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I, Kathie Sund, hereby submit this original work as part of the requirements for the degree of Doctor of Education in Curriculum & Instruction.

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From Rhetoric to Reality:
Case Studies of Two Fifth Grade Science Teachers to Inform Reform

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by

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Abstract

The purpose of this qualitative study was to explore two elementary teachers’ implementation of engineering design over two academic years and to describe how their teaching practice changed over the two instructional cycles. This study used field notes and audio transcripts of the teachers during their engineering design teaching, written reflections, and a final interview to generate data that were analyzed for emerging themes and patterns. These data answered the following research questions: (a) How do two fifth grade science teachers implement an engineering design activity? (b) How do these same two fifth grade science teachers’ instructional practices change as they implement the same engineering design activity for a second time the following academic year? And, (c) What factors do the teachers identify as to why their practice changed? The findings of this study concluded that with experience teachers made more explicit connections to science and engineering content and practices. Additionally, they more actively facilitated deeper questioning and troubleshooting. An additional finding was that teacher change is not an isolated event, but a system of interacting influences. The findings in this research study provide insight and implication for supporting teacher change in practice in K-12 educational reform efforts as we move to implement engineering and engineering design into the K-12 science curriculum.
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Chapter 1

Introduction

In this chapter, I frame my dissertation by providing an organizing guide with which to view my research. I begin by describing information about me the researcher; this background provides information that clarifies my interest in the research topic of this dissertation. It explains why I am passionate about education as a way to a better life and why I think Science, Technology, Engineering, and Math (STEM) education and authentic instructional strategies, such as engineering design, can change lives. In the next section of this chapter, I position my research within the state of the nation and its historical and current focus on scientific literacy, STEM education, and engineering design as one strategy to support reform of K-12 science instruction. This introduction is followed by the statement of the problem in that, if engineering as an instructional strategy does support positive student outcomes, then we must be concerned with how teachers implement engineering design. This section points out that there is currently very little research on teachers’ implementation of engineering design in K-12 science classrooms. This leads to the last section of this chapter, which provides an overview of my research questions, my conceptual framework, and the design of my dissertation study.

Personal Background and Interest

I am a “border crosser” (Giroux, 1992, p. 3): an Appalachian girl whose parents did not graduate high school; a first generation college student. I was not supposed to be successful, but I wanted more. By being a border crosser, Giroux (1992) suggests that one has to reinvent traditions through processes that are “transformational and responsive” rather than through the more traditional discourses of “tradition, submission, and repetition” (Giroux, 1992, p. 22). I have worked my way into the educational fray; entwined in the educational ladder of
achievement in order to prove that I am smart and capable; determined to make a difference in my life through education. I have taught successfully for 16 years as a middle and secondary grades teacher and recognize the educational disparity that exists for disenfranchised and other struggling learners. My experiences have made me want to make a difference not only in my life, but in the lives of other teachers and students.

As I immerse myself in educational reform, I am excited about the possibilities to support a change in teachers’ instructional practices as they strive to connect learning to the real world. When I work in urban, high-needs classrooms, I see students disengaged and disinterested. However, when engineering design and other authentic STEM experiences are implemented in the classroom, many of these same students become engaged and excited. For them, learning becomes contextualized, relevant, and real.

Authentic STEM experiences, including engineering design, are promising instructional strategies that can engage and excite disenfranchised learners. Furthermore, engineering design as an instructional strategy can be seen as a way to increase STEM literacy for all students, including those like my former peers who were not able to escape the borders that still confine them. To this very day, I still want more. I want to describe, to define, and capture what engineering design and other authentic STEM experiences look like in the classroom. I want to help teachers and schools operationalize these authentic experiences into their classrooms. I want all students to have increased opportunity, access, and equity for achieving STEM literacy for an increased participation in the 21st Century.

Statement of the Problem

In the United States (U.S.), the need for increased achievement in math and science first captured national attention in 1957, with the Soviet launch of Sputnik 1 (National Commission
on Excellence in Education [NCEE], 1983). Soon after, the term “science literacy” was proposed for the first time by Paul Hurd (1958). Paul Hurd stated that every person needed a certain level of mastery in science, in order to be successful in “modern” life (1958, p. 14). The idea of science literacy was more concretely defined in the *Benchmarks for Science Literacy* (American Association for the Advancement of Science [AAAS], 1993, 2001, 2007) and the *National Science Education Standards* (National Research Council [NRC], 1996). Currently, the idea of science literacy is being further developed in the *Next Generation Science Standards*, with their addition of the typical practices engaged in by scientists and engineers (NSTA, 2012; NRC, 2011). As evidenced by nearly 55 years of reform, improving scientific literacy and achievement for all learners is not new to U.S. K-12 classrooms (AAAS, 1993, 2001, 2007; NRC, 1996; NCEE, 1983). However, what is new is a current focus not only on science education, but on STEM education (NRC, 2009, 2011). In our highly technological world, STEM literacy is now being proclaimed as critical for both global competitiveness and individual success (Carnevale, Smith, & Strohl, 2010). In order to meet the demand for achieving STEM literacy, a relatively new instructional strategy of engineering design integrated into the science classroom is currently being recommended to reform K-12 science classrooms (NRC, 2009).

In the NRC report *Engineering in K-12 Education: Understanding the Status and Improving the Prospects*, it was stated that engineering and engineering design as an instructional strategy may facilitate: (a) an improvement in science and math achievement; (b) an increase in awareness of engineering and the engineering design process; (c) an increase in interest to pursue an engineering career; and, (d) an increase in technological literacy (Katehi et al., 2009, p. 49-50). Current educational research supports the premises of the NRC (2009) in that engineering design integrated into science instruction has been shown to have positive
outcomes for students in learning, attitude, and thinking skills (Apedoe, Reynolds, Ellefson, & Schunn, 2008; Clewett & Tran, 2003; Duschl, Schweingruber, & Shouse, 2007; Fortus, Krajcik, Dershimer, Marx, & Mamlok-Naaman, 2005).

If engineering design can indeed help achieve STEM literacy for learners, we must ask how teachers can most effectively implement engineering design as an instructional strategy in the science classroom in order to achieve the potential student outcomes suggested by the research. Currently, there is very little educational research on teachers’ implementation of engineering design in the science classroom (Brophy, Klein, Portsmore, & Rogers, 2008; Crismond, Lo, & Lohani, 2006). The research that does exist points to teachers’ struggles with engineering design in terms of unknown content, unfamiliar practices, and not being comfortable with the open-ended nature of engineering design (Brophy, Klein, Portsmore, & Rogers, 2008; Kimmel, Carpinelli, & Rockland, 2007; Kimmel & Rockland, 2002; Lewis, 2006; McGinn & Roth, 1998; Yasar, Baker, Sarason-Kurpius, Krause, & Roberts, 2006).

**Significance and Purpose**

This study sought to address the existing research gap by describing two teachers’ implementation of engineering design in the K-12 classroom. Additionally, this study sought to understand the factors necessary to facilitate changes in teacher practice. Reform of classroom instruction is confusing and complex, and requirements for supporting these reforms must center on the supports needed for teacher change. Teachers are the linchpin for change, as they decide what does or does not happen in their classrooms (Opfer & Pedder, 2011). Because of this, the purpose of my study was to describe how two 5th grade science teachers implemented the reform strategy of engineering design into their science classroom for the first time. Additionally, I will describe how their practices changed as they implemented the same activity a second time the
following school year. Lastly, I asked these teachers to identify why their teaching changed.

Thus, my research questions were:

1) How do two fifth grade science teachers implement an engineering design activity?

2) How do these same two fifth grade science teachers’ instructional practices change as they implement the same engineering design activity for a second time the following academic year?

3) What factors do the teachers identify as to why their practice changed?

**Conceptual Framework**

As this study addressed teachers’ implementation of a new instructional practice (engineering design) and their reasons for change in practice over two years of implementation, the conceptual framework that was used for this study is teacher change in practice. Specifically, my research was framed by Guskey’s model of teacher change (2000, 2002). This conceptual framework is further described in Chapter two. The teacher instructional change in practice research provides not only an analytical lens with which to view my research, but also provides prior research with which to connect and extend my research findings and conclusions. The teacher instructional change research provides a wealth of information about the types of changes that teachers make as they implement new instructional practices (Abkus & Hand, 2012; Adamson, 2013) as well as the types of professional development that are supportive of teacher change in practice (Desimone, 2009; Guskey, 2002; Richardson, 1994b).

**Summary**

My dissertation study involved a qualitative exploratory case study. Qualitative research seeks to describe understandings, meanings, and processes (Merriam, 2009). This was the most appropriate design for my study, as I wanted to be able to describe teachers’ implementation of
engineering design as well as their understandings of why change occurred in their practice.

Furthermore, an exploratory design was most appropriate in that it allowed beginning knowledge and practice to be described in order to generate more specific hypotheses for future research (Marshall & Rossman, 2010). In Chapter 2, I discuss the literature that informed my study. The first part of this chapter analyzes the literature concerning teacher change. Teacher change in practice provides the conceptual framework for my dissertation research. The second part of this chapter focuses on engineering design, the tensions of science versus engineering, engineering design as an instructional strategy in the K-12 classroom, research on engineering design in the K-12 science classroom, and the Engineering is Elementary curriculum. Chapter 3 outlines my research design as a qualitative, exploratory case study of the instructional practices of two fifth grade science teachers’ implementation of an engineering design unit. I describe my data collection methods of observations, written reflections, and a final interview. Both typological and inductive analyses were used to analyze my data in order to answer the research questions. In Chapter 4, I present the findings of my study. In Chapter 5, I connect these findings back to the literature in my discussion. Additionally, I present conclusions of my research in terms of supporting teacher change as well as provide recommendations for future research.
Chapter 2: Review of the Literature

My research examined two teachers’ change in practice as they implemented an engineering design activity for the first time one academic year and then how their practice changed as they implemented the same activity for a second time during the following year. The purpose of this chapter is to discuss the literature that informed my study. The first part of this chapter describes Guskey’s model of teacher change which provided the conceptual framework for my study. Additionally, I provide a historical overview of the teacher change research, analyze the current research concerning teacher change in practice supported by professional development, and explain how this body of historical and current literature informed my study. The second part of this chapter focuses on an overview of engineering design, a description of science versus engineering, background on engineering design in the K-12 science classroom, research on engineering design in the K-12 science classroom, and the Engineering is Elementary (EiE) curriculum.

Teacher Change in Practice

Even though the theoretical underpinnings of the majority of the teacher change research has been based on a social constructivist framework (Vygotsky, 1962), with a small portion grounding their work in critical theory (Anyon, 1980; Giroux, 1988; Halliday, 1985), it is extremely unhelpful to look back to the literature for a single definition of teacher change. Teacher change has been described in a myriad of ways in the literature: teacher change as learning, teacher change as growth or development, teacher change that creates cognitive or affective improvements, or teacher change as effective implementation of new or different instructional practices (Richardson & Placier, 2001). In my study, I considered teacher change in
terms of this last definition. Teacher change is defined in my study as effective implementation of new or different instructional practices (Richardson & Placier, 2001).

As this study addressed teachers’ implementation of a new instructional practice (engineering design), the conceptual framework that was used for my study was Guskey’s (2002) “Model of Teacher Change” (p. 7). In his model, he explained that for most teachers becoming a better teacher means better student outcomes. Guskey (2000, 2002) described the process of teacher change as complex interactions among three interrelated variables: change in teacher classroom practices, change in student outcomes, and change in teacher’s attitude and beliefs. He described change as a learning process that was “developmental and primarily experientially based” (p. 7). Teachers need to be able to see that an instructional practice has immediate impact on student learning outcomes. Moreover, it is the experience of successful implementation and the results of such efforts that ultimately transform teacher’s attitudes and beliefs. Guskey (2002) stated that, “significant changes in teachers’ attitudes and beliefs result from improvements in student learning” (p. 383). Guskey suggested that this model of teacher change holds true not just for gains in student achievement, but for changes in student attitude, behavior or social ability. In conclusion, when student outcomes improve followed by a change in teacher beliefs, the new practice is more likely to be sustained (Franke, Fenema, & Carpenter, 1997). Franke, Fenema, and Carpenter (1998) call this type of change “self-sustaining, generative change” (67); this means that for teacher change to be continual, teachers need to become “ongoing learners” (p. 67).

In this next section, I provide a historical perspective of teacher change and then review the current teacher change literature over the last 10 years. In order to understand teacher change in practice, it is helpful to have both a historical as well as a current understanding of the teacher
change literature. The historical view situates teacher change in practice within the broader context in which it belongs. A more in-depth review of the current research of the last 10 years is most appropriate, because the major focus of the literature in the last 10 years has been on teacher change in practice as a result of professional development. This is directly related to my study as I examined teacher change within the context of a broader PD effort. At the end of this section, I explain how the historical and current literatures informed my research.

**Historical overview of the teacher change research.** In this historical overview, I provide a chronology of the teacher change research. In their review of the teacher change research, Richardson and Placier (2001) pointed out the teacher change research has historically been of two types: “individual or small group cognitive, affective, or behavioral change processes or an organizational view of change that connects the structural, cultural, and political components of the school organization to teacher change” (p. 905). In the next sections, I describe the research in these two areas as well as the early work on professional development as a means to create teacher change in practice.

The first factor of teacher change to be discussed in this historical overview is the role of the individual teacher. The individual teacher factor includes cognitive influences, affective influences, and teaching practices (Richardson & Placier, 2001). Cognitive refers both to prior knowledge and acquired knowledge or learning by the teacher (Borko & Niles, 1987). The affective factors include things like dispositions, personality, attitude, and beliefs (Richardson, 1996). Teaching behaviors include areas such as instructional skills and practices (Shulman, 1986). The individual teacher change research was of three types historically: teacher beliefs, teacher cognition, or constructivist teaching (Richardson & Placier, 2001). In the next
paragraphs, I provide an overview of these three focal areas of the individual teacher in the
teacher change research.

The earliest focus of the teacher change research was on teacher beliefs. The recognition
of the importance of affective factors resulted in years of studies investigating the connections
between teacher beliefs and practices (Green, 1971; Novak & Knowles, 1992; Powell & Birrell,
suggested that perhaps, beliefs and practices develop together during the teacher change process.
Additionally, it has been found that beliefs are heavily dependent on past and present
three sources of teacher beliefs: personal experience, school and teaching experience, and
experience with content and pedagogical content knowledge.

Following the earliest area of emphasis on beliefs in the teacher change research, the next
major focus of the teacher change research was on cognition. Research on cognition as a factor
in teacher change became prevalent in the 1980s (Borko & Niles, 1987; Clark & Peterson, 1986;
Shavelson & Stern, 1981). Some of these studies focused on the effect of cognition on the
process of teacher change, while others focused on cognition as an outcome of change activities
(Richardson & Placier, 2001). In examining cognition from either of these perspectives, Opfer
and Pedder (2011) pointed out that for a long time there was a lack of consensus on what it was
that teachers needed to know. However, in 2001, Ball, Lubienski, and Mewborn stated that the
current consensus was that teachers needed a distinct rather than a generic body of knowledge.
This ‘distinct’ knowledge was first defined by Schulman’s (1986) concept of pedagogical
content knowledge. Pedagogical content knowledge includes knowing the most effective
methods, strategies, and ways to help students learn, as well as the most effective ways for the
instruction of specific content knowledge and skills (Shulman, 1987; Wilson, Shulman, & Richert, 1987). This concept was further developed by Gess-Newsome (1999), when she described a unique form of knowing that was synthesized in the learning process from three types of knowledge: subject, pedagogy, and context knowledge. Thus, teacher learning is generated from the reciprocal interaction of these three types of knowledge (Gess-Newsome, 1999).

After these first two focal areas of beliefs and cognition in the teacher change research, the third major focus was on teaching practices, more specifically teaching practices that support constructivist learning. The focus of the teacher change research on constructivist teaching was strongly driven by educational reform efforts (Richardson & Placier, 2001). Teaching that facilitates student constructivist learning played and continues to play a significant role in national and state educational policy documents (American Association for the Advancement of Science [AAAS], 1993, 2001, 2007; National Research Council [NRC], 2007, 2009). An example of this can be found in the National Science Education Standards (NSES) of 2001 and currently the Next Generation Science Standards (NGSS) of 2013. Both of these documents support the use of constructivist teaching in K-12 science classrooms. However, teaching that supports constructivism does not translate easily into classroom practice. One reason for the difficulty in using a constructivist approach is that teachers lack experience in their own education with constructivist learning (Windschitl, 2002). A second difficulty is that changing to teaching that supports this type of learning requires a change from a teacher-centered approach to a learner-centered approach, which requires a change in teacher beliefs and practices (Richardson & Placier, 2001). These changes in beliefs and practices can serve as a basis for instructional change. However, teachers must also be supported to change the cultures of their
classrooms as well as receive support for dealing with the conservative educational policies that continually push towards teaching to the test as opposed to teaching for understanding (Apple, 1982; Little, 1993; Purpel & Shapiro, 1995; Windschitl, 2002).

The second factor of teacher change to be discussed in this historical overview is the role of the school on teacher change. The school factor of teacher change includes structural, cultural, and political factors (Richardson & Placier, 2001). According to Richardson and Placier (2001), the structural factors of school include numbers of things such as the schedule, the facilities, and the resources available, to name a few. The cultural factors include the norms and ways of interacting within the school environment. Lastly, the political factors take into account the power structures within the school environment such as administration, school boards, and teacher unions.

This body of research has demonstrated that the school, its structures, cultures, and politics, can both enable and constrain teacher change (Galloway, Parkhurst, Boswell, Boswell, & Green, 1982; Mortimore, Sammons, Stoll, Lewis, & Ecob, 1990; Pollard, 1985; Rutter, Maugham, Mortimore, & Ouston, 1979; Woods, Jeffery, & Troman, 1997). An example of this can be seen in the research of Hollingsworth (1999) of elementary math teachers involved in professional development (PD). He found that the teachers involved in his study identified challenges in changing their teaching due to a lack of support by their school in terms of an absence of coordinated leadership, low levels of professional collegiality, and a lack of obvious commitment to the PD from the school administration.

Richardson and Placier (2001) described the existing research on school as a factor of teacher change as falling into one of three categories: “how teaching in schools change teachers; how school and district context influence planned efforts to change teachers; and how planned
efforts to change schools change teachers” (p. 923). Their major finding in the review of this particular body of literature was that the relationship between teacher change and schools was “complex and ambiguous” (p. 923). They explained this by pointing out that sometimes teachers changed even in environments that were not supportive; other times teachers did not change even with organizational changes in place that should have supported it.

Four processes that schools need to have in order to support teacher change emerged from a historical look at the literature. The first process that emerged from the literature is that to foster change, schools must nurture learning environments at every level within the school community (Barth, 1986; Hopkins, West, & Ainscow, 1996; Senge, 1990). The second process is that self-evaluation and reflection is a powerful way to promote learning and change for the individuals and the collective (MacBeath, 1999; MacBeath & Mortimore, 2001; Rosenholtz, Bassler, & Hoover-Dempsey, 1986). The third process for promoting teacher and school change is to continually examine explicit and implicit values, assumptions, and beliefs of the school and the teachers (Argyris, 1993; Argyris & Schon, 1978; Deal, 1984; Huberman & Miles, 1984; Senge, 1990). The fourth and last process that emerged from the literature described the need for creating management systems that leverage core capabilities and resources as well as the expertise of teachers and students (Hargraeves, 1999; Leithwood, Leonard, & Sharratt, 1998; Marks, Louis, & Printy, 2000; Nickols, 2000; Nonaka & Takeuchi, 1995; Rosenholtz et al., 1986; Zack, 2000).

The last factor of teacher change to be discussed in this historical overview is professional development that is designed to facilitate teacher change. The research discusses professional development most frequently in one of three ways: structures, processes, and mechanisms (Opfer & Pedder, 2011). Structures of professional leaning include things such as:
professional development should allow teacher expertise to be valued; control of learning should be shared among teachers, researchers, and professional developers (Richardson, 1994b); and learning should be sustained over a longer period of time (Desimone, 2009). Processes of professional development describe the path or paths that teachers go through to change. In his research, Guskey (2002) provided an example of such a process in which teachers’ attitudes and beliefs change only after they see the effects on their students of a new instructional practice. Lastly, mechanisms include the types of learning activities used in the professional development. This includes activities such as professional learning communities, lesson studies, or coaching.

Almost 25 years ago, Carpenter, Fennema, Peterson, Chiang, and Loef (1989) conducted a randomized experiment of teachers who participated in either an 80-hour PD program or a 4-hour PD program. The students of the teachers involved in the longer PD program significantly outperformed the students of the teachers involved in the shorter program. This study influenced a flurry of research on the structures of effective professional development. The research has concluded that the amount of time spent in professional development is critical to teacher change (Garet, Porter, Andrew, & Desimone, 2001). Teachers need to be involved in sustained and intensive professional learning over time where they can discuss, develop, and practice new teaching knowledge (Garet, Porter, Andrew, & Desimone, 2001). The recommendation was for a significant number of contact hours (approximately 100 hours) sustained over the academic year (Guskey, 2000).

In addition to the call for PD that is sustained over time, another structure that emerges from the literature is more effective PD is accomplished if teachers from the same school or grade participate collectively in the professional development activities (Birman et al., 2000; Desimone et al., 2002; Garet, Porter, Desimone, et al., 2001; Wayne et al., 2008). Furthermore,
effective PD should allow teacher expertise to be valued and control of learning should be shared among teachers, researchers, and professional developers (Richardson, 1994b).

The research on PD not only informs structures for effective PD, but it provides recommendations for mechanisms or the types of activities that teachers should be engaged in during PD activities. The research confirms that teachers learn best when the pedagogy of the PD requires teachers to be active and learn in ways that is reflective of how they should teach their own students (Borko & Putnam, 1997; Darling-Hammond & McLaughlin, 1999). Additionally, effective PD should be connected to the daily work of teachers (Greeno, 1994; Hawley & Valli, 1999; Leinhardt, 1988; Wideen, Mayer-Smith, & Moon, 1998), and include similar materials used within their typical classroom instruction (Borko & Putnam, 1997; Greeno, 1991; Hawley & Valli, 1998; Putnam & Borko, 2000).

A separate body of literature focuses on communities of practice as a mechanism for supporting change in teacher practice. This research explains how and why collaboration is important to support a change in practice for teachers (Ball, 1997; Cochran-Smith & Lytle, 1999; Goldenburg & Gallimore, 1991; McLaughlin & Talbert, 1993; Richardson & Anders, 1994; Thomas, Wineburg, Grossman, Myhre, & Woolworth, 1998). The third factor of the professional development influencer of teacher change is process or processes of PD. The best example of a process of professional development that facilitates teacher change is offered by the research of Guskey (2000, 2002), which has been explained previously and provides the conceptual framework for my research study. Furthermore, Guskey (2000, 2002) was the first to research the role of the student in influencing teacher change. In the next section, I analyze the research concerning teacher change in practice supported by professional development.
Literature review of the current teacher change in practice research. Much of the current teacher change in practice research over the last 10 years has focused on teacher change in practice as a result of professional development. Research on teacher professional development has been motivated by the assumption that effective professional development will change and improve teachers’ instructional practice, which will result in greater student learning (Opfer & Pedder, 2011). According to Opfer and Pedder (2011), this assumption has led to a significant research focus on ‘effective’ professional development. The change supported by professional development is described primarily in terms of changes within an individual teacher. However, there is a small amount of the current research that focuses on the influence of students on teacher change. None of the articles reviewed focused on the school as an influence of teacher change, except as including the school as part of the background or context of the individual teacher.

I completed a general review of the empirical, peer-reviewed research conducted over the last 10 years. The content search terms that I used were teacher change, teacher development, instructional reform, and professional development. The population search term used was K-12 teachers. Articles were selected based on the following inclusion criteria: all studies identified a population sample of K-12 teachers, teacher change was the focus of each study, and all studies were data-driven. The literature discovered in this broader search was also reviewed to determine which factor of teacher change was included in each study. Of the articles reviewed for this section, 14 were studies that concerned a change in teaching practices based on specific factors of the professional development that was provided. Additionally, two of the research studies focused on changes in teacher knowledge associated with professional development. Three
articles reviewed focused on changes in affective factors of teachers and three focused on student influences of teacher change.

**Teacher change in practice supported by PD.** The first study that focused on changes in teacher knowledge supported by professional development was conducted by Hill and Ball (2004) and confirmed previous findings that teachers learned more and improved student learning when PD was extended over time (Desimone, 2009). The second study that focused on teacher knowledge as an outcome of PD explicated types and processes of teacher learning common during professional development (Kitchenham, 2006). Kitchenham (2006) conducted a mixed methods study with 10 teachers, who were attempting to integrate technology into their classrooms. Teachers not only learned more technology content and skills during the PD as demonstrated by improved scores on a post-test, but showed an increase in the amount and quality of critical discourse and self-reflections.

In terms of the studies that focused on the affective outcomes of professional development, the first study (Meirink, 2008) found that other teachers were strong influencers of teachers. That, as teachers heard their colleagues talking about instructional practices that worked, those teachers were more likely to try those particular practices and were more likely to change their teaching. The second study (Saunders, 2012) identified emotions as an important part of the affective factor in teacher change. Saunders (2012) identified that emotions could mediate behaviors and interactions during the change process. The findings in this study demonstrated that teachers’ emotions during the process of change were influenced by relationships with their colleagues, by feelings of support or lack of support, and by the culture and norms of the context. The third study was a case study of two science educators as they worked to improve their practice (Greensfeld & Elkod-Lehman, 2006). One finding of this study
is that teacher knowledge was personal and context-bound. They emphasized that motivation and metacognition support changes in thinking and practice. Additionally, they pointed out the importance of the situational aspects of teacher change in terms of context and culture.

Of the studies that focused on influence of students on teacher change, the study by Greensfeld & Elkod-Lehman (2006) described above was also included as one of the two studies in this category. This study demonstrated that the interaction between student and teacher was central to change in teacher practice. Both teachers in the study discussed the importance of their students to whether they made changes or not. The second study that mentions the influence of students on teacher change was a quantitative study that used survey data from 260 secondary school teachers. The major conclusion of this study was that teachers, who identified themselves as more ‘student-oriented’, participated more frequently and actively in professional development and made more changes in their instructional practices. Teachers, who identified themselves as ‘subject-oriented’, participated less frequently or actively in professional development and made fewer changes in their instructional practices.

Of the 14 research studies reviewed that focused on a change in teaching practices as a result of professional development, four focused on the processes of PD that resulted in a change in teaching practices, three focused on the structures of PD, and 8 focused on the mechanisms or activities of the PD that influenced teaching practices. Two of the three studies that focused on processes of PD that supported change in teaching practices validated findings by Guskey (2002) that a change in teacher beliefs and practices were supported by changes in student outcomes (Gatt, 2009; McGee, 2013). The third study was conducted by Vetter (2013) and found that teacher change should be thought of as an identity process that was a dynamic, complex interaction. This identity process to facilitate teacher change was best supported by discursive
practices within collaborative teacher groups. This study suggested that personal stories were important in the process in that they fostered self-reflection.

The three studies that focused on the structures of effective PD necessary to facilitate teacher change found: that change is a slow, but constant evolution (Vazquez-Bernal, 2011); that to foster change that is sustained teachers must participate in self-identifying learning needs (Slavit & McDufee, 2013); and that it is helpful to use a PD model that provides ongoing support as teachers are implementing a new instructional strategy (Concannon-Gibney & McCarthy, 2012). This study emphasized the need for coaching of teachers as they engage in a process of change in practice.

The eight studies that focused on mechanisms of professional development supported the findings that PD activities should be extended over time, engage teachers actively in roles that mirror their daily practice, put them into the role of a learner, create dialogue with colleagues, and facilitate self-reflection (Desimone, 2009). Three of the studies focused on using video with teachers to successfully facilitate dialogue and reflection (Muir, Beswick, & Williamson, 2009; Thomas, Hassaram, Rieth, Raghavan, Kinzey, Mulloy, 2012; van Es, 2012). Three of the studies focused on the power of communities of practice in facilitating teacher change (Pang & Ling, 2010; Poekert, 2012; Witterholt, 2012). All of these studies described changes in teaching practices, improved collaboration across teachers, and increased use of self-reflection.

The last two studies looked at the types of changes that teachers made as they were implementing new instructional practices (Abkus & Hand, 2012; Adamson, 2013). Abkus and Hand (2012) examined the changes in teaching practices during a new instructional approach called the mathematics reasoning approach (MRA). MRA focused on problem solving and writing to learn in math. This study used a mixed methods approach with three algebra teachers.
as they implemented the strategies. Levels of implementation were measured by the Reformed Teaching Observation Protocol (RTOP) instrument. A significant improvement in terms of increased inquiry teaching. Teachers implementation levels among the three teachers differed, but all three teachers showed an improvement in the skill of questioning first.

Adamson (2013) examined elementary teachers’ instructional strategies for supporting scientific understanding and inquiry as well as supporting English language development with diverse student groups. The study was part of a 5-year research and development project with data consisting of 213 post-observation interviews with third, fourth, and fifth grade teachers. All teachers in the study consistently identified similar strategies to promote science learning: making connections to prior knowledge, making real-world connections, engaging in hands-on activities. However, none of the teachers reported more sophisticated inquiry strategies such as: designing original science investigations, making predictions or hypotheses, asking questions that could be answered using science experimentation, or using models to construct explanations. Adamson (2012) gives two possible reasons for these findings: 1) teachers might not be aware of the varying levels of sophistication of inquiry; and, 2) teachers followed the curriculum like a ‘script’ as opposed to internalizing the student-centered approach of the curriculum.

Summary of current and historical literature and connections to my research. The last section of this chapter summarizes the findings of the current and historical literature and connects it back to my research. The research analyzed in both the historical and current literatures have tended to view teacher change in isolation; as an event as opposed to a complex system of interacting and reciprocal events. The teacher change research that exists is unbalanced. There is very little research on the influence of the student on teacher change; a lot
of research on the effect of professional development on teacher change; and no research that
exists that address the complexity of teacher change as a system. Teacher change is difficult in
that it demands that teachers challenge and recreate deeply embedded beliefs, ideas, and
instructional practices (Borko & Putnam, 1996; Pennington, 2005; Vetter, 2012). The research of
Clarke and Hollingsworth (2002) illustrate that the process of teacher change is cyclical; that
change may occur in one area but not in another area. For example, teachers may change their
beliefs, but their practices remain the same. Teachers may ultimately change their practices, but
student outcomes do not change. This is further complicated in that teacher change is influenced
not only by the individual teacher, but by the school, the students, and by the professional
development in which they engaged. For teacher growth to really occur, multiple areas of
influence must change (Clarke & Hollingsworth, 2002). “Learning in one system must affect and
be enacted and supported in another system. As a result, “effective” teacher learning [and
change] requires multiple and cyclic movements between the systems of influence in teachers’
worlds” (Opfer & Pedder, 2011, p. 395).

The teacher change research presented here provides the lens through which I view my
own research. My research sought to understand change through the complex interaction of
influences. My research described changes in teaching practices supported by professional
development and asked the teachers involved to identify the complexity of influences by which
their teaching practice changed. This lens allows us to begin to understand why, how, and under
what conditions teachers change. In the next part of this chapter, I review the literature on STEM
education, engineering, and engineering design that also informed my research study.
STEM in K-12 Education

The ‘S” and “M” in STEM education, science and math, are the two school subjects with the longest history in K-12 education (NRC, 2009). Furthermore, proficiency in these two subjects is considered essential to success for life in the 21st century (Carnevale, et al., 2010). In K-12 schools, science is generally understood to mean the natural sciences: biology, chemistry, physics, earth, space, and environmental sciences (NRC, 2012). The “T” in STEM education, technology, is offered in a small number of schools, with only 12 states requiring the completion of a technology course for high school graduation (Dugger, 2007). Technology education is currently defined more broadly as the study of the human-made world (NRC, 2002). If technology has sparse representation in K-12 schools, then the “E” in STEM education might be considered “the missing letter in STEM” (NRC, 2009, p. 20). Few teachers and schools include engineering and engineering design in their curriculum (NRC, 2009). The current lack of inclusion of engineering in the K-12 curriculum represents both an “opportunity and uncertainty” (NRC, 2009, p. 20). The opportunity is to strengthen math and science learning through the inclusion of engineering into K-12 education. The uncertainty is caused by the unanswered questions of how to integrate engineering into K-12 classrooms as well as determining the value of existing engineering curricula and approaches (NRC, 2009). The NRC report, Engineering in K-12 Education (2009), stated that engineering design in the K-12 classroom showed great promise, but that the limited amount of reliable data did not allow for “unqualified claims of impact” (p.154). The report continued by calling for additional studies that explored both student outcomes and teacher implementation. Furthermore, even with the promise of the benefits, the push to include engineering and engineering design into an already full curriculum creates additional tensions for schools and teachers. The current high-stakes environment of K-12
schools with the emphasis on standardized testing creates barriers to the addition of one more curriculum initiative, such as the integration of engineering into the science classroom (Lewis, 2006). The question persists of why should schools and teachers add one more thing to their already full plates. My study seeks to begin to answer the question of why include engineering design in K-12 science. In the next sections of this chapter, I define engineering design, describe engineering design as a K-12 instructional strategy, review the literature on teacher’s implementation of engineering design in the k-12 classroom, and describe an existing engineering curriculum for the K-6 classroom.

**Engineering Design Defined**

Engineering design is considered the main work of professional engineers (Katehi, Pearson, & Feder, 2009). It is the process that begins at identifying the problem and ends at creating a solution that meets human needs or wants (Apedoe, Reynolds, Ellefson, & Schunn, 2008). Engineering design has been defined as “design under constraint” (Wulf, 1998, p. 4), which emphasizes that engineering design requires not only creativity but a deep understanding of the multitude of variables that can affect a design solution. Engineers must work within the physical and societal constraints of the real world to create successful designs (Wulf, 1998). The engineering design process is presented in a variety of ways, but follows a general structure that includes: identifying a need or problem, investigating the problem, imagining possible design solutions, creating a prototype or model, evaluating the design, and redesigning to create the most effective design (Crismond, Lo, & Lohani, 2006). This typical process is detailed in the next paragraph.

The first step of the engineering design process is to identify a need or problem (Apedoe, X. S., Reynolds, B., Ellefson, M. R., & Schunn, C. D., 2008). Typically, in professional
engineering, the problem is determined by the client. The second step is to investigate the problem, which involves further defining the problem as well as defining constraints and understanding similar problems and problem solutions (Crismond, et al., 2006). The third step uses this greater understanding of the problem and begins to imagine possible design solutions. From the designs that are developed by an engineer, the fourth step includes choosing a design and creating a prototype or model of that design solution. A prototype is an approach for evaluating a design solution in that it forces the engineer to consider physical constraints (Silk, Schunn, & Cary, 2009). The fifth step of the engineering design process is to evaluate the design solution. Evaluation addresses how well a particular design will solve the defined problem and can occur at any time during the engineering design process (Crismond, et al., 2006). Based on the evaluation of the design, the sixth step is redesigning to create the best solution. Redesign is perhaps the most critical step in the engineering design process, in that it is this process of continual improvement that allows the problem to be solved with the most effective design (Apedoe et al., 2008). Although I have portrayed engineering design as a step-by-step approach, it is not a linear process (Atman, Chimka, Bursic, & Nachtmann, 1999). The engineering design process is iterative (Crismond, et al., 2006). In fact, Crismond, et al., (2006) prefer the term “iterate” (p. 46) instead of redesign. At any stage of the design process, an engineer may go back to any stage of the engineering design process, based on problems they encounter or new information needed. The iterative nature of the engineering design process allows for the fluidity that is needed to solve real-world problems (Apedoe et al., 2008).

**Engineering design in the K-12 science classroom.** The inclusion of engineering design as an instructional strategy in the K-12 science classroom is a relatively new suggestion (Katehi et al., 2009). In the K-12 science classroom, engineering design is a strategy that can be used to
immerse learners in the practices of real engineers. In this section, I review the benefits of engineering design in the K-12 science classroom and describe the recommendations for the inclusion in the K-12 science and engineering curriculum of core engineering principles, science and engineering practices, as well as science content. I conclude this section with a discussion of the current research literature on engineering design in the K-12 science classroom.

The National Research Council (NRC) report, *Engineering in K-12 Education*, has identified several benefits of integrating engineering design into K-12 education: improved learning of math and science, increased awareness and interest in engineering and the engineering design process, and an increase in technological literacy (Katehi et al., 2009, p. 49-50). In addition to identifying the benefits for the inclusion of engineering design into the K-12 classroom, the NRC report also identified core engineering principles that should be included as part of a K-12 engineering curriculum (Katehi et al., 2009). These core engineering principles include: systems, modeling, specifications and constraints, optimization, and trade-offs (Katehi et al., 2009, p. 121). These five core engineering principles are detailed in the paragraphs below.

The first core engineering principle, systems, can be defined as individual parts of an object or process that work together to perform a job. In most situations, a system is “more than the sum of its parts, and understanding a system involves not only understanding the individual parts but also understanding how the parts interact” (Katehi, et al., 2009, p.42). Engineers mostly deal with systems, and thus, must understand how systems work and what things affect the performance of a system (AAAS, 1993). The second core engineering principle suggested by the NRC (2009) report is modeling. Modeling is a drawing or 3-dimensional representation that helps to understand what may happen when the actual object or process is used (Katehi et al., 2009). A good model should incorporate the physical constraints found in the real world. The
third engineering principle is specifications and constraints. Specifications are the requirements of the design. Constraints are the limitations on the design. It is rarely possible to meet all of the specifications and at the same time accommodate all of the constraints in a design. Thus, the most effective design requires balancing the competing or conflicting demands inherent in a design solution. The fourth engineering principle is optimization, which is the stage of the design process when the effectiveness of a design is maximized. The last of the five core engineering principles suggested by the NRC report (2009) is trade-offs. Trade-offs are decisions made by an engineer to not maximize one desirable feature in a design in order to be able to maximize a different desirable feature. The most effective design is one that is closest to meeting the given specifications, falls within the defined constraints, and has the smallest number of negative features (AAAS, 1993).

In addition to the core engineering principles outlined previously, engineering in K-12 science classrooms should also embed the practices of engineering used by engineers to solve real-world problems (Apedoe et al., 2008). A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas (NRC, 2011) provides a framework that can guide K-12 science teachers as they integrate engineering and engineering design into their classrooms (Achieve, 2013). This framework differentiates science as the study of the natural world from engineering which uses science and math to solve a problem of daily life by creating technologies (NRC, 2011). However, this framework also describes the similarities of science and engineering in that they both require knowledge and practice. The report continues by stating that by engaging in the practices of science and engineering students are able to understand the work of scientists and engineers. Science and engineering are similar in that they both are iterative and systematic. They are different in that engineering seeks an immediate practical
application while science seeks to answer questions about the natural world (NRC, 2011). Even with the differences between science and engineering, the NRC report (2011) outlines eight overlapping science and engineering practices that are considered essential to the K-12 science and engineering curriculum. Six of the eight practices are in common between science and engineering. The first difference is that science asks questions; engineering defines problems. The second difference is that science constructs explanations; engineering designs solutions. The practices include: 1) Asking questions or defining problems; 2) Developing and using models; 3) Planning and carrying out investigations; 4) Analyzing and interpreting data; 5) Using math and computational thinking; 6) Constructing explanations or designing solutions; 6) Engaging in argument from evidence; and, 8) Obtaining, evaluating, and communicating information (NRC, 2011, p. 49). These engineering practices are further defined in the following paragraphs.

According to *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* (NRC, 2011), the first engineering practice is to define the problem. This requires that students ask questions that clarify the problem, determine the criteria for success, and identify constraints (p. 50). The second engineering practice is to develop and use models. Models allow students to analyze and test proposed systems, in order to determine both the strengths and limitations of their designs (NRC, 2011, p. 50). The third engineering practice is to plan and carry out investigations. These investigations allow students to identify variables, specify criteria or parameters, and test proposed designs (NRC, 2011, p. 51). The fourth engineering practice is to analyze and interpret data (NRC, 2011, p. 51). Analyzing data from the testing of designs allows students to compare solutions and determine the best design solution. The fifth engineering practice is to use math and computational thinking, which allows students to represent mathematical relationships and principles in the design process (NRC, 2011, p. 52).
The sixth engineering practice is to design solutions (NRC, 2011, p. 52). The practice expects that students will develop systematic solutions to problems, based on math and science knowledge as well as by balancing competing criteria to create the most optimal design. The seventh engineering practice is to engage in argument from evidence (NRC, 2011, p. 53). This practice expects that students will use systematic methods to identify the best solution by comparing alternatives, formulating evidence based on data, making arguments to defend conclusions, and critically evaluating the ideas of others. The eighth practice is obtaining, communicating, and evaluating information (NRC, 2011, p. 53). This last practice engages students in creating, understanding, and communicating using both oral and written communications.

The current recommendations not only include the integration of core engineering principles as well as science and engineering practices into the K-12 science classroom, but also to ensure that the engineering design activities tie explicitly to science content. Engineering is frequently thought of as applied math and science (Wulf, 1998). Thus, when using the instructional strategy of engineering design, one of the main purposes in a K-12 science classroom is to provide learners with an authentic context with which to learn science more effectively. Science content can be organized in the forms of scientific concepts, scientific patterns, and scientific principles (Borich, 1992; Eggen & Kauchak, 1999). Scientific concepts can be defined as a cognitive label that represents things in the natural or human-made world. Scientific patterns can be thought of as something in the natural or human-made world that is repeated and thus can be predicted. Lastly, scientific principles are formalized abstractions that represent scientific truths.
The three areas in this section: core engineering principles, science and engineering practices, and science content provide the pre-determined codes for the typological analysis for research questions one and two in my research study. These codes and the sub-codes as well as brief definitions are summarized in Table 2.1.

Table 2.1

Pre-determined Codes, Sub-codes, and Definitions

<table>
<thead>
<tr>
<th></th>
<th>Sub-codes</th>
<th>Definitions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Core Engineering</td>
<td>Systems</td>
<td>Individual parts of an object or process work together to perform a job.</td>
</tr>
<tr>
<td>Principles</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Modeling</td>
<td></td>
<td>A drawing or 3-d representation that helps to understand what may happen</td>
</tr>
<tr>
<td></td>
<td></td>
<td>when the actual object or process is used.</td>
</tr>
<tr>
<td>Specifications &amp;</td>
<td></td>
<td>Specifications are the requirements of the design.</td>
</tr>
<tr>
<td>Constraints</td>
<td></td>
<td>Constraints are the limitations on the design.</td>
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<tr>
<td>Optimization</td>
<td></td>
<td>Stage of the design process when the effectiveness of a design is</td>
</tr>
<tr>
<td></td>
<td></td>
<td>maximized.</td>
</tr>
<tr>
<td>Trade-offs</td>
<td></td>
<td>Decision to not maximize one desirable feature in a design in order to be</td>
</tr>
<tr>
<td></td>
<td></td>
<td>able to maximize a different desirable feature.</td>
</tr>
<tr>
<td>Engineering</td>
<td>Defining</td>
<td>Asks questions that clarifies the problem, identifies constraints, and</td>
</tr>
<tr>
<td>Practices</td>
<td>Problems</td>
<td>determines the criteria for success</td>
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<td></td>
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<td></td>
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<tr>
<td>Developing &amp;</td>
<td></td>
<td>Design and use models to analyze and test proposed systems in order to</td>
</tr>
<tr>
<td>Using Models</td>
<td></td>
<td>determine strengths and limitations of designs</td>
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<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Planning &amp;</td>
<td></td>
<td>Conduct investigations to identify variables, specify criteria or parameters,</td>
</tr>
<tr>
<td>Carrying out</td>
<td></td>
<td>and test proposed designs</td>
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<tr>
<td>Investigations</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Analyzing and</td>
<td></td>
<td>Analyze data from the testing of designs to compare solutions and determine</td>
</tr>
<tr>
<td>interpreting data</td>
<td></td>
<td>the best design solution</td>
</tr>
<tr>
<td>Using math &amp; computational thinking</td>
<td>Represent relationships and principles with mathematics and computation in the design process</td>
<td></td>
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<tr>
<td>-----------------------------------</td>
<td>------------------------------------------------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>Designing Solutions</td>
<td>Develop systematic solutions to problems based on math and science knowledge as well as by balancing competing criteria to create the most optimal design</td>
<td></td>
</tr>
<tr>
<td>Engaging in Argument from Evidence</td>
<td>Use systematic methods to identify the best solution by comparing alternatives, formulating evidence based on data, making arguments to defend conclusions, and critically evaluating the ideas of others</td>
<td></td>
</tr>
<tr>
<td>Communicating</td>
<td>Create, understand, and communicate different types of communications: oral, written, tables, graphs, drawings, models</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Science Content Connections</th>
<th>Scientific Concept</th>
<th>A cognitive label that represents things in the natural or human-made world.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scientific Pattern</td>
<td>Something in the natural or human-made world that is repeated and thus can be predicted.</td>
<td></td>
</tr>
<tr>
<td>Scientific Principle</td>
<td>A formalized abstraction that represents a scientific truth.</td>
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</table>

**Research on engineering design in the k-12 science classroom.** Most of the research on engineering design as an instructional strategy in the K-12 science classroom has focused on student outcomes. A brief overview of the studies focused on students will be provided in this section, but a more detailed description will be given of the research that exists on teacher’s implementation of engineering design in the K-12 science classroom. The current educational research that exists supports the premises of the National Research Council (2009) in that engineering and engineering practices integrated into science instruction has been shown to: 1) increase students’ science content knowledge (Apedoe, Reynolds, Ellefson, & Schunn, 2008; Cantrell, Pekhan, Itani, Velasquez-Bryant, 2006; Fortus, Dershimer, Krajcik, Marx, & Mamlok-
Naaman, 2004; Mehalik, Doppelt, & Schuun, 2008; Mooney & Laubach, 2002; Riskowski, Todd, Wee, Dark, & Harbor, 2009); 2) improve students’ attitudes of science and engineering (Apedoe et al., 2008; Atwater, Wiggins, & Gardner, 1995; Clewett & Tran, 2003; Cunningham & Lachapelle, 2010; Freedman, 1997); and, 3) potentially develop student science and engineering practices such as critical thinking and problem solving (Duschl, Schweingruber, & Shouse, 2007; Fortus, Krajcik, Dershimer, Marx, & Mamlok-Naaman, 2005; NRC, 2000, 2011; Woods, 2000; Zacharia & Barton, 2004). Additionally, numerous research studies have highlighted the benefits of including engineering into the science curriculum as a means for motivating students in science (Apedoe, et al., 2008; Kolodner, et al., 2003; Silk, Schunn, & Cary, 2009).

However, if engineering design can support the positive outcome for students as outlined above, we must ask how teachers can most effectively implement engineering design as an instructional strategy in the science classroom. As stated previously, there is very little research on teachers’ implementation of engineering design in the science classroom. The research conducted by Brophy, Klein, Portsmore, & Rogers, 2008; Kimmel, Carpinelli, & Rockland (2007) found that teachers will often avoid teaching content they do not understand. Furthermore, engineering content is currently not a part of typical teacher education or professional development. In fact, teachers, like many of their students, hold a narrow, stereotypical view of engineering and engineers (Yasar et al., 2006). In addition to teachers’ lack of engineering content knowledge, Lewis (2006) found that the practices of engineering design were also relatively unknown to many K-12 teachers. Kimmel and Rockland (2002) state that the principles and practices of engineering design are typically unfamiliar to K-12 teachers and therefore are less likely to be implemented in classroom instruction.
Perhaps, the greatest obstacle to incorporating engineering design into the K-12 science classroom is its open-endedness. Open-endedness is defined here as an instructional situation that has multiple correct answers and supports iterative trials in which new possibilities can emerge and be pursued. There is no list of correct answers in an engineering design activity. In fact, engineering design activities are purposefully open-ended and have many possible correct solutions (McGinn & Roth, 1998). The research shows that many teachers are uncomfortable with the open-endedness and the lack of correct answers inherent in engineering design activities (Brophy et al., 2008; Kimmel, Carