levels based on gender, ethnicity, Title I school status, and grade level taught.

Keywords: elementary, engineering education, teacher efficacy, self-efficacy

Introduction

The United States has become increasingly dependent on technology, which has led to an increased demand for workers in science, technology, engineering, and mathematics (STEM) fields and STEM literate citizens (International Technology Education Association, ITEA, 2007). To address these concerns, *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* (National Research Council, NRC, 2012) identified key scientific and engineering practices that all students should learn during K-12 education; this framework was used to develop the *Next Generation Science Standards* (NGSS) (NGSS Lead States, 2013). The NGSS call for the infusion of engineering practices into K-12 science classrooms; however, we know very little about how prepared elementary teachers are to successfully teach engineering standards. Current research findings suggest that elementary teachers feel unprepared to teach engineering concepts and practices to their students (Banilower, Smith, Weiss, Malzahn, Campbell, & Weis, 2013; Sargianis, Yang, & Cunningham, 2012). In fact, a national survey of science and mathematics teachers indicated that only 4% of elementary teachers reported feeling very well prepared to teach engineering compared to 39% for science and 77% for mathematics (Banilower et al., 2013).

Most teacher preparation programs do not prepare elementary teachers to incorporate engineering practices into their classrooms, and engineering focused professional development opportunities for in-service elementary teachers are limited (Committee on K-12 Engineering Education, 2009). Determining perceptions elementary teachers hold about their abilities to teach engineering practices will be required to ensure that elementary teachers receive the training necessary to successfully implement engineering practices in their classrooms. Research literature devoted to K-5 educators' knowledge and perceptions of engineering and engineering design, however, are far from complete, with a dearth of studies devoted to elementary engineering education and engineering teaching self-efficacy. The current study helps to address the gaps in the literature related to elementary engineering education by uncovering elementary teachers' perceived engineering self-efficacy and engineering teaching self-efficacy.

Objectives of the Study

The overall objective of this study was to gain information related to K-5 teachers' preparedness to implement the engineering standards contained within the *Next Generation Science Standards.* More specifically, the current study sought to answer the following research questions:

1. How self-efficacious are in-service elementary teachers in their knowledge of engineering and engineering design and their abilities to teach engineering and engineering design?
2. Are there differences in teachers' engineering self-efficacy or engineering teaching efficacy between different demographic groups?
3. Is there a correlation between teachers' engineering self-efficacy and their familiarity with design/engineering/technology (DET)?
4. Is there a correlation between teachers' engineering teaching self-efficacy and their familiarity with design/engineering/technology (DET)?

Related Literature

Self-efficacy

Self-efficacy refers to one's belief in his or her ability to produce a desired outcome. Albert Bandura (1977) described self-efficacy as consisting of two dimensions – efficacy expectation and outcome expectancy. Efficacy expectation is defined as "the conviction that one can successfully execute the behavior required to produce outcomes" and outcome expectancy is defined as "a person's estimate that a given behavior will lead to certain outcomes" (Bandura, 1977, p. 193). Self-efficacy develops from four information sources: performance accomplishments, vicarious experiences, verbal persuasion, and emotional arousal (Bandura, 1977, 1989; Pajares, 2002). Personal accomplishments, the most powerful of the four sources, are a result of personal successes and failures that result from completing a specific behavior. Vicarious experiences affect self-efficacy when an individual witnesses a peer's success or failure at a certain behavior. Additionally, individuals may be verbally persuaded into believing they will succeed in a given behavior, especially if they view the persuader as credible. Finally, emotional arousal, such as fear, anxiety, or excitement may impact the way individuals view their capabilities.

Teacher Efficacy

Teacher efficacy can be defined as a teacher's belief in his or her ability to influence student learning (Guskey & Passaro, 1994). Gibson and Dembo (1984) grounded their studies of self-efficacy in Bandura's (1977) two dimensions of self-efficacy – outcome expectancy and efficacy expectation – and developed the Teaching Self-efficacy Scale (TES). The TES instrument consists of two subscales – General

Teaching Efficacy (GTE) and Personal Teaching Efficacy (PTE). PTE is a teacher's belief that he or she can elicit student learning, while GTE is a teacher's belief that external factors, such as home life, limit a teacher's ability to bring about student learning. Research studies employing TES have reported that high teacher efficacy is associated with greater teaching effort and persistence in difficult situations, as well as higher student achievement (Tschannen-Moran, Woolfolk Hoy, & Hoy, 1998). High PTE has been linked to a willingness to implement new and/or innovative teaching methods (Allinder, 1994) and willingness to work longer with academically struggling students (Gibson & Dembo, 1984) before referring them for special education services (Allinder, 1994). Additionally, teachers with high teacher efficacy are more likely to use small group instruction as opposed to whole class lecture and less likely to criticize students who give incorrect responses to discussion questions (Gibson & Dembo, 1984).

Teacher efficacy is situation and content specific and influenced by subject area, grade level, and student characteristics (e.g., socio economic status, special education, English language learners) (Tschannen-Moran et al., 1998; Utley, Moseley, & Bryant, 2005). Because teaching efficacy is subject specific, Riggs and Enochs (1990) developed the Science Teaching Efficacy Belief Instrument (STEBI) to better measure teacher efficacy related to science teaching. Different variants of the STEBI have been developed for application in specific content areas (Enochs, Riggs, & Ellis, 1993; Enochs, Smith & Huinker, 2000). Studies employing STEBI and its derivatives have reported that science teachers with low teacher efficacy rely more on textbook-based, teacher centered instruction (Cakiroglu, Capa-Aydin, & Woolfolk Hoy, 2012; Enochs, Scharmann, & Riggs, 1995). Additionally, elementary teachers with low science teacher efficacy spend less time teaching science than more efficacious teachers or may completely avoid science teaching (Cakiroglu et al., 2012).

Extensive research has been conducted on science teaching self-efficacy; however, there is a dearth of research related to engineering teaching self-efficacy. In fact, the Teaching Engineering Self-Efficacy Scale (TESS), developed by Yoon, Evans, and Strobel (2014), was the first validated instrument for measuring K-12 engineering teacheing efficacy to surface in the literature. However, published studies employing TESS are absent in the literature due to the newness of the instrument. Similarly, Carberry, Lee, and Ohland (2010) developed the Engineering Design Self-Efficacy Instrument (EDSI) to measure individuals' self-concepts (including self-efficacy) related to engineering design.

The *Next Generation Science Standards* (NGSS) incorporate engineering standards, which results in the expectation that engineering will be taught in K-12 science classrooms. Likewise, the *Oklahoma Academic Science Standards* are modeled after NGSS and incorporate engineering practices into the K-12 science curriculum (Oklahoma State Department of Education, 2014). The way in which teachers approach engineering instruction in their classrooms will be influenced by their engineering teaching self-efficacy. Just as a teacher with high teaching self-efficacy for high school chemistry may have low teaching self-efficacy for middle school life science (Tschannen-Moran et al., 1998), teachers who have high teaching self-efficacy in the science content area they regularly teach may not have high engineering teaching self-efficacy.

Teaching efficacy is dependent upon teachers' content knowledge and pedagogical content knowledge (Committee on Integrated STEM Education, 2014).

Science teaching efficacy is higher for teachers who took greater numbers of high school science courses (Mulholland, Dorman, & Odgers, 2004) and college science courses (Cantrell, Young, & Moore, 2003). According to Yilmaz-Tuzun (2008), increased science content knowledge due to having more course work may help teachers make more appropriate pedagogical choices when teaching science. This enhanced pedagogical content knowledge could lead to more student success in the classroom, which in turn enhances teacher efficacy. Few elementary teachers have high school or college coursework in engineering (Committee on Standards, 2010), which suggests that elementary teachers may lack the required background knowledge to teach engineering, which could result in low engineering teaching self-efficacy.

Perceptions of Engineering

In 2008, the National Academy of Engineering reported that the majority of the general population have preconceived misconceptions about engineers. Many individuals confuse the work of scientists with the work of engineers (Oware, Capobianco, & Diefes-Dux, 2007) and view engineers as unresponsive to society's needs (Committee on K-12 Engineering Education, 2009). Further, stereotypical characteristics, such as viewing engineers as highly, intelligent, nerdy men with poor social skills, are also perpetuated through popular culture such as that seen in television's *The Big Bang Theory*. Because elementary teachers are part of the general population, it is not surprising that researchers contend that elementary teachers' perceptions of engineering should be similar to those of the general public (Nadelson et al., 2013).

Teachers' perceptions of engineering are affected by their limited understanding of engineering (Yasar, Baker, Kurpius-Robinson, Krause, & Roberts, 2006a; Yasar, Baker, Kurpius-Robinson, Krause, & Roberts, 2006b) which can be passed on to their students. Due to a limited understanding of engineering, elementary teachers may believe that only “super smart” teachers and students can learn engineering concepts (Cunningham, 2009). These perceptions of engineering can impact teacher efficacy because if a teacher believes that only “super smart” people can understand engineering he or she may doubt his or her ability to teach engineering. Additionally, teachers are likely to spend less time teaching in a content area that they have low efficacy in (Appleton, 2003; Harlen & Holroyd, 1997). Because teachers learn and grow with teaching practice, avoiding teaching experiences due to low efficacy can result in teachers missing valuable learning opportunities that could enhance their pedagogical content knowledge (Appleton, 2003), which will, in turn, impact the quality of elementary engineering education.

Methodology

Measures

To answer the research questions, a number of subscales from a variety of established instruments were used. Only those subscales which were pertinent to the research questions were included in the current questionnaire to reduce the time required to complete the instrument. The separation of different subscales is commonly used in the field of education, as seen with the use of individual subscales from the Fennema-Sherman Mathematics Attitudes Scales (Fennema & Sherman, 1976) in studies related to mathematics (Iben, 1991; O’Neal, Ernest, McLean, & Templeton, 1988). The Fennema-Sherman subscales have been validated when the instrument has been used in part (O’Neal et al., 1988) or as a whole (Broadbooks, Elmore, Pedersen, & Bleyer, 1981).

This study used the following subscales from established instruments: the *Self-efficacy* subscale from the Engineering Design Self-efficacy Instrument (Carberry et al., 2010); the *Engineering Pedagogical Content Knowledge Self-efficacy, Engineering Engagement Self-efficacy*, *Engineering Disciplinary Self-efficacy, Engineering Outcome Expectancy*, and *Overall Teaching Engineering Self-efficacy* subscales from the Teaching Engineering Self-efficacy Scale (Yoon et al., 2014); and the *Familiarity with Design Engineering and Technology* subscale from the Design Engineering and Technology Survey (Hong, Purzer, & Cardelal, 2011). The *Familiarity with DET* subscale was included to gather data on how familiar participants were with engineering, as assessed by previous engineering experiences and coursework.

Engineering Design Self-Efficacy Instrument (EDSI). Carberry, Lee, and Ohland (2010) developed the EDSI to measure individuals' self-concepts related to engineering design. The instrument contains four subscales designed to measure one of four task-specific self-concepts towards engineering design tasks: self-efficacy, motivation, outcome expectancy, and anxiety. Each subscale included nine 11-point Likert questions. The first question of each EDSI subscale was designed to measure an individual's self-concept toward conducting engineering design and is labeled EDSI Engineering Design (EDSI ED). Questions 2 through 9 of each subscale were modeled after an eight step engineering design process used by the Massachusetts Department of Education (MDOE). The steps in the MDOE design process include: identify a design need, research a design need, develop design solutions, select the best possible design, construct a prototype, evaluate and test a design, communicate a design, and redesign. Questions 2 through 9 of each of the four EDSI items were designed to measure an individual's self-concept related to the corresponding MDOE design process task and is labeled EDSI Engineering Design Process (EDSI EDP). Scores on the EDSI ED and EDSI EDP can range from 0 to 100, with higher scores indicating greater efficacy. Carberry et al. (2010) established the validity and reliability of the instrument and reported a Cronbach's α value 0.967 for the self-efficacy subscale.

Teaching Engineering Self-efficacy Scale (TESS). The TESS was specifically developed to measure K-12 teachers' self-efficacy related to teaching engineering (Yoon, Evans, & Strobel, 2014; Yoon, Evans, & Strobel, 2012). The TESS is a 23-item instrument with a six-point Likert scale ranging from strongly disagree (score of 1) to strongly agree (score of 6). The 23 items are divided into four subscale factors: (1) Engineering Pedagogical Content Knowledge Self-efficacy (KS, Cronbach's α = 0.96), defined as a teacher's personal belief in his or her knowledge of engineering that will be useful for teaching engineering; (2) Engineering Engagement Self-efficacy (ES, Cronbach's α = 0.93), defined as a teacher's belief in his or her ability to engage students while teaching engineering; (3) Engineering Disciplinary Self-efficacy (DS, Cronbach's α = 0.92), defined as a teacher's belief in his or her ability to handle student behaviors during engineering activities; and (4) Engineering Outcome Expectancy (OE, Cronbach's α = 0.89), defined as a teacher's belief in the effect of his or her teaching on students' learning of engineering. The subscales are combined to form a fifth factor, Total Engineering Self-efficacy (TES, Cronbach's α = 0.98).

The TESS may be scored by calculating the mean for each individual subscale or by calculating an overall score for engineering teaching self-efficacy (Yoon, Evans, & Strobel, 2014). The KS score is determined by calculating the mean of items 1 through 9, the ES score is determined by calculating the mean of items 10 through 13, the DS score is determined by calculating the mean of items 14 through 18, and the OE score is determined by calculating the mean of items 19 through 23. The overall self-efficacy score is determined by summing the mean scores for the subscales. The mean score for each subscale may range from 1 to 6, while the overall self-efficacy score may range from 4 to 24.

Design Engineering and Technology (DET) Survey. The DET is a 40-item, five-point Likert instrument originally developed by Yasar, Baker, Robinson-Kurpius, Krause, and Roberts (2006) and later re-evaluated and revised by Hong, Purzer, and Cardella (2011). The DET is used to measure teachers' perceptions of engineering and familiarity with teaching engineering, engineering design, and technology. The first draft of the survey was created by ten graduate students at Arizona State University after an extensive literature review. Exploratory factor analysis resulted in a four factor structure which explained 43.5% of the variance. Items with factor loading values below 0.4 were eliminated, resulting in a 41 item survey with a Cronbach's α = 0.88. The resulting factors were *Importance of DET* (18 items, α *= 0.91), Familiarity with DET* (12 items, α = 0.83), *Stereotypical Characteristics of Engineers* (5 items, α = 0.76), and *Characteristics of Engineers and Engineering* (6 items, α = 0.66).

Hong, Purzer, and Cardella (2011) re-evaluated the DET and proposed a new model that explained 74% of the variance. Exploratory factor analysis using a new sample of 405 participant teachers resulted in a 40-item four-factor instrument with an overall Cronbach's α = 0.88. The resulting factors were *Importance of DET* (19 items, α *= 0.91), Familiarity with DET* (8 items, α = 0.81), *Stereotypical Characteristics of*

Engineers (7 items, α = 0.77), and *Barriers to Integrating DET* (6 items, α = 0.68). The *Familiarity with DET* subscale was the only DET subscale included in the EEEQ and has a score range of 7 to 35.

Participants

A link to the online questionnaire was emailed to the 16,546 Oklahoma K-5 public school teachers whose email addresses were on file with the state department of education, however 1,008 emails were returned as undeliverable. The questionnaire was completed by 542 participants who were responsible for the science instruction of their students, resulting in a 3.5% response rate. Table 4.1 presents the demographics for the sample. Because the state encompasses a large geographic region made up of both urban and rural populations, the researchers wanted to ensure that the sample was representative of the geographic distribution of the state population. The Oklahoma State Department of Education has assigned all school districts in the state to one of eight geographic regions, which were used to evaluate the geographic distribution of the sample. From the data in Table 4.1, it is evident that the sample was representative of the state population with regard to geographic distribution of teachers, gender, education level, grade level taught, and years of work experience.

Table 4.1.

Demographics of Oklahoma K-5 Teacher Population and Study Sample

		Population		Sample	
		Number	Percentage	Number	Percentage
Region	1	670	4.03	26	4.80
	2	1181	7.10	48	8.86
	3	3538	21.28	159	29.34
	4	2180	13.11	55	10.15
	5	1049	6.31	18	3.32
	6	1384	8.32	37	6.83
	7	1058	6.36	30	5.54
	8	5567	33.48	169	31.18
Gender	M	698	4.20	16	3.00
	F	15929	95.80	526	97.00
Education Level					
	Bachelor's	13090	78.73	381	70.30
	Master's/Education Specialist	3498	21.04	157	28.97
	Doctorate	36	0.22	4	0.74
	N/A	3	0.01	0	0.00
Work Experience (Years)	1 to 5	4926	29.63	163	30.07
	6 to 10	3501	21.06	111	20.48
	11 to 15	2506	15.07	85	15.68
	16 to 20	2224	13.38	69	12.73
	21 to 25	1613	9.70	48	8.86
	26 to 30	912	5.49	38	7.01
	31 to 35	534	3.21	15	2.77
	36-40	323	1.94	10	1.85
	over 40	88	0.53	3	0.55
Certification Type					
	Traditional	15951	95.93	491	90.59
	Nontraditional	676	4.07	51	9.41
Grade Level	K	3176	19.10	91	16.79
	1	3638	21.88	98	18.08
	2	3601	21.66	102	18.82
	3	3658	22.00	112	20.67
	4	3370	20.27	120	22.14
	5	3527	21.21	98	18.08

Data Analysis

Participant responses on the questionnaire were transferred to SPSS and analyzed. To determine the internal consistency of each subscale, Cronbach's α was computed. The DET and TESS subscale data were analyzed to yield frequencies of respondents choosing each response category. As suggested by Carberry et al. (2010), question 1 of the EDSI was used to determine a participants' self-efficacy towards conducting engineering design (ED) and questions 2 through 9 of the EDSI were averaged to determine each participant's engineering design process (EDP) score. Pearson correlation coefficients were generated to determine if relationships existed between familiarity with DET and engineering self-efficacy or between familiarity with DET and teaching engineering self-efficacy. Researchers used one-way ANOVA to determine if any significant differences existed on subscale scores of different demographic groups including gender, ethnicity, grade level taught, education attainment level, pathway to certification, geographic region, and years of teaching experience. Because ANOVA assumes equality of variance, the Levene's test for equality of variance was run before interpreting the results of the one-way ANOVA. When the assumption of equal variances was violated (Levene's test less than .05), the Welch test was used because it does not assume equal variances.

Results and Discussion

Prior to analysis, Cronbach's α values were calculated to determine the internal consistency of the subscales used. Cronbach's α values were EDSI EDP, α = 0.97, TESS PCK, α = 0.96, TESS Engagement, α = 0.96, TESS Disciplinary, α = 0.98, TESS Outcome Expectancy, α = 0.95, TESS Total, α = 0.97, and Familiarity with DET, α = 0.90, which are all consistent with those presented in the literature.

Figure 4.1 provides box and whiskers plots of EDSI subscale data. The EDSI is used to measure participants' engineering self-efficacy, with the EDSI ED measuring participants' self-efficacy for conducting engineering design and the EDSI EDP measuring the level of self-efficacy related to completing each step of the engineering design process. The scores for the EDSI can range from 0 to 100. Seventy-five percent of participants scored below a 50 on the EDSI ED and below 60 on the EDSI EDP. This, combined with the mean score of 31.97 (*SD* = 28.49) on the EDSI ED and 39.80 (*SD* = 27.34) on the EDSI EDP indicates that participants have low self-efficacy related to conducting engineering design and completing each step of the engineering design process. Together, these values indicate that elementary teachers have low self-efficacy related to their personal abilities to engage in engineering design.

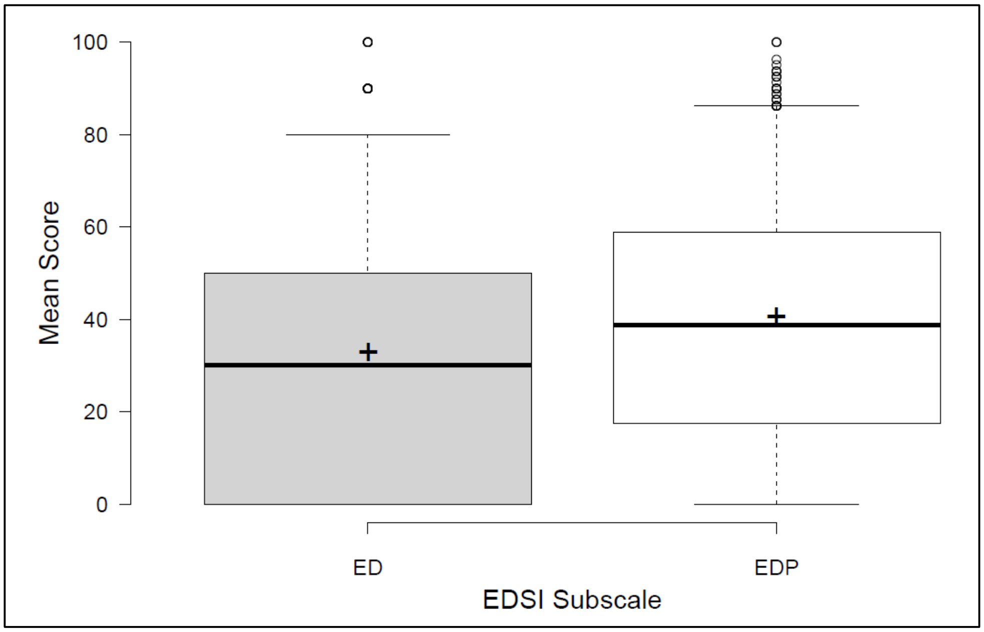

Figure 4.1. Mean Engineering Design Self-Efficacy Instrument (EDSI) data for Engineering Design (ED) and Engineering Design Process (EDP) questions. The whiskers extend from the 5th to 95th percentile of scores and the “+” represents the mean.

Figure 4.2 provides box and whiskers plots of TESS subscale data, where the range of all TESS subscales was 1 to 6. For TESS subscales, higher mean scores are indicative of more positive teaching engineering self-efficacy. Visual inspection of the data in Figure 4.2 indicates that participants scored lower on the TESS Pedagogical Content Knowledge (KS) subscale when compared to the other subscales. Notably, fewer than 5% of the sample had strong positive teaching engineering self-efficacy (greater than 5.5) with regard to KS. To determine if the TESS KS subscale mean scores were significantly different than the other three TESS subscale mean scores, independent-samples t-tests were run. Mean scores for PCK were significantly lower than for TESS Engagement ($t(541) = 22.50$; $p < .001$), TESS Disciplinary ($t(541) = 21.59$; $p < .001$), and TESS Outcome Expectancy ($t(541) = 11.58$; $p < .001$).

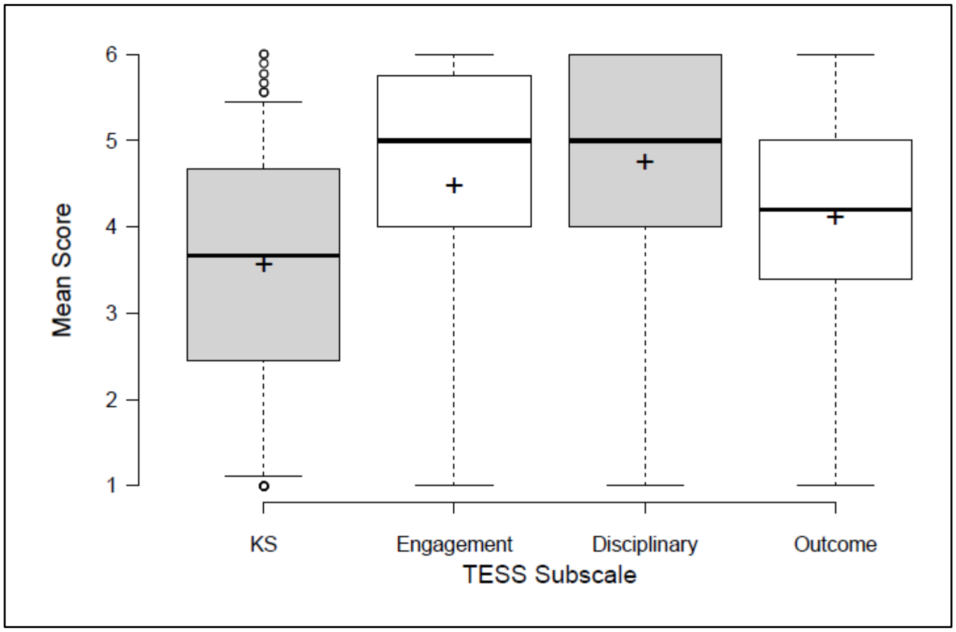

Figure 4.2. Mean Teaching Engineering Self-Efficacy Scale (TESS) data for the Pedagogical Content Knowledge (KS), Engagement, Disciplinary, and Outcome Expectancy subscales. The whiskers extend from the 5th to 95th percentile of scores and the "+" represents the mean.

While participants had relatively low engineering self-efficacy, as indicated by the EDSI subscales, participants' responses to the TESS indicated higher levels of teaching engineering self-efficacy. The TESS KS subscale measures teachers' engineering teaching self-efficacy for pedagogical content knowledge related to teaching engineering. Overall, participants responded negatively with regard to KS, suggesting that teachers had lower teaching self-efficacy for TESS KS than for the other TESS subscales. The lower score on the TESS KS compared to the other TESS subscales may indicate that while teachers feel they have the classroom management skills and teaching strategies required to successfully engage, discipline, and motivate students in their classroom, they feel less secure in their knowledge of engineering and which engineering resources to use with their students. Likewise, the lower scores on the TESS Outcome Expectancy scale may indicate that teachers do not feel as positive about their abilities to help their students learn engineering. The scores on the DET Familiarity subscale (*M* = 13.80, *SD* = 6.37) suggest that participants had little experience with engineering or exposure in engineering coursework or professional development, which could be contributing to their lower self-efficacy scores on the EDSI and TESS KS.

Differences between demographic groups

One-way ANOVA and post hoc tests were used to determine if differences existed in participants' engineering self-efficacy or engineering teaching efficacy based on participant gender, ethnicity, grade level taught, education attainment level, pathway to certification, years of teaching experience, and Title I school status. EDSI scores were used to determine differences in engineering self-efficacy, and TESS scores were used to determine differences in engineering teaching efficacy. Significant differences were found for engineering self-efficacy for grade level, gender, Title I school status, and ethnicity. No significant differences were found for engineering teaching efficacy. Table 4.2 presents descriptive statistics for the groups where significant differences were identified.

Table 4.2.

Descriptive statistics for different demographic groups for the Engineering Design Self Efficacy Instrument (EDSI)

		EDSI ED		EDSI EDP	
Demographic Group	Number	Mean	St. Deviation	Mean	St. Deviation
Grade Level					
K-2	245	26.29	26.21	35.55	25.91
3-5	280	37.11	29.38	43.50	25.91
Gender					
Male	16	26.47	38.07	57.21	31.11
Female	526	31.18	27.81	39.24	27.06
Title I School Status					
Title I		30.83	27.85	38.99	27.84
Non-Title I	432	40.48	28.66	46.71	24.53
	84				
Ethnicity					
African American	5	16.0	25.10	22.75	17.71
American Indian or Alaskan Native	42	35.48	30.06	46.40	28.29
Hispanic	13	40.0	23.82	51.73	24.43
Asian or Pacific Islander	4	32.5	32.02	35.00	36.24
White	453	31.26	28.19	38.50	26.87
More than one race	16	43.75	33.64	55.16	31.26
Other	8	31.25	29.49	43.91	34.24

Note. ED = Engineering Design; EDP = Engineering Design Process.

Grade Level. NGSS breaks the engineering design standards into two grade bands: kindergarten, first, and second grade (K-2) and third, fourth, and fifth grade (3-5). Teachers were placed into one of the grade bands based on current grade taught. Teachers who taught within both grade bands (e.g., teaches 2nd and 3rd grades; n=18) were not included in the current analysis. The results of the one-way ANOVA and Welch tests revealed that teachers in the 3-5 band had significantly higher EDSI ED scores than teachers in the K-2 band, F (1, 522.86) = 19.96, p<.001, η^2 = .04. Grade 3-5 teachers also had significantly higher EDSI EDP scores than K-2 teachers, *F* (1, 523) = 11.40, *p* = .001, η^2 = .02). These results indicate that teachers in the 3-5 grade band have significantly higher engineering self-efficacy than teachers in the K-2 grade band. Teachers in grades 3-5 must prepare students for state mandated tests in mathematics (grades 3-5) and science (grade 5), and could have had additional college coursework or professional development in the areas of mathematics and science. While the grade structure (e.g. departmentalized, self-contained) of the current sample is unknown, there is a trend toward departmentalization at the upper elementary level, where teachers with more experience and training in math and science are responsible for teaching those subjects (Delviscio & Muffs, 2007; Strohl, Schmertzing, & Schmertzing, 2014). Science teacher efficacy is higher for teachers who have had more science education (Cantrell, Young, & Moore, 2003; Mulholland, Dorman, & Odgers, 2004). While it is estimated that few elementary teachers have previous coursework in engineering (Committee on Standards, 2010), an increase in mathematics and science training might enhance engineering self-efficacy due to the interrelatedness of engineering, science, and mathematics. This could explain why teachers in grades 3-5 had higher engineering self-efficacy than grade K-2 teachers.

Gender. One-way ANOVA and Welch tests revealed that female participants had significantly lower scores on the EDSI ED than male teachers, *F* (1, 16.56) = 7.38, *p* = .015, η^2 = .02. Female teachers also had significantly lower EDSI EDP scores than male teachers, *F* (1, 541) = 7.19, *p* = .008, η^2 = .01. The lower EDSI scores indicate that female teachers have lower engineering self-efficacy than their male counterparts. Self-efficacy is impacted by mastery experience, therefore individuals who have more experiences with engineering would have greater opportunities to enhance their engineering self-efficacy. Gender role socialization, often initiated by parents and other family members during infancy, and parental expectations influence children’s perceptions of their abilities (Eccles, 2007), and can result in females having fewer experiences with math and science related activities than males (Hyde, 2007). The lower efficacy levels of females is very concerning because most elementary teachers are female. Teachers tend to avoid teaching what they are not comfortable with, which suggests that many children may not receive adequate engineering instruction due to the lower efficacy of their teachers.

Title I school status. Twenty-six teachers did not know the Title I status of their schools and were not included in this analysis. Teachers working in Title I schools had significantly lower scores on EDSI ED than their peers who did not teach at Title I schools, F (1, 514) = 8.03, p = .005, η^2 = .02. Title I teachers also had significantly lower EDSI EDP scores than non-Title I teachers, F (1, 128.23) = 6.66, p = .011, η^2 = .01. These results indicate that Title I school teachers had lower engineering self-efficacy than non-Title I school teachers. Research studies have shown that schools serving disproportionately larger numbers of disadvantaged students have a harder time finding and retaining teachers (Sass, Hannaway, Xu, Figlio, & Feng, 2012). These schools also have fewer highly qualified teachers and more teachers who teach outside of their licensure area (Machtinger, 2007).

Ethnicity. One participant chose not to report ethnicity and was not included in this analysis. The only significant difference due to ethnicity was on the EDSI EDP subscale (F (6, 540) = 2.23, p = .039, η^2 = .02). Post hoc Fisher’s LSD tests indicated that African American participants scored significantly lower than both Hispanic (mean difference = -28.98, *p* = .043) participants and participants reporting more than one race (mean difference = -32.41, *p* = .02). Additionally, White participants scored significantly lower than participants reporting more than one race (mean difference = -16.68, *p* = .016). The reason for these differences is not fully understood.

Familiarity with DET

Pearson Correlation values were calculated to explore any potential correlations between participants' familiarity with design/engineering/technology and their engineering self-efficacy and engineering teaching self-efficacy (see Table 4.3). Participants' familiarity with engineering, as measured by the DET familiarity subscale, was significantly and positively correlated with all EDSI and TESS subscales, which could indicate that teachers who are more familiar with engineering and what engineers do have higher engineering self-efficacy and engineering teaching self-efficacy. Similarly, Carberry et al. (2010) reported that engineering self-efficacy, as measured by EDSI scores, increased with more engineering experiences. The values presented in Table 4.3 indicate that DET Familiarity was more highly correlated with EDSI ED (r = .55), EDSI EDP (r = .55), and TESS KS (r = .55) than with TESS Engagement (r = .46), TESS Disciplinary (r = .35), and TESS Outcome (r = .41). This could indicate that familiarity with engineering has an impact on engineering teacher efficacy; however, some areas of teacher efficacy, such as the ability to motivate and discipline students during engineering activities may not be as greatly influenced by a teacher's familiarity with engineering.

Table 4.3.

Pearson Correlation Values for Instrument Subscales

Instrument Subscale	EDSI ED	EDSI EDP	TESS KS	TESS ENG	TESS DIS	TESS OUT	TESS Total
EDSI EDP	.85**	-					
TESS KS	.21**	.25**	-				
TESS ENG	.19**	.24**	.78**	-			
TESS DIS	.15**	.21**	.57**	.77**	-		
TESS OUT	.22**	.27**	.65**	.69**	.66**	-	
TESS Total	.22**	.28**	.86**	.93**	.86**	.85**	-
DET Familiarity	.55**	.55**	.55**	.46**	.35**	.41**	.50**

Note. EDSI = Engineering Design Self-efficacy Instrument; ED = Engineering Design; EDP = Engineering Design Process; TESS = Teaching Engineering Self-efficacy Scale; KS = pedagogical content knowledge, ENG = engagement, DIS = disciplinary, OUT = outcome expectancy.
**Significant at $p<0.01$

Conclusion and Implications

Findings in the current study indicate that K-5 teachers have low engineering self-efficacy and engineering teacher efficacy related to engineering pedagogical content knowledge. Previous research shows that teacher efficacy is a strong indicator of a teacher’s ability to be successful in the classroom (Cakiorglu et al., 2012). Further, regardless of subject or grade level taught, effective classroom instruction requires the teacher to possess subject matter content knowledge, curricular knowledge, and pedagogical content knowledge (Shulman, 1986). The findings suggest that elementary teachers may lack the level of engineering self-efficacy and engineering teaching efficacy related to KS necessary to successfully implement engineering standards into their classrooms.

Understanding the level of engineering self-efficacy and teacher efficacy elementary teachers bring to the classroom is important when identifying their professional development (PD) needs. A lack of these could indicate that teachers need mastery experiences (Bandura, 1977) in the area of engineering design and teaching engineering in order to improve their teacher efficacy and effectiveness in the classroom. This could be accomplished through the development of preservice coursework and in-service workshops specifically devoted to engineering education.

While the current study points to the need of mastery experiences for teachers, further research is needed to determine the specific types of mastery experiences and professional support that K-5 teachers need in order to successfully implement the engineering components of NGSS into their classrooms. Recently, the American Society for Engineering Education released a report entitled *Standards for Preparation and Professional Development for Teachers of Engineering* (Farmer, Klein-Gardner, & Nadelson, 2014) that provides a description of the components that should be included in training programs for teachers. The development of the standards took over 30 months and made use of the input of 39 engineers at the K-12 and postsecondary level. PD developers need to create professional growth opportunities for elementary teachers that fit these standards, make them readily available to teachers, and assess the impacts of these programs on teachers' engineering efficacy and teaching engineering efficacy. Additionally, administrators, need to be aware of their teachers' needs and help them actively seek out and fund PD that will lead to mastery experiences related to teaching engineering.

CHAPTER V

ELEMENTARY TEACHERS' PERCEPTIONS OF K-5 ENGINEERING EDUCATION AND PERCEIVED BARRIERS

Target Journals: A. Journal of Research in Science Teaching

B. Journal of Engineering Education

Authors: Rebekah Hammack, Toni Ivey

Abstract:

The Next Generation Science Standards call for the infusion of engineering content and practices within elementary science curriculum. This mixed methods study explored elementary teachers' perceptions about incorporating engineering within K-5 classrooms as well as the barriers they perceive to doing so. Results indicated that most elementary teachers support the inclusion of engineering within the science standards for elementary grades. Teachers describe lack of preservice and in-service training, lack of background knowledge, lack of materials, lack of time for planning and implementing lessons, and lack of administrative support as barriers to implementing engineering activities within their classrooms.

Keywords: elementary, engineering education, barriers, NGSS

Introduction

In their 2011 report *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core* Ideas, the National Research Council, NRC, addresses the need to address the leaky pipeline of students who discontinue pursuing STEM, and in particular, engineering. However, we must not lose focus of educating the masses, or the mainline, as all citizens need to develop a level of technological literacy proficiency (NRC, 2011). As the United States becomes more dependent upon technology, education must shift to adequately prepare the nation's children to become technologically literate adults (mainline), while also providing the content knowledge and skills to those children who will enter the STEM workforce (pipeline). To address both pipeline and mainline concerns, the *Next Generation Science Standards* (NGSS) have incorporated engineering practices into K-12 science standards (NGSS Lead States, 2013). Because NGSS calls for K-12 science teachers to integrate engineering into their classrooms, action must be taken to ensure that teachers are prepared to successfully implement the new standards. Little is known about the preparedness of elementary teachers to incorporate engineering practices into their science lessons. Determining what perceptions elementary teachers hold about K-5 engineering and the barriers they believe limit their abilities to implement engineering standards will be necessary to ensure that elementary teachers receive the professional training and support needed to implement the engineering components of NGSS.

Purpose of the Study

The purpose of this explanatory sequential mixed methods study (Creswell & Plano Clark, 2011) was to identify the perceptions that elementary teachers have towards

K-5 engineering as well as identify any barriers that K-5 teachers believe might prevent them from successfully teaching engineering in their classrooms. In particular, the researchers sought to answer the following research questions:

1. What perceptions do in-service elementary teachers hold about K-5 engineering education?
2. What factors do in-service elementary teachers perceive as barriers to teaching engineering and engineering design?

Related Literature

The need to create both a STEM pipeline and STEM mainline make the incorporation of engineering into the elementary classroom important. The infusion of engineering standards within the *Next Generation Science Standards* implies that all K-5 educators should incorporate engineering within their science curricula, however K-5 engineering education is a relatively new field of study. This section reviews the current research literature related to the developmental appropriateness of K-5 engineering education as well as perceived barriers to implementing engineering practices into K-5 classrooms.

Developmental Appropriateness of K-5 Engineering

Children are born with a natural desire to figure out how things work and design their own creations (Cunningham, 2009). The fundamental activity of engineering is design, which naturally permeates children's lives (Petroski, 2003), and researchers suggest that children are capable of successfully working through the design process (Brophy, Klein, Portsmore, & Rogers, 2008). Berrett (2006) reported that while some engineering concepts may be more challenging for children to understand, such as optimization and robust design, elementary students do have the ability and interest to benefit from engineering curriculum. Further, Perrin (2004) reported that K-4 students are able to question and investigate the world around them, and have the motor skills needed to use measurement tools and complete engineering activities.

If presented in the right way, with the correct support structures, engineering is developmentally appropriate for children, and they can engage in sophisticated design challenges well before young adulthood (Schunn, 2009). Cunningham (2009) reported that students who participated in the *Engineering is Elementary* curriculum developed by the Boston Museum of Science had an improved understanding of engineering, technology, and science as a result of their engagement in engineering activities. Likewise, Yoon Yoon and colleagues reported that 2nd-4th grade students whose teachers used integrated science, engineering, and technology (STE) lessons had significant content knowledge gains related to STE when compared to a control group (Yoon Yoon, Lucietto, Capobianco, Dyehouse, & Diefes-Dux, 2014). Further, using design to teach mathematics and science can enhance children's communication and spatial reasoning skills, and their abilities to develop cognitive models of systems, synthesize information, and conduct experiments (Brophy et al., 2008). In fact, the engineering-focused Douglas L. Johnson Jr. Elementary School has seen significant gains in state reading and mathematics scores and a decrease in discipline issues by using an all engineering-focused curriculum (Barger, Gilbert, Poth, & Little, 2006). It is important to note, however, that this program is still young and the results should not be heavily relied upon until further data is collected.

Barriers to Teaching K-5 Engineering

Teachers are uncomfortable teaching what they do not know or are unfamiliar with (Brophy et al., 2008). Many prekindergarten through eighth grade teachers have limited STEM content knowledge (Brophy et al., 2008) which may result in the avoidance of teaching engineering. The familiarity with engineering construct is not well developed in the research literature and studies are limited to those using an instrument developed by Yasar and colleagues (Appendix A). Yasar et al. (2006a, 2006b) used a Likert scale instrument to measure K-12 teachers' familiarity with engineering, engineering design, and technology (DET). Most teachers in the study had low familiarity with DET, which they attributed to lack of knowledge, lack of administrative support, lack of training, and lack of time for learning about DET. Subsequent studies using the instrument developed by Yasar et al. (2006a, 2006b) reported similar findings (Hsu, Cardella, Purzer, & Diaz, 2010; Hsu, Purzer, & Cardella, 2011).

There is a dearth of research devoted to the barriers of implementing engineering at the elementary level. Although the research community does not know a lot about the barriers to implementing engineering in the elementary classroom, we are better informed about the barriers to implementing science in the elementary curriculum. When describing the barriers to implementing inquiry science at the elementary level, many teachers list lack of content knowledge (Burton & Frazier, 2012; Sexton, 2013); inadequate pre-service training (Blanchard et al., 2013); and a lack of resources, planning time, and instructional time (often due to a focus on tested subject matter) as inhibiting factors (Blanchard, Osborne, Wallwork, & Harris, 2013; Cartright, 2014; Santau & Ritter, 2013). Further, Blanchard et al. (2013) reported that teacher comfort related to the inquiry teaching methods was the most significant variable in determining whether teachers would teach using inquiry (Blanchard et al., 2013). In fact, when interviewing award winning science teachers from grades K-12, Burton and Frazier (2012) found that all respondents said that elementary teachers lacked the content and pedagogical knowledge required to teach inquiry and that many were intimidated by inquiry and avoided teaching with it.

Overall, the research literature reveals that elementary students are capable of participating in and learning from engineering activities. However, the barriers teachers have related to implementing these activities at the elementary level have not been fully explored. The current study addresses this void in the literature by describing the barriers K-5 teachers perceive as limiting their abilities to teach engineering to their students.

Methodology

This study is part of a larger study that utilized an explanatory sequential mixed methods research approach to study elementary teachers' perceptions of engineering and engineering design, as well as their preparedness to teach engineering. During the first phase of the current study, participants completed an online questionnaire containing selected response and Likert questions. The results from Phase 1 were used to finalize the interview protocols used during the individual and focus group sessions that took place during Phase 2 of the study. The results from both phases were merged and used to answer the research questions. A mixed approach was chosen to attain benefits of both quantitative and qualitative methods and to provide the researcher with a fuller understanding of the research questions (Creswell & Plano Clark, 2011).

Measures

No individual questionnaire existed that would address all of the research questions that were a part of the present study. As a result, the researcher combined subscales form existing instruments in order to gather data pertinent to all of the research questions. The separation of different subscales is common in the field of education, as seen with the use of individual subscales from the Fennema-Sherman Mathematics Attitudes Scales (Fennema & Sherman, 1976), which have been validated when used as a whole (Broadbooks, Elmore, Pederson, & Bleyer, 1981) or in part (O'Neal, Ernest, McLean, & Templeton, 1998). Specifically, the questionnaire items analyzed during the current study included (a) the *Barriers to Integrating DET* subscale from the Design Engineering and Technology Survey (Hong et al., 2011) and (b) modified versions of some questions from the Texas Poll of Elementary School Teachers (McNamara, 2000; McNamara, 1999; McNamara, Stuessy, Parker, McNamara, Garcia, & Quenk, 1998).

Design Engineering and Technology Survey, DET. The DET, originally developed by Yasar, Baker, Robinson-Kurpius, Krause, and Roberts (2006b) and re-evaluated by Hong, Purzer, and Cardella (2011), is a 40 item, five-point Likert instrument used to measure teachers' perceptions of engineering and familiarity with teaching engineering, engineering design, and technology. The original instrument consisted of 41 items (Chronbach's α = 0.88) that explained 43.5% of the variance and loaded of four factors – *Importance of DET* (18 items, α *= 0.91), Familiarity with DET* (12 items, α = 0.83), *Stereotypical Characteristics of Engineers* (5 items, α = 0.76), and *Characteristics of Engineers and Engineering* (6 items, α = 0.66). Hong, Purzer, and Cardella (2011) re-evaluated the DET using a new sample of participants. The resulting instrument contained 40-items (Chronbach's α = 0.88) that explained 74% of the variance and loaded on four factors – *Importance of DET* (19 items, α *= 0.91), Familiarity with DET* (8 items, α = 0.81), *Stereotypical Characteristics of Engineers* (7 items, α = 0.77), and *Barriers to Integrating DET* (6 items, α = 0.68).

Texas Poll of Elementary School Teachers. The Texas Poll of Elementary School Teachers was designed to gather information that could be used to improve science teaching at the elementary level (McNamara, 1999). A two-stage cluster sampling design was used to select 200 elementary teachers to participate in the telephone survey. The study had an 88% response rate resulting in 175 participants. The telephone questionnaire included 27 items including four open-ended and 23 closed-ended questions. The margin of error for the closed-ended questions was five percent. The reported findings were descriptive in nature. For the current study, questions 3, 4, 5, 6, 9, 10, 26, and 27 of the Texas Poll were modified by replacing the word "science" with "engineering." For example, item 3 on the Texas Poll "Do you believe science is a high priority in you school?" was changed to "Do you believe engineering is a high priority in your school?" See Appendix A for a full list of the modified Texas Poll questions included in this study. The majority of the Texas Poll questions were selected response, with three of the Texas Poll questions followed with "Please elaborate on your previous response." The questions containing follow ups were: "Are you satisfied with the extent to which your school provides you with instructional materials to teach engineering? Please elaborate on your response," "What are the two most important things that would help you improve engineering teaching in your classroom. Please elaborate on your response," and "Assume you have been appointed to a national task force that wishes to construct a new preservice teacher methods course devoted explicitly to teaching engineering in elementary schools. What two things would you recommend they stress in developing this new preservice course? Please elaborate on your response."

Participants

A database containing contact information for Oklahoma K-5 public school teachers (n = 16,546) was obtained from the Oklahoma State Department of Education (OKSDE). A link to the questionnaire was emailed to all Oklahoma K-5 public school teachers in the database, however 1,008 emails were returned undeliverable. The questionnaire was completed by 542 participants who were responsible for the science instruction of their students, resulting in a 3.5% response rate. The Oklahoma State Department of Education has assigned each school district in the state to one of eight geographic regions, called Reac^{3}h regions (OKSDE, 2014). The state covers a large geographic region including urban, suburban, and rural populations and the Reac^{3}h Region of participants was used to determine how geographically representative the sample population was. Tables 5.1 and 5.2 present demographic information for the sample. Overall, the sample was representative of the state population with regard to education level, gender, grade level taught, years of teaching experience, and geographic distribution of teachers.

Table 5.1.

Demographics of Oklahoma K-5 Teacher Population and Study Sample

		Population		Sample	
		Number	Percentage	Number	Percentage
Oklahoma Reac³h Region[1]					
	1	670	4.03	26	4.80
	2	1181	7.10	48	8.86
	3	3538	21.28	159	29.34
	4	2180	13.11	55	10.15
	5	1049	6.31	18	3.32
	6	1384	8.32	37	6.83
	7	1058	6.36	30	5.54
	8	5567	33.48	169	31.18
Gender					
	M	698	4.20	16	3.00
	F	15929	95.80	526	97.00
Highest Education Level					
	Bachelor's	13090	78.73	381	70.30
	Master's/Education Specialist	3498	21.04	157	28.97
	Doctorate	36	0.22	4	0.74
	N/A	3	0.01	0	0.00
Teaching Experience (Years)	1 to 5	4926	29.63	163	30.07
	6 to 10	3501	21.06	111	20.48
	11 to 15	2506	15.07	85	15.68
	16 to 20	2224	13.38	69	12.73
	21 to 25	1613	9.70	48	8.86
	26 to 30	912	5.49	38	7.01
	31 to 35	534	3.21	15	2.77
	36-40	323	1.94	10	1.85
	over 40	88	0.53	3	0.55
Teacher Certification Type					
	Traditional	15951	95.93	491	90.59
	Nontraditional	676	4.07	51	9.41
Grade Level Taught					
	K	3176	19.10	91	16.79
	1	3638	21.88	98	18.08
	2	3601	21.66	102	18.82
	3	3658	22.00	112	20.67
	4	3370	20.27	120	22.14
	5	3527	21.21	98	18.08

[1] The Oklahoma Reac³h regions were used to determine the geographical representation of the state. A map of the Reac³h regions can be found at http://ok.gov/sde/reac3h-network.

Table 5.2.

Ethnicity and Title I school status of study participants.

	Number	Percentage
Do you teach in a Title I school?		
Yes	432	79.70
No	84	15.50
Don't Know	26	4.80
Ethnicity		
African American	5	0.92
American Indian or Alaskan Native	42	7.75
Hispanic	13	2.40
Asian or Pacific Islander	4	0.74
White	453	83.58
More than One	16	2.95
Other	8	1.48

Data Analysis

Quantitative and qualitative data from the questionnaire were analyzed separately and then merged to look for convergence or divergence of findings (Creswell & Plano Clark, 2011). Additionally, interview and focus group data collected during Phase 2 were analyzed independently and then merged with the Phase 1 data..

DET analysis. Participant responses for the DET subscale were transferred to SPSS version 22. Researchers analyzed data to yield frequencies of responses to each subscale question.

Texas Poll analysis. All selected response questions were transferred to SPSS and analyzed to yield frequencies of respondents choosing each response category. Responses to the three open-ended questions were printed onto cards which were used during the coding process (Creswell, 2007). First, attribute coding was used to log essential demographic information about the participants for future reference (Saldana, 2013). Each card was coded with the participant's gender, ethnicity, years of teaching experience, education attainment level, geographic region, pathway to certification, and grade level taught. The researcher then read through each response and compiled an initial list of codes to use during coding. Next, as described by Saldana (2013), the researcher used the initial code list to complete a round of descriptive coding. During this initial round of descriptive coding, additional codes were generated and added to the preliminary code list and code frequencies were determined. The frequencies with which each code appeared in the data were based on the number of participants who used a particular code, not the number of times that the code appeared (Namey, Guest, Thairu, & Johnson, 2008).

Focus groups and interviews. After completing the online questionnaire, participants were redirected to an unlinked survey where they could voluntarily provide contact information to participate in a follow-up interview or focus group. Based on individual availability, three focus groups were scheduled in two different large cities in the state. Seven to ten individuals were scheduled for each session, however, actual focus group attendance was low, with four individuals participating in the first focus group and the last two focus group sessions becoming individual interviews. A total of 11 individual interviews were conducted: two in person and nine over the phone. Protocols for the interview and focus group sessions are in Appendices B and C, respectively. Interview questions were developed in the hopes of eliciting responses that would help answer the research questions. All follow-up sessions were audio recorded and the researcher wrote field notes. Immediately following each follow-up session, the researcher reviewed the field notes and wrote a reflection over the session. Demographic information for focus group and interview participants is presented in Table 5.3.

Table 5.3.

Demographic information of interview and focus group participants.

	Number		Number
Oklahoma Reac^{3}h Region[1]		*Teaching Experience (Years)*	
1	1	1 to 3	6
2	1	4 to 6	1
3	6	7 to 10	2
4	1	11 to 15	0
5	1	16 to 20	3
6	0	21 to 25	1
7	1	over 25	2
8	3	*Teacher Certification Type*	
Gender		Traditional	12
F	15	Nontraditional	3
M	0	*Grade Level Taught*	
Highest Education Level		K	4
Bachelor's	10	1	2
Master's/Education Specialist	5	2	4
Doctorate	0	3	1
Ethnicity		4	5
Asian or Pacific Islander	1	5	1
Hispanic	2	*Do you teach in a Title I school?*	
Native American or Alaskan Native	1	Yes	13
White	11	No	2

[1] The Oklahoma Reac^{3}h regions were used to determine the geographical representation of the state. A map of the Reac^{3}h regions can be found at http://ok.gov/sde/reac3h-network.

All focus group and interview sessions were transcribed verbatim by the researcher who conducted the session (Oliver, Serovich, & Mason, 2005). Each participant was provided with a copy of the transcript to allow for member checking and to ensure that the findings remained true to the participants' perspectives, and changes were made to the transcripts based on participants' feedback. Pairings of interview questions were used to gain a deeper understanding of participants' views related to specific research questions. The researcher inductively analyzed the data by attempting to make sense of the data without imposing predetermined expectations (Patton, 2002). First, the researcher conducted an initial read through of the transcripts, during which a list of codes was generated. During a second reading of the transcripts, the codes were examined to identify patterns and themes. Finally, the patterns and themes related to each research question were identified, explored, and triangulated with the Phase 1 data in order to answer each research question.

Researcher Stance

As a middle school engineering teacher, the researcher came to the study with preconceived ideas about responses. The researcher expected participants to have limited experiences with engineering and hold preconceived notions about engineers, just as the researcher did prior to teaching engineering for the first time. The researcher acknowledged these preconceived ideas and remained open and true to the data that emerged.

Trustworthiness and Credibility

For every qualitative study, Creswell (2007) recommends the use of at least two of the following validation strategies for qualitative research – prolonged engagement in the field; triangulation; peer review; negative case analysis; clarifying researcher bias at the beginning of the study; member checking; rich, thick descriptions; and external audits. In the current study, the researcher was open with participants about the nature of the study, and provided participants with the opportunity to review the researcher's written description and interpretation of the interviews and focus group sessions. The themes emerging from the interview and focus group sessions were compared with the information obtained from the questionnaire responses and analysis to allow for triangulation (Gall, Gall, & Borg, 2003). The researcher also established inter-rater reliability by having additional scholars independently analyze the transcripts and compare the resulting codes.

Results

When answering our research questions, the researcher analyzed the Phase 1and Phase 2 data separately and then merged the two to come to a deeper understanding of the underlying phenomena. The findings are presented in a similar manner, with the Phase 1 and 2 findings reported separately in the results section and then merged and described in the discussion section.

Phase 1

During Phase 1, the *Barriers to Implementing DET* subscale data and modified *Texas Poll* questions were analyzed. Figure 5.1 displays participant responses to the Design, Engineering, and Technology, DET, subscale questions, which are a measure of how strong of a barrier to teaching engineering participants perceive each of the areas to be. The majority of participants strongly agreed that lack of time to teach DET (57%), lack of teacher knowledge of DET (50%), and lack of training in DET (57%) are barriers to implementing engineering into their classrooms. While administrative support was also reported as a barrier by approximately half of the participants, it was not reported as a strong barrier as frequently as the others.

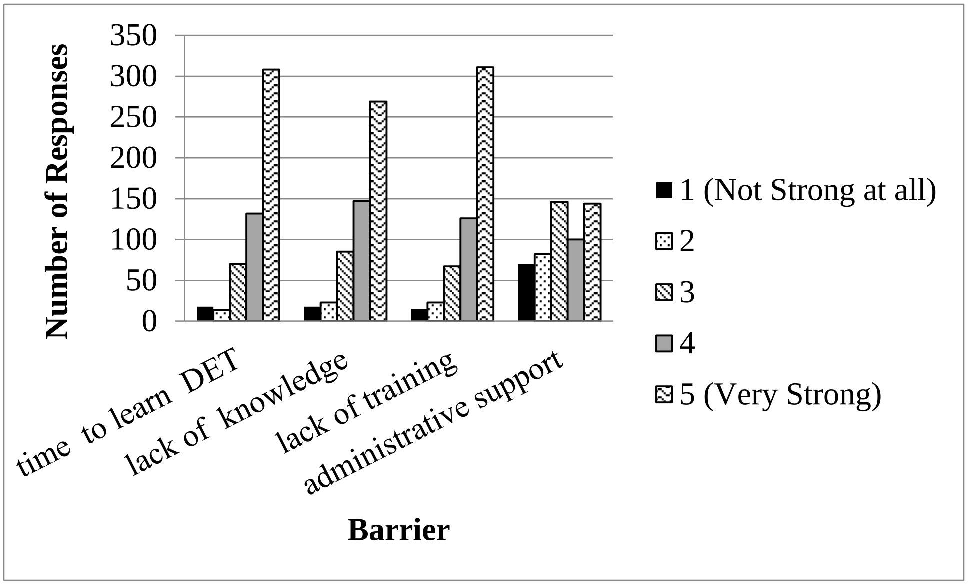

Figure 5.1. Frequency of participant responses to items on the *Barriers to Integrating Design/Engineering/Technology* subscale.

When asked if participants had attended engineering focused professional development (PD) during the last three years, 85% reported that they had not. Of the 15% who had attended engineering focused PD, only 40% reported that their district paid for them to attend the PD. Examples of engineering focused PD that participants attended included Project Lead the Way, STEM workshops developed by the Oklahoma Energy Resource Board, and robotics trainings such as Botball and FIRST Lego League. Many participants could not remember the name of the PD they attended and simply called it a STEM training.

Figure 5.2 displays participant responses to the modified Texas Poll question “Do you believe engineering is a high priority…” Overall, participants did not believe that engineering was a priority in their schools, in their school districts, to the parents in their schools, or to the communities where their schools were located.

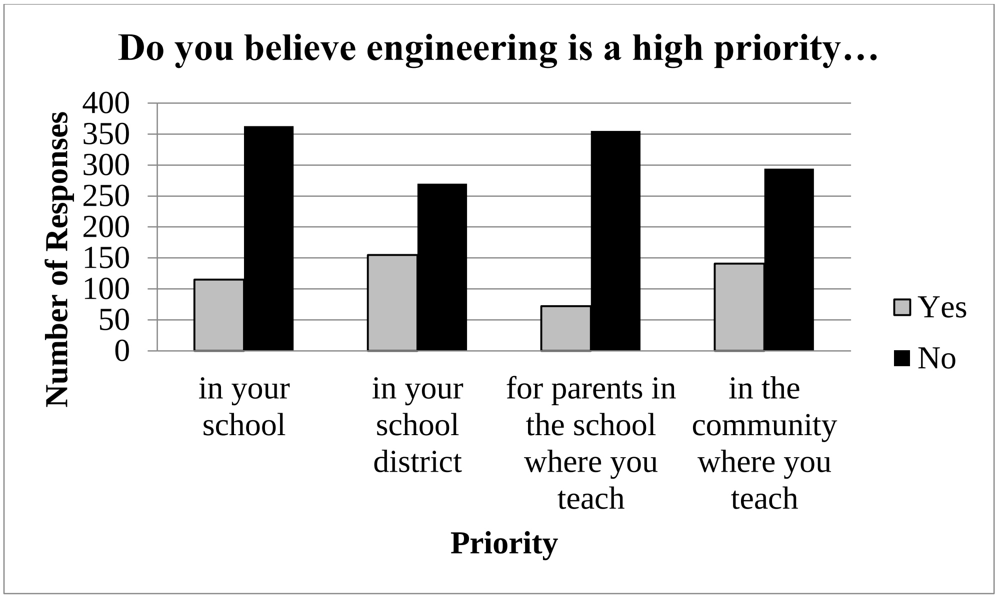

Figure 5.2. Participant responses to perceived priority level of engineering.

When asked if they were satisfied with the extent to which their school provides instructional materials for teaching engineering, 81% of participants said they were not satisfied. Interestingly, of the 103 (out of 542) participants who were satisfied, 35% commented that their district did not provide any resources, but because they do not teach engineering, they have no need for instructional materials. Those who stated that they were unsatisfied mentioned that there was too much emphasis placed on reading and mathematics, so materials and training for science and engineering were not offered. One participant wrote, “There is really nothing provided and for the most part it boils down to 'it's not tested in my grade, so don't spend too much time on it'.” Another wrote, “As far as I know, we have no support in this. We do not even have sufficient support in science...the last time we received new teaching materials was in the 1990s. I am also missing one of my science textbooks and have asked for it to be replaced the past 3 years...hasn't been replaced yet.”

Improving ability to teach engineering. Participants were asked to identify the two most important things that would help improve their abilities to teach engineering in their classrooms. Responses are displayed in Figure 5.3. Training and information about how to teach engineering was the most commonly selected item (76%), followed by additional materials (56%), guidance in what to teach in engineering classes (42%) and support for teaching engineering (18%). Nine percent of participants selected "other" and listed additional time for planning and/or teaching engineering as an area for improvement.

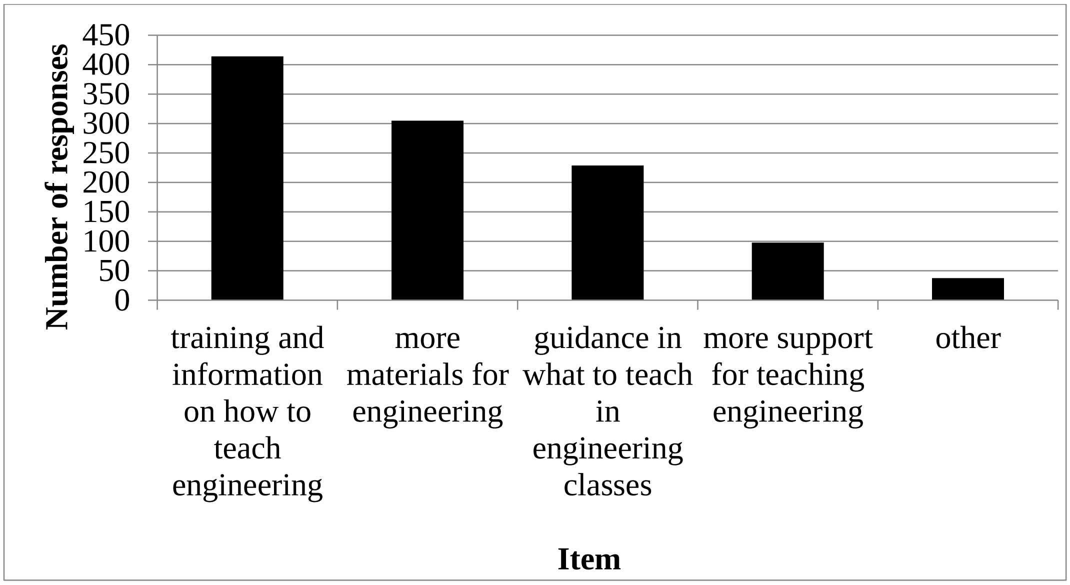

Figure 5.3. Items identified as important for improving engineering teaching.

When asked to elaborate on their answers, participants' responses fell within six categories: materials, support, knowledge and training, time, guidance, and not appropriate for elementary. Many participants' responses fell within more than one category and were counted in each category in which they fell.

Materials. Responses in this category focused on a lack of physical materials or curriculum materials for teaching engineering. One participant stated, "I don't know of anything in my classroom I could use right now to teach an engineering lesson with." Another participant wrote, "Without the proper supplies it makes it extremely hard to teach these standards."

Support. Responses included in this category related to the lack of administrative support for teaching engineering or the understanding that engineering was not encouraged or required to be taught. For example, one participant stated, "Engineering is not in our PASS skills [state standards] for my grade level. If it was in the PASS we would teach it." One teacher stated, "I haven't even been told we are supposed to teach about this subject." Others mentioned support for teaching engineering to certain groups of students, "Engineering lessons are reserved for students who are a part of the Gifted and Talented program," but not for others, "special education is not encouraged to teach it." Another participant wrote, "We just don't talk about science much at all. We're pretty much told to focus on math and reading since those are two subject areas we test in each year. We do teach science for half the year, but I don't think the administration cares how, when, or how much it is taught."

Knowledge and training. Responses in this category were related to participants' lack of knowledge of engineering. Some participants said that they knew so very little about engineering that they did not know what they needed. As one teacher stated, "I don't know what I need to teach it but my district is underfunded so I don't even know that we have the materials to teach it if I knew what to do." Many participants said that they need to understand engineering well enough to teach it, "We need to understand what we are supposed to teach before we could possibly introduce it to our classes." Other teachers mentioned being intimidated by their lack of engineering knowledge, which resulted in not teaching it, "I don't know. I have no idea about teaching any kind of engineering. I do not attempt nor would I attempt to teach engineering."

Time. Responses in this category focused on a lack of time for preparing or teaching engineering. Many participants said that they did not have time to teach engineering because they had to focus on content that would be on state assessments, "This is not done in our elementary school for time is spent on focusing on the skills the students will be tested on." Some participants were frustrated with the amount of material to be covered and the lack of time to do it in, "We already have too much on our plate. This would be one more thing…" As another teacher stated, "I don't have time to find materials, produce lessons, and research how to do it all myself."

Guidance. Many participants said that they would be willing to teach engineering to their students if they were given guidance on what was appropriate to teach at their grade level and how to implement it, "I would need some ideas of engineering projects appropriate to the 3rd and 4th grade and more time to do it in." Another participant stated, "More guidance to understand what is actually [considered] engineering."

Not appropriate for elementary. A surprising category to emerge from the data was the idea that engineering should not be incorporated into the elementary curriculum. Participants were asked to elaborate on the items they needed to better enhance their abilities to teach engineering, so it was expected they would describe items needed to help them teach engineering, yet some responded by saying that engineering should not be taught in elementary school. One participant stated, “We must stay focused on reading and math basics for the children’s sake.” Another wrote, “At this age level, I don’t understand the need or reason for engineering when basic facts are no longer of importance.” Others stated that engineering is “not appropriate in kindergarten,” and “There is so much we already have to teach that expecting design and engineering when kids can’t even pass writing and reading tests is just crazy.”

Elements of preservice engineering methods course. Participants were also asked to identify the two most important elements that should be included in a preservice engineering methods course and to elaborate on their answer. Figure 5.4 illustrates participants’ responses. *How to teach engineering* and *how to use materials to teach engineering* were the most frequently chosen elements. For the “other” category (n = 28), participants listed things like lesson plan ideas, hands-on training, and ideas for funding. Interestingly, one participant who chose other wrote, “not important for my grade and social status children.”

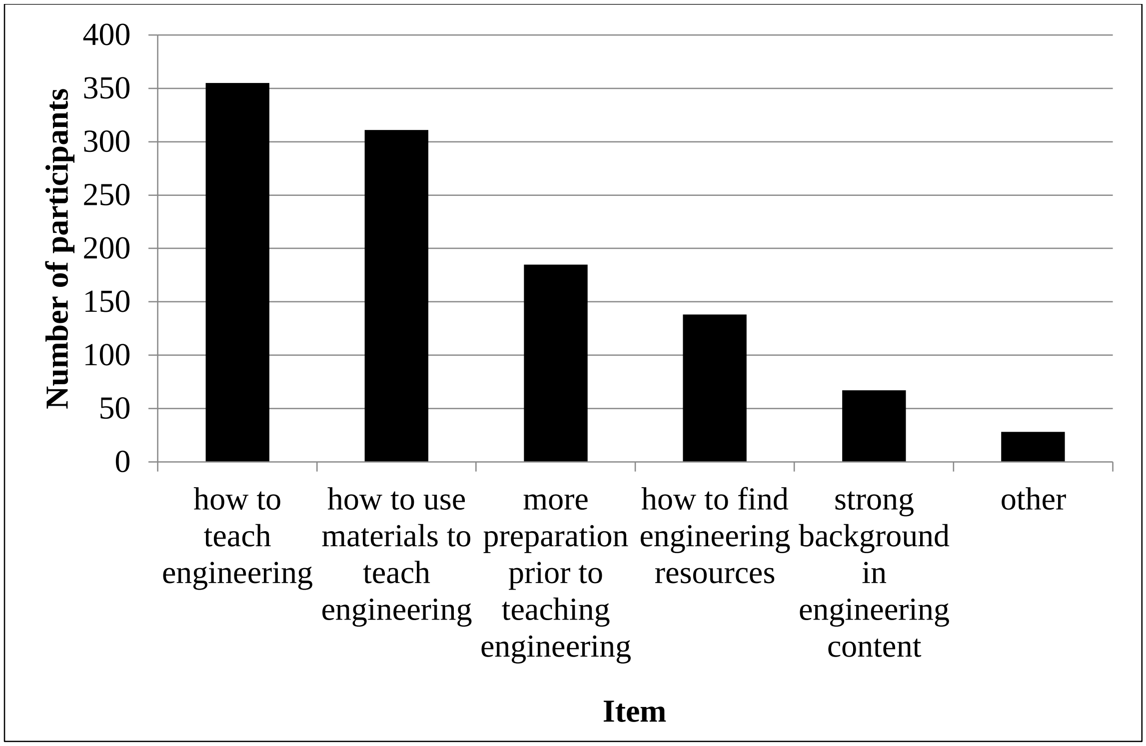

Figure 5.4. Elements identified as important to include in a preservice engineering methods course.

When participants were asked to elaborate, their responses fell into five categories: *how to use materials, hands-on training, how to find resources, background knowledge,* and *not appropriate for elementary.* Responses often fell within more than one category, in which case they were included in each category in which they fit.

How to use materials. Many participants stressed the importance of being trained on how to use materials to teach engineering, “Materials without knowledge about how to use them leads to students not learning, and knowledge without proper materials just scratches the surface with regards to students needing hands-on learning.” Another participant wrote, “Providing materials is not enough. Many rooms have excess materials. Teachers must be taught how to use materials.”

Hands-on and applicable training. The importance of hands-on training that is applicable to the classroom was also stressed, “Preservice teachers need real life experiences in teaching engineering lessons, rather than lectures over the topic.” Another participant wrote, “I would like to be shown explicit ways to introduce and to implement engineering in the classroom. Often times these courses go on and on about what engineering is, but I need to know how to implement it in an elementary classroom. Show me examples of lessons.”

How to find resources. This category contained responses related to being able to locate resources when they are needed, “Since engineering is now part of the standards, I think how to teach engineering would be important in a class and since curriculum specifically for engineering will not always (or even usually?) be provided, I think how to find engineering resources and/or how to use other materials to teach engineering would also be important.” Another participant wrote, “Knowing where to find the resources is a very important component in including it in the classroom. When schools do not provide resources, teachers should know how to teach engineering.”

Background knowledge. Many participants mentioned the importance of teachers understanding the content knowledge they must teach. For example, “Teachers need to understand what you mean by engineering. We try and teach our kids to think, but what type of engineering projects would the state approve as ‘good’ and teachers think are ‘good’ could be very different.” Another participant wrote, “If teachers don’t have background knowledge and understand it themselves, they WILL NOT implement their training in their classrooms!”

Not appropriate for elementary. This category contained responses related to reasons why engineering is not needed in elementary school or negative responses related to engineering, "Why would we want to teach engineering when the children are having difficulty learning to read, write and do basic math?" Another participant wrote, "I still think this is asking more than what is reasonable." Others responded, "I didn't become an elementary teacher thinking I would teach elaborate engineering" and "I feel teachers have enough to teach without adding more to our plate, with students that can't even read."

Phase 2

This section presents findings from the individual interviews and focus group sessions. For ease of reading, Phase 2 data has been organized based on the protocol question being answered.

Do you feel prepared to teach engineering? Why or why not?

Most of the participants did not feel prepared to teach engineering. Some mentioned lack of knowledge as a reason, "I have not been trained. I feel like I am limited on my knowledge of it so I definitely don't feel like I could teach it, having a limited amount of understanding myself." Others cited lack of materials and curriculum resources as reasons, "I feel that as far as my understanding of it, I could teach it at a 4th grade level, but what I am lacking would be the materials and the textbooks to teach it," Still, others cited lack of resources and knowledge, "I don't feel prepared. I don't feel like I have the materials to teach it properly. I don't feel like I have the background knowledge to teach them properly and…the necessary training to be able to teach them the skills they need to know." While the reasons for unpreparedness to teach engineering were different among participants, the consensus was that participants felt unprepared to teach engineering.

What sorts of things do you need to better your abilities to teach engineering in your classroom?

Overall, participants stated that they needed materials, curriculum resources, professional development, time for planning, and time to implement engineering activities. One kindergarten teacher described the amount of time it takes to locate your own materials, "You need the supplies to teach some of those things…some good resources, some place we could go and look online. Time is a big factor when you go looking for something because you could spend hours cruising through YouTube, Pinterest, Teacher pay Teacher. I would love a website where we could go for our science stuff. I could go to science, kindergarten, click on worksheets or activities and recommended reading to go with it." For this teacher, finding the time to gather quality resources was a considerable barrier to teaching.

Another teacher focused on receiving the proper training to use resources and the time needed to implement it into the schedule, "I need support from my district and that can include financial support, curriculum support, I need training on the materials so I can use them the most appropriately. A lot of times teachers are given things and they sit in a corner if they aren't given the proper training. I need time in my schedule to be able to teach it. That's a big piece also, there's so much in the day that we have to do so we have little time for extra things, so I need flexibility to do things too so if there is time provided in my schedule to teach it during the day." This teacher's response touched on many areas of need, including lack of support, lack of training, and lack of time to fit engineering into the daily schedule.

What do administrators need to know about your needs?

When answering this question, most participants mentioned a lack of time to fit everything that they are required to teach, “I think they are aware that we do need to teach the students this but there’s only so many hours in the day and right now as a school we have to get our grades up in reading and math areas.” They also mentioned a lack of materials as a concern that needed to be brought to the attention of administrators, “It is so hard to fit it in. We are so far behind technology wise. It does them no good to read about it if they can’t do it hands-on and see how it works. We don’t have time and we don’t have the resources.” Additionally, participants mentioned their lack of training “They need to know that I need training and I wouldn’t feel comfortable teaching it without some training,” as well as the importance of long term professional development, “They tell us all this stuff that we have to implement and they give us some little workshop which are good for some, and some still don’t understand it, but there’s not any follow-up to see how things are going.” Participants’ responses indicated that they are stretched very thin because they have to find ways to fit engineering within an already packed curriculum and teach it without training, materials, or long term support.

What does the State Department of Education need to know about your needs?

The answers to this question fell into three categories: too much emphasis on testing, inadequate preservice education, and micromanagement. Many teachers described the problems with high-stakes tests and how it resulted in only mathematics and reading being priorities, “There’s too much emphasis on testing and it’s too high stake that it does force us to focus on the tested skills instead of the non-tested ones.” Another mentioned making STEM a priority “They need to make STEM a priority instead of just saying it. We’ve concentrated on reading and math necessary in order to do the STEM exercises but our kids are not going to succeed at STEM without a lot of help unless we say it is a priority and we put some bite into it and give schools some money that do it and those who don’t, don’t [get money].” These quotes illustrate that participants felt the pressures of teaching for the purpose of preparing students for success on mandated state assessments, which left little to no time for teaching non tested subjects.

Lack of preparation was a common issue. “I don’t feel like I’m alone in that I don’t feel prepared to teach it. As far as college curriculum, that’s not something I took. I think they need to know that they’re asking us to teach something that we’ve not ever dealt with and unless you’re a science or math teacher you might have had some but if you’re not then you wouldn’t be prepared to teach it. I think they’re asking us to do something that we’re not prepared to do.” The lack of preservice training was also mentioned, “I think lack of training in colleges and teachers out in practice, there’s not a whole lot for science in general. They also need to know that we don’t have materials and that without proper materials it’s really hard to teach science. If it’s not really given to us then it often doesn’t get done.”

Additionally, some participants described a climate of micromanagement and an almost us vs. them attitude, “If the state department understood that we need the resources and we need the time and if they let us do what we know how to do instead of putting all this stuff on us that they think needs to happen." Another teacher seemed frustrated that the state department did not trust her enough to do the job she was hired to do "I think they have too much. Sometimes I feel like I don't have any say in what I want to teach or how I want to teach it and they're just like you have to do it this way because we're going to check up on you. Give me the freedom. I was hired because you thought I knew how to do my job so let me do my job."

What are your thoughts about including engineering in K-5 science standards?

The interview participants felt that engineering had a place in K-5 classrooms but not all shared the same reasons. Some pointed to the importance of early career awareness:

> I think it's important for the kindergarten teacher to explore all areas of science and math and all aspects of academic areas because I want my kindergarten students to know all of the different opportunities available to them. I want them to know that they can be anything they want to be and I want them to have a variety of experience and opportunities of different interests so they can learn about different things in different ways. I think there are different ways that you would teach it at the middle school and high school level that are developmentally appropriate, with their skills and their abilities but I definitely think it has a place at the elementary level so that kids can be exposed to a variety of knowledge.

Other teachers mentioned the development of skills that could be used in the future:

> I think it's a wonderful thing, some of it's gonna go over their heads but that's in every subject that we do. You're gonna have kids that do great in science but

> reading they really struggle with. I think it’s a wonderful idea because it lights an interest in kids at a young age and can take that and develop skills that they can use as a career path.

Another teacher stated:

> They need to know that it’s not for every kid but every kid needs to be exposed to it. I think every kid would take away something even if they’re not going to be an architect or an engineer. I think the upper grades would appreciate it if we had more things like that at the lower grades.

Still others mentioned the creativity that is innate to children:

> I know reading and writing are important but I feel like kids are so creative that if you give them time to think and create things, they really enjoy that so I feel like there needs to be a little more of that and more time for kids to do other things than reading and writing.

While the participants had different views for the why engineering should be incorporated into the science standards, none were opposed to the idea.

Discussion and Conclusion

As previously stated, the purpose of this study was to identify the perceptions that K-5 teachers hold about engineering education as well as the barriers they believe prevent them from implementing engineering into the classroom. To achieve this purpose, qualitative and quantitative data were merged and used to answer the research questions. Overall, the qualitative data supported the quantitative findings and provided deeper insight into the participants' views on engineering education than would have been achieved using quantitative methods alone.

Research Question 1: What perceptions do in-service elementary teachers hold about K-5 engineering education?

Questionnaire responses indicated that most participants felt K-12 engineering was not a priority in their schools, school districts, communities, or for the parents at their schools. Participant comments also suggested that they felt engineering was not a priority to administrators and the state department of education. Rather, the participants perceived that the focus of school administration was on state mandated assessments in mathematics and reading. Similar findings have been reported in the research literature related to lack of time for teaching inquiry science due to a focus on mandated tests (Blanchard, Osborne, Wallwork, & Harris, 2013; Cartright, 2014).

While analyzing the questionnaire responses, it became clear that many participants were supportive of engineering education. However, some did not feel engineering should be included in K-5 curriculum. These responses appeared to be based on a lack of understanding of engineering and the engineering practices described in NGSS. Comments about engineering being just another topic added onto an already overflowing plate, indicate that teachers are unaware of the infusion approach taken by NGSS with regard to engineering (NGSS Lead States, 2013). Engineering practices are woven within NGSS and linked to science content standards that are already being taught in K-5 classrooms, therefore the addition of engineering content and practices to NGSS does not add additional requirements to the science standards already being taught. Although NGSS is not adopted in Oklahoma, the new Oklahoma Academic Science

Standards, OAS-S, mirror NGSS. Further, many participants stated that even though they did not receive any resources for teaching engineering, they were satisfied with this because they did not teach engineering anyway. This reveals that teachers do not understand the science standards they are required to teach as part of OAS-S, which require them to be engineering teachers.

Some participants' responses indicated that teachers held misconceptions about the difficulty or nature of engineering. For example, a few participants mentioned that it is not appropriate to teach engineering when they have students who struggle with basic reading and math skills. Again, this shows a lack of understanding of how engineering can be infused within the existing curriculum. In fact, the incorporation of engineering into lessons has been shown to be an effective way to teach mathematics and improve scores on mathematics achievement tests at the elementary level (Hotaling et al., 2007; Parsons et al., 2007).

Unlike the questionnaire responses, all follow-up participants had positive things to say about including engineering in the K-5 science standards. Multiple participants talked about the importance of career awareness and that students need to be exposed to as many careers as possible when they are in elementary school. Furthermore, participants mentioned that the skills students learn from participating in engineering activities would be valuable regardless of their future career paths. Additionally, one participant mentioned the natural creativity that elementary students possess and how engineering would be the perfect outlet for building on that innate creativity. This match between engineering and children's creativity has been previously supported in the research literature (Cunningham, 2009; Petroski, 2003).

Taken together, these findings suggest that many elementary teachers support the idea of infusing engineering into elementary curriculum and view engineering as beneficial to their students. In fact, many participants stated that if they were given the training and materials they would enjoy teaching engineering to their students. The few exceptions to this could be attributed to a lack of understanding of how the engineering standards are designed to be implemented and the perceived lack of priority that has traditionally been placed on engineering at the elementary level.

Research Question 2: What factors do in-service elementary teachers perceive as barriers to teaching engineering and engineering design?

As expected, the barriers reported in the research literature related to teaching inquiry science were similar to those identified in the current study, namely lack of time (Cartright, 2014), lack of knowledge (Sexton, 2013), lack of training (Blanchard et al., 2013), and lack of resources (Cartright, 2014). Many of the issues related to these barriers are overlapping, such as lack of time to find materials or lack of training on how to use materials.

Participants stated that they did not have enough time in the school day to teach all of the required curriculum components. Many reported that the majority of the school day was devoted to mathematics and reading due to the associated mandated testing in those areas, and science was often only incorporated into reading time or was completely left out. Similar findings have been reported pertaining to teaching inquiry science (Blanchard et al., 2013; Santau & Ritter, 2013). Lack of time for planning was another common barrier. Most teachers spend hours planning before they teach a new lesson. They take time to research and go over the content to make sure they fully understand it, gather and set up materials, and create assessments for the lesson. Further, the fewer resources a teacher has for a particular topic, the more time he or she must spend planning for those lessons by searching for and gathering curriculum resources. Elementary teachers are planning lessons for multiple subjects, which takes a great amount of time each week. This, coupled with the fact that most teachers do not have engineering curriculum resources available to them or even know where to look for those resources, could make finding enough time to adequately prepare engineering lessons difficult to come by.

Lack of knowledge about engineering and training to teach engineering were also mentioned as barriers to implementing the new standards into the curriculum. Many participants felt that they knew what engineering was but they didn’t know how to teach it to their students because they lacked the specific vocabulary and strategies needed to teach it, while others felt a complete lack of knowledge related to engineering. In fact, some teachers mentioned knowing so little about engineering that they didn’t know enough to know what they didn’t know. Further, questionnaire responses indicated that most participants did not feel that their preservice program provided them with the background knowledge and training necessary to teach engineering. When describing the components to include in a preservice program, participants asked for relevant hands-on training on how to use materials, as well as training on where to locate available resources. One participant mentioned that many teachers have materials they could use for engineering, but because they did not receive training on how to use the materials, the materials sit unused, making training imperative.

Many participants mentioned the lack of curriculum and instructional materials for teaching engineering. Budget concerns were mentioned regularly, with participants stating that even with administrative support they still could not gather the materials needed because their school districts did not have enough funding to operate effectively. Many participants stated they have spent their own money purchasing instructional materials and spent hours searching online for lesson ideas, which was very straining on them. Multiple participants asked for a central website where they could go to locate engineering activities based on grade level and content standard and share teacher tested activities with each other. In addition, teachers need training to better understand the types of materials that can be used to teach engineering activities, and shown ways to incorporate high quality design activities into their classrooms by using inexpensive supplies such as paper, index cards, paperclips, and straws.

Another barrier that participants mentioned was lack of support at both the local and state level. Many participants stated that the administration only supported science instruction if it was included in the reading curriculum, or said the administrators didn’t care if science was taught at all because their sole focus was on test scores. There were, however, many participants who said their local administrators were supportive, but there was not a lot they could do because of budget cuts and mandates from the state department of education. Participants also voiced a lack of support at the state level, commenting that the state department of education puts all of these requirements in place without providing teachers with the tools and training to meet the requirements.

Strengths and Limitations

A strength of the current study was that the sample closely mirrored the state K-5 teacher population with regard to geographic region, education level, pathway to certification, gender, teaching experience, and grade level taught. Additionally, the use of both qualitative and quantitative methods helps to offset the weaknesses associated with using only one method. The study does have limitations. First, data was limited to the members of the population who chose to participate, and because the data was self-reported there could be response bias. Additionally, only public school teachers in Oklahoma were included in the study, which could limit the generalizability to teachers from private schools or those employed in other states.

Implications and future research

Findings form this study indicate that many elementary teachers support the infusion of engineering standards into the elementary science curriculum if they are provided with the appropriate resources, training, and support. Administrators at the local and state level need to be aware of these findings. If administrators are going to ask teachers to teach engineering standards in K-5, then they must take steps to provide teachers with the tools they need to do so. This will require the development of curriculum and instructional resources and training on how to infuse engineering within already existing science lessons. Further, a website containing links to quality online engineering education resources needs to be developed and maintained, whether it be by a state or federal agency, or educational outreach organization.

If elementary teachers are expected to teach NGSS as it is written, then they must be provided with the necessary funding to do so. At the state and national level, funding needs to be set aside for science and engineering education to develop engineering resources, provide professional development, and purchase materials for classroom use. Additional funding to provide long term support to teachers, such as follow-up trainings and professional learning communities, will also be required.

Preservice coursework in engineering education needs to be developed and offered to all elementary education majors. While the current study addressed what teachers would like to see in a preservice engineering education course, further research will be needed to determine the best components of a preservice course.

To help address the future STEM pipeline and mainline needs, the *Next Generation Science Standards* call for the infusion of engineering activities into elementary science curriculum. While many elementary teachers support the use of engineering activities in their classrooms, there are numerous barriers preventing them from doing so. In order to ensure that NGSS are incorporated into elementary classrooms as they were intended, elementary teachers must be provided with the necessary training, resources, and support.

CHAPTER VI

SUMMARY

The overall goal of this study was to gain information related to elementary teachers' preparedness to teach engineering and engineering design as prescribed by the Next Generation Science Standards (NGSS) (NGSS Lead States, 2013). More specifically, the objectives of this study were to:

- identify the perceptions that in-service teachers hold about the nature of engineering and K-5 engineering education,
- identify how these perceptions compare with the engineering practices put forth in NGSS,
- examine elementary teachers' self-efficacy related to teaching engineering,
- examine how in-service elementary teachers view their own knowledge of engineering, and
- examine how in-service elementary teachers view their abilities to teach engineering to children.

The overall research approach for this study was an explanatory sequential mixed methods design. During the first phase of the study, participants completed an online questionnaire consisting of selected response, Likert scale, and open-ended questions. Data from the questionnaire were analyzed and used to inform the second phase of the study. Additionally, the NGSS document was analyzed to identify the engineering practices and content that K-5 teachers are expected to implement as part of the standards. During the second phase, the researcher conducted individual interviews and focus groups sessions in order to expand on and enrich the data collected during Phase 1. Study results were organized into three manuscripts which are summarized below.

Summary of Findings

Overall, the findings from this study indicate that elementary teachers are not prepared to incorporate engineering practices into their classrooms. Not only do they have limited, and often stereotypical, views of engineering, but most have little to no experience teaching engineering activities. Further, K-5 teachers have low engineering self-efficacy and low engineering teaching efficacy related to pedagogical content knowledge. The remainder of this section explains the focus of each chapter manuscript, as well as a discussion of the significance of each study.

Chapter Three, titled "A Survey of Oklahoma Elementary Teachers' Perceptions of Engineering and Engineering Design," focused on identifying the perceptions K-5 teachers hold about engineers and the engineering design process and how those perceptions compare with the engineering standards in NGSS. The research questions answered by this study were: (1) How familiar are in-service elementary teachers with engineering and engineering design? (2) What perceptions do in-service elementary teachers hold about engineers and engineering design? (3) Are there differences in teachers' familiarity with engineering or perceptions of engineers between different demographic groups? and (4) How do in-service elementary teachers' perceptions of engineering and engineering design compare with expectations set by K-5 engineering education standards?

The results suggest that K-5 teachers are unfamiliar with engineering and engineering design. Yasar et al. (2006a, 2006b) reported similar findings. Elementary teachers hold misconceptions about the work of engineers, have little experience teaching engineering activities, and struggle to identify classroom activities that incorporate engineering design. The results of the NGSS qualitative analysis revealed that in order to teach the engineering standards, teachers must understand engineering design as well as pedagogical strategies for implementing design activities into the classroom. Teachers must also have a basic understanding of how the work of engineers impacts society. The findings of this study indicate that teachers' perceptions of engineering and engineering design do not align with NGSS. These results are valuable to the field because they indicate that elementary teachers are not prepared to incorporate engineering practices in their classrooms as prescribed by NGSS.

Chapter Four, titled "Examining Elementary Teachers' Engineering Self-efficacy and Engineering Teacher Efficacy," explored teachers' personal efficacy related to engaging in engineering design and their efficacy related to teaching engineering to students. The research questions answered by this study were: (1) How self-efficacious are in-service elementary teachers in their knowledge of engineering and engineering design and their abilities to teach engineering and engineering design? (2) Are there differences in teachers' engineering self-efficacy or engineering teaching efficacy between different demographic groups? (3) Is there a correlation between teachers' engineering self-efficacy and their familiarity with design/engineering/technology (DET)? and (4) Is there a correlation between teachers' engineering teaching self-efficacy and their familiarity with design/engineering/technology (DET)?

The findings indicate that K-5 teachers have low engineering self-efficacy and engineering teacher efficacy related to engineering pedagogical content knowledge. Further, the study identified significant differences in engineering self-efficacy among different demographic groups (i.e., grade level taught, gender, Title I school status, and ethnicity). Results also revealed that familiarity with DET was significantly correlated with engineering self-efficacy and engineering teacher efficacy. This suggests that as teachers have more experiences with engineering, their efficacy increases. These results are important because they reveal that K-5 teachers (a) lack efficacy related to engaging in and teaching engineering design and (b) need mastery experiences to help improve efficacy.

Chapter Five, titled "Elementary Teachers' Perceptions of K-5 Engineering Education and Perceived Barriers," explored K-5 teachers' views of infusing engineering activities within the elementary curriculum as well as the barriers to teaching that curriculum. The research questions addressed by this study were: (1) What perceptions do in-service elementary teachers hold about K-5 engineering education? and (2) What factors do in-service elementary teachers perceive as barriers to teaching engineering and engineering design?

Results indicated that most participants indicated that engineering was not a priority in their school districts. However many participants did indicate the benefits of including engineering activities in their classrooms. Those who indicated that engineering should not be included in K-5 curriculum also had a lack of understanding of engineering and the engineering practices described in NGSS, which could explain their hesitancy to include engineering in elementary classrooms. Furthermore, participants reported many barriers to implementing engineering into the classroom, including the lack of planning time, instructional time, materials, curriculum resources, content knowledge, training, and administrative support. Similarly, Yasar and colleagues (2006a, 2006b) found that teachers reported lack of knowledge, lack of administrative support, and lack of training as barriers to implementing design, engineering, and technology activities into their classrooms. These findings are valuable because they indicate that many elementary teachers support the infusion of engineering standards into the elementary science curriculum if they are provided with the appropriate resources, training, and support. Further, the identified barriers provide administrators and PD providers with a place to start when planning training opportunities for teachers.

Implications

Taken together, the findings from these three studies advance the body of research literature related to elementary engineering education and provide an alarming wake up call for all those with a vested interest in STEM education. Elementary teachers are a part of the frontline that must battle to improve the STEM mainline and pipeline, yet they are not being provided with the tools they need to complete the jobs they have been tasked with. This is made evident by the questionnaire and interview responses presented in this dissertation.

First, the findings indicate that while K-5 teachers see the benefits of incorporating engineering content and practices into their classrooms, they lack the knowledge, experience, and resources to do so effectively. Not only do elementary teachers have little experience with teaching engineering activities, but they also have extremely limited understanding of what engineers do and how engineering design benefits society. In fact, most participants I interviewed had never used engineering activities and were not able to distinguish between science and engineering activities or between engineering and mere building with blocks. . There are numerous low cost, high quality engineering activities that can be implemented in the elementary classroom; however K-5 teachers are largely unaware of this. If elementary teachers do not understand engineering and cannot identify quality engineering activities, they will not be able to teach NGSS as it is prescribed. This will limit the effectiveness of schools to bring about the needed changes in the STEM pipeline and mainline that were intended to result from the infusion of engineering practices within NGSS.

Next, teachers are limited in their abilities to properly implement engineering content and practices into their classrooms because they have not been provided with the necessary resources, training, and support. Teachers do not receive the necessary training in engineering teaching methods during their preservice education and very few in-service teachers have attended training devoted to engineering education. Many of the teachers who have attended engineering focused trainings have done so voluntarily and funded those trainings on their own. Legislators need to take note of this because if they are requiring teachers to enact engineering standards in their classrooms, then they must provide teachers with the required training to do so. Teachers should not be left to search for and fund their own professional development. Steps need to be taken to incorporate engineering training within preservice programs while simultaneously providing training to in-service teachers. Preservice teachers enter the classroom with a lack of practical experience and look to veteran teachers to provide them with guidance and support. If in-service teachers are not incorporating engineering into their classrooms due to lack of knowledge and training, they will be unable to mentor novice teachers in the area of engineering education. For these reasons, it is imperative that training on how to teach engineering starts at the preservice level and continues throughout in-service to provide a career long continuum of support for elementary educators.

Further, if stakeholders expect a true change in the number of children who leave public education ready to join the STEM mainline or enter the STEM pipeline, then there must be a shift away from high stakes testing. Currently, elementary teachers do not have administrative support or adequate instructional time to teach engineering, or any science for that matter, due to "teach to the test" pressures. Arguably, reading and math skills are important. However, children will not develop the desired critical thinking and problem solving skills if elementary teachers must spend all of their time focused on teaching students how to fill in the bubble on a standardized test. Rather, teachers must be given the freedom to make use of integrated teaching methods that allow students to solve real world and community based problems while simultaneously learning science, engineering, mathematics, social studies, and language arts concepts. These methods will allow teachers to make more efficient use of the class time and provide students with a more authentic learning experience because in the real world subject areas are integrated and do not exist within their own bubbles.

Legislators, administrators, and other stakeholders should be alarmed of the limited knowledge and misconceptions that elementary teachers are bringing into the classroom, as well as the lack of support they are provided to incorporate the required standards. Immediate steps must be taken to address this problem. Funding must be provided at the national and state level to develop and provide engineering training programs and resources for teachers and purchase materials for classroom use. Administrators need to be aware of the needs of their teachers and actively seek out training and resources for them. Additionally, long term support must be provided to teachers through follow-up trainings, professional learning communities, and access to a library of quality on-line resources to ensure ongoing professional growth and continuous access to the latest methods and resources.

Future Research

Overall, these findings suggest pathways for future research related to elementary engineering education. First, more research is needed to identify the components to include in in-service training programs related to engineering education as well as the impact that attending such trainings has on classroom instruction. This research might focus on the development and assessment of different curricular resources (e.g. teacher guides, student guides and activity sheets, supplemental videos), how teachers implement training materials into their classrooms, as well as how students respond to the implemented activities. A pocket of research should also be devoted to identifying ways to reduce the engineering related differences between demographic groups that were identified within this study, such as gender and Title 1 school status. Additionally, research will be needed on the development and implementation of preservice elementary engineering methods coursework.

Next, future research should examine the impacts of teacher motivation on elementary engineering education. Research might focus on links between motivation and engineering self-efficacy or teaching engineering efficacy, as well as between motivation and the willingness to attend training and implement training resources into the classroom. Additionally, research could investigate any links between motivation to teach engineering and student achievement or interest in engineering as well as student perceptions of engineering.

Finally, future research is needed on the impacts of teachers' perceptions of engineering on their instruction. This research could explore relationships between teachers' perceptions of engineering and the types of activities and pedagogical strategies they use with their students. Additionally, researchers should explore if any relationships exist between teachers' perceptions of engineering and student achievement, student attitudes toward engineering, or student perceptions of engineering.

In conclusion, this research makes important contributions to the area of elementary engineering education. The study reveals the limited understanding that elementary teachers hold about engineering, as well as their limited knowledge of and experience with engineering design. Further, the study shows that elementary teachers tend to have low engineering self-efficacy and low engineering teaching efficacy related to pedagogical content knowledge. Finally, the study brings to light that while many elementary teachers see the benefits of including engineering activities in their classrooms, they face many barriers that limit their abilities to implement engineering standards. Future research will be vital to providing teachers with the training and resources they need to implement engineering content and practices as prescribed by NGSS.

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APPENDICES

Appendix A

Online Questionnaire

What words or phrases would you use to describe the characteristics of a typical engineer? Please list at least 3 words or phrases in the box below.											
What do engineers do as part of their work?											
Do you believe engineering is a high priority in your school?	Yes	No	Don’t know								
Do you believe engineering is a high priority in your school district?	Yes	No	Don’t know								
Do you believe engineering is a high priority for the parents in the school where you teach?	Yes	No	Don’t know								
Do you believe engineering is a high priority in the community where you teach	Yes	No	Don’t know								
Rate your degree of belief in your current ability to perform the following tasks by recording a number from 0 to 100 (0 = cannot do it at all; 50 = moderately can do it; 100 = highly certain can do it)											
Conduct engineering design	0	10	20	30	40	50	60	70	80	90	100
Identify a design need	0	10	20	30	40	50	60	70	80	90	100
Research a design need	0	10	20	30	40	50	60	70	80	90	100
Develop design solutions	0	10	20	30	40	50	60	70	80	90	100
Select the best possible design	0	10	20	30	40	50	60	70	80	90	100
Construct a prototype	0	10	20	30	40	50	60	70	80	90	100
Evaluate and test a design	0	10	20	30	40	50	60	70	80	90	100
Communicate a design	0	10	20	30	40	50	60	70	80	90	100
Redesign	0	10	20	30	40	50	60	70	80	90	100

This survey contains statements about teachers' teaching engineering self-efficacy. Here, teaching engineering self-efficacy is defined as teachers' personal belief in their teaching engineering ability to positively affect student learning of engineering. Please indicate the degree to which you agree or disagree with each statement below by marking on the appropriate letters to the right of each statement. SD = strongly disagree, MD = moderately disagree, D = disagree slightly more than agree, A = agree slightly more than disagree, MA = moderately agree, SA = strongly agree						
I can discuss how engineering is connected to my daily life.	SD	MD	D	A	MA	SA
I can recognize and appreciate the engineering concepts in all subject areas.	SD	MD	D	A	MA	SA
I can spend time necessary to plan engineering lessons for my classes.	SD	MD	D	A	MA	SA
I can employ engineering activities in my classroom effectively.	SD	MD	D	A	MA	SA
I can craft good questions about engineering for my students.	SD	MD	D	A	MA	SA
I can discuss how given criteria affect the outcome of an engineering project.	SD	MD	D	A	MA	SA
I can guide my students' solution development with the engineering design process.	SD	MD	D	A	MA	SA
I can gauge student comprehension of the engineering materials that I have taught.	SD	MD	D	A	MA	SA
I can assess my students' engineering products.	SD	MD	D	A	MA	SA
I can promote a positive attitude toward engineering learning in my students.	SD	MD	D	A	MA	SA
I can encourage my students to think critically when practicing engineering.	SD	MD	D	A	MA	SA
I can encourage my students to interact with each other when participating in engineering activities.	SD	MD	D	A	MA	SA
I can encourage my students to think creatively during engineering activities.	SD	MD	D	A	MA	SA
I can calm a student who is disruptive or noisy during engineering activities.	SD	MD	D	A	MA	SA
I can get through to students with behavior problems while teaching engineering.	SD	MD	D	A	MA	SA
I can keep a few problem students from ruining an entire engineering lesson.	SD	MD	D	A	MA	SA
I can control disruptive behavior in my classroom during engineering activities.	SD	MD	D	A	MA	SA
I can establish a classroom management system for engineering activities.	SD	MD	D	A	MA	SA
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.	SD	MD	D	A	MA	SA

When my students do better than usual in engineering, it is often because I exerted a little extra effort.	SD	MD	D	A	MA	SA
If I increase my effort in engineering teaching, I see significant change in students' engineering achievement.	SD	MD	D	A	MA	SA
I am generally responsible for my students' achievements in engineering.	SD	MD	D	A	MA	SA
My effectiveness in engineering teaching can influence the achievement of students with low motivation.	SD	MD	D	A	MA	SA

Definition of Design/Engineering/Technology (DET) The term "technology," as used in the national science standards, implies the design, engineering, and the technological issues related to conceiving, building, maintaining, and disposing of the useful objects and/or processes in the human-built world. Sometimes this term is referred to as "technological education," but, please note that it is separate from the use of computers and educational technology in the classroom. It is also distinctly different from job training or vocational education. In this questionnaire, we use the term "Design/Engineering/Technology" or DET, synonymously with what the national science education standards (NRC, 1996) call "technology." DET encompasses a number of concepts and skills, including the ability to: identify a problem or a need to improve on current technology, propose a problem solution - solutions may be conceptual or physical objects, identify the costs and benefits of solutions, select the best solution from among several proposed choices by comparing a given solution to criteria it was designed to meet, implement solutions by building a model or a simulation, communicate the problem, the process and the solution in various ways. Examples of different Design/Engineering/Technology (DET) functions include: Designing activities for a school outing. Building a paper bridge that will support a weight, Designing the layout of a new playground, Inventing a new device or process, Designing and piloting a new device or process, Analyzing the economics of two different types of paper towels in absorbing water, Building working models of devices or processes

Please answer the following questions, choosing the most appropriate answer (1 = Not at all, 5 = Very Much).

How familiar are you with Design/Engineering/Technology as typically demonstrated in the examples given on the previous page?	1	2	3	4	5
Have you had any specific courses in Design/Engineering/Technology outside of your preservice curriculum?	1	2	3	4	5
Did your preservice curriculum include any aspects of Design/Engineering/Technology?	1	2	3	4	5
Was your preservice curriculum effective in supporting your ability to teach Design/Engineering/Technology at the beginning of your career?	1	2	3	4	5
How confident do you feel about integrating more Design/Engineering/Technology into your curriculum?	1	2	3	4	5

Do you use Design/Engineering/Technology activities in the classroom?	1	2	3	4	5
Does your school support Design/Engineering/Technology activities?	1	2	3	4	5
To what extent do you agree that a typical engineer…(1 = strongly disagree, 5 = strongly agree)					
Works well with people	1	2	3	4	5
Has good verbal skills	1	2	3	4	5
Has good math skills	1	2	3	4	5
Has good writing skills	1	2	3	4	5
Earns good money	1	2	3	4	5
Likes to fix things	1	2	3	4	5
Does well in science	1	2	3	4	5
To what extent do you agree with the following statements…(1 = strongly disagree, 5 = strongly agree)					
Most people feel that female students can do well in Design/Engineering/Technology.	1	2	3	4	5
Most people feel minority students can do well in Design/Engineering/Technology.	1	2	3	4	5
How strong is each of the following a BARRIER in integrating Design/Engineering/Technology in your classroom? (1 = not strong at all, 5 = very strong)					
lack of time for teachers to learn about Design/Engineering/Technology.	1	2	3	4	5
lack of teacher knowledge	1	2	3	4	5
lack of training	1	2	3	4	5
lack of administrative support	1	2	3	4	5
How much do you know about the…(1 = very little, 5 = very much)					
National science standards related to Design/Engineering/Technology	1	2	3	4	5
Are you satisfied with the extent to which your school provides you with instructional materials to teach engineering?	Yes		No		
Please elaborate on your previous response.					
What are the two most important things that would help you improve engineering teaching in your classroom? ☐ more materials for engineering ☐ more support for teaching engineering ☐ training and information on how to teach engineering ☐ guidance in what to teach in engineering classes ☐ other ____________________					
Please elaborate on your previous response.					

Assume you have been appointed to a national task force that wishes to construct a new preservice teacher methods course devoted explicitly to teaching engineering in elementary schools. What two things would you recommend they stress in developing this new preservice course? ☐ how to use materials to teach engineering ☐ how to teach engineering ☐ strong background in engineering content ☐ more preparation prior to teaching engineering ☐ how to find engineering resources ☐ other ____________________					
Please elaborate on your previous response.					
In the past three years, have you attended one or more professional development workshops devoted explicitly to teaching engineering in elementary schools?	Yes		No		
What was the name of the PD program you attended (e.g. Engineering is Elementary, Botball)?					
Did your district pay for you to attend the PD?	Yes		No		
Would you be interested in learning more about engineering through…(1 = not at all interested, 5 = very interested)					
in-service professional development	1	2	3	4	5
workshops	1	2	3	4	5
peer training or coaching	1	2	3	4	5
college courses	1	2	3	4	5
Which grades do you teach (mark all that apply)? PK K 1 2 3 4 5 6 7 8 9 10 11 12					
Do you teach in a Title I school?	Yes	No		Don't know	
In what field is your Bachelor's degree?					
Do you have a Master's degree?	Yes			No	
If yes, what field is your Master's degree in?					
Do you have a Doctoral degree?	Yes			No	
If yes, what field is your Doctoral degree in?					
Including the current school year, how many years have you been teaching?					

Which of the following best describes your pathway to certification? ○ Accredited Professional Education Program ○ Oklahoma Alternative Certification ○ Troops to Teachers ○ Paraprofessional Credential ○ ABCTE ○ Teach for America ○ Four Year Olds and Younger Certificate		
Which best describes your ethnicity ○ African American, not Hispanic ○ American Indian or Alaskan Native ○ Hispanic ○ Asian or Pacific Islander ○ White, not Hispanic ○ More than one ○ Other		
What is your birth year?		
What is your gender?	Male	Female
Please use the drop down menu to select the county and district where you teach. Then, select your Reac3h Region (only one option will be available).		
Thank you for completing the questionnaire. Please click the arrow below to submit you survey. After submitting, you will also be redirected to a website where you can provide contact information if you would like to be entered in a VISA gift card drawing. You will also be asked if you would be willing to participate in a follow-up focus group or individual interview. Participation in the follow-up interview and focus group is voluntary and all information shared will remain confidential. Participants in the follow-up session will be entered in a drawing for an additional VISA gift card.		

Appendix B

Individual Interview Protocol

1. What comes to mind when you think of an engineer?
2. Do you use engineering activities in your classroom?
    a. If yes, please describe examples.
    b. If no, what types of science activities do you use in your classroom?
3. Do you ever have your students design, create, or build something?
4. How would you describe your understanding of engineering?
5. What do you know about the engineering design process?
6. Do you feel prepared to teach engineering? Why or why not?
7. What sorts of things do you need to better your abilities to teach engineering in your classroom?
8. What do administrators need to know about your needs?
9. What does the State Department of Education need to know about your needs?
10. What are your thoughts about including engineering in K-5 science standards?

Appendix C

Focus Group Protocol

1. What comes to mind when you think of an engineer?
2. Do you use engineering activities in your classroom?
    a. If yes, please describe examples.
    b. If no, what types of science activities do you use in your classroom?
3. Do you ever have your students design, create, or build something?
4. How would you describe your understanding of engineering?
5. Do you feel prepared to teach engineering? Why or why not?
6. What sorts of things do you need to better your abilities to teach engineering in your classroom?

Appendix D

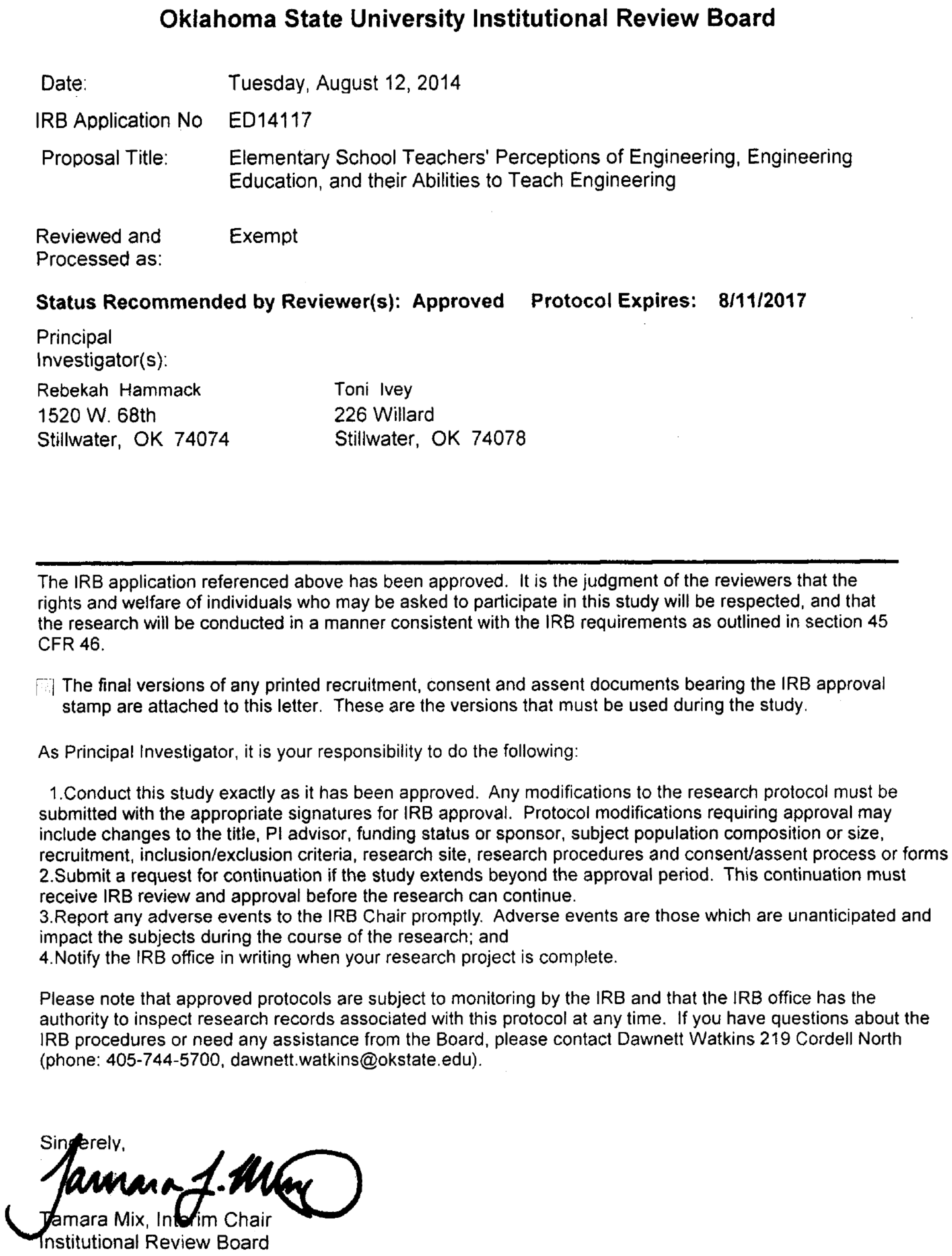
DET Questions

Definition of Design/Engineering/Technology (DET) The term "technology," as used in the national science standards, implies the design, engineering, and the technological issues related to conceiving, building, maintaining, and disposing of the useful objects and/or processes in the human-built world. Sometimes this term is referred to as "technological education," but, please note that it is separate from the use of computers and educational technology in the classroom. It is also distinctly different from job training or vocational education. In this questionnaire, we use the term "Design/Engineering/Technology" or DET, synonymously with what the national science education standards (NRC, 1996) call "technology." DET encompasses a number of concepts and skills, including the ability to: identify a problem or a need to improve on current technology, propose a problem solution - solutions may be conceptual or physical objects, identify the costs and benefits of solutions, select the best solution from among several proposed choices by comparing a given solution to criteria it was designed to meet, implement solutions by building a model or a simulation, communicate the problem, the process and the solution in various ways. Examples of different Design/Engineering/Technology (DET) functions include: Designing activities for a school outing. Building a paper bridge that will support a weight, Designing the layout of a new playground, Inventing a new device or process, Designing and piloting a new device or process, Analyzing the economics of two different types of paper towels in absorbing water, Building working models of devices or processes					
Please answer the following questions, choosing the most appropriate answer (1 = Not at all, 5 = Very Much).					
How familiar are you with Design/Engineering/Technology as typically demonstrated in the examples given on the previous page?	1	2	3	4	5
Have you had any specific courses in Design/Engineering/Technology outside of your preservice curriculum?	1	2	3	4	5
Did your preservice curriculum include any aspects of Design/Engineering/Technology?	1	2	3	4	5
Was your preservice curriculum effective in supporting your ability to teach Design/Engineering/Technology at the beginning of your career?	1	2	3	4	5
How confident do you feel about integrating more Design/Engineering/Technology into your curriculum?	1	2	3	4	5
Do you use Design/Engineering/Technology activities in the classroom?	1	2	3	4	5
Does your school support Design/Engineering/Technology activities?	1	2	3	4	5

To what extent do you agree that a typical engineer…(1 = strongly disagree, 5 = strongly agree)					
Works well with people	1	2	3	4	5
Has good verbal skills	1	2	3	4	5
Has good math skills	1	2	3	4	5
Has good writing skills	1	2	3	4	5
Earns good money	1	2	3	4	5
Likes to fix things	1	2	3	4	5
Does well in science	1	2	3	4	5

Appendix E

IRB Approval Letter



Oklahoma State University Institutional Review Board

Date:	Tuesday, August 12, 2014
IRB Application No	ED14117
Proposal Title:	Elementary School Teachers' Perceptions of Engineering, Engineering Education, and their Abilities to Teach Engineering
Reviewed and Processed as:	Exempt

Status Recommended by Reviewer(s): Approved Protocol Expires: 8/11/2017

Principal Investigator(s):

Rebekah Hammack	Toni Ivey
1520 W. 68th	226 Willard
Stillwater, OK 74074	Stillwater, OK 74078

The IRB application referenced above has been approved. It is the judgment of the reviewers that the rights and welfare of individuals who may be asked to participate in this study will be respected, and that the research will be conducted in a manner consistent with the IRB requirements as outlined in section 45 CFR 46.

☐ The final versions of any printed recruitment, consent and assent documents bearing the IRB approval stamp are attached to this letter. These are the versions that must be used during the study.

As Principal Investigator, it is your responsibility to do the following:

1.Conduct this study exactly as it has been approved. Any modifications to the research protocol must be submitted with the appropriate signatures for IRB approval. Protocol modifications requiring approval may include changes to the title, PI advisor, funding status or sponsor, subject population composition or size, recruitment, inclusion/exclusion criteria, research site, research procedures and consent/assent process or forms
2.Submit a request for continuation if the study extends beyond the approval period. This continuation must receive IRB review and approval before the research can continue.
3.Report any adverse events to the IRB Chair promptly. Adverse events are those which are unanticipated and impact the subjects during the course of the research; and
4.Notify the IRB office in writing when your research project is complete.

Please note that approved protocols are subject to monitoring by the IRB and that the IRB office has the authority to inspect research records associated with this protocol at any time. If you have questions about the IRB procedures or need any assistance from the Board, please contact Dawnett Watkins 219 Cordell North (phone: 405-744-5700, dawnett.watkins@okstate.edu).

Sincerely,

Tamara Mix, Interim Chair
Institutional Review Board

VITA

Rebekah Jane Hammack

Candidate for the Degree of

Doctor of Philosophy

Thesis: ELEMENTARY TEACHERS' PERCEPTIONS OF ENGINEERING, ENGINEERING DESIGN, AND THEIR ABILITIES TO TEACH ENGINEERING: A MIXED METHODS STUDY

Major Field: Education

Biographical:

Education:

Completed the requirements for the Doctor of Philosophy in Education at Oklahoma State University, Stillwater, Oklahoma in May, 2016.

Completed the requirements for the Master of Science in Animal Science at Oklahoma State University, Stillwater, Oklahoma in 2003.

Completed the requirements for the Bachelor of Science in Agriculture at The Ohio State University, Columbus, Ohio in 1998.

Experience: Engineering Teacher at Stillwater Middle School, Stillwater, OK, 2012-present; Adjunct Faculty at Oklahoma State University, College of Education, Stillwater, OK, 2014 – 2015; Science teacher at Stillwater Middle School, Stillwater, OK, 2006-2012; Science teacher at Hennessey High School Hennessey, OK 2005-2006; Graduate Teaching Assistant, Oklahoma State University, Animal Science Department, Stillwater, OK, 2001.

Professional Memberships: National Science Teachers Association, Oklahoma Science Teachers Association, Association of Middle Level Educators, Association for Career and Technical Education, School Science and Mathematics Association, Oklahoma Association for Career and Technical Education, Phi Kappa Phi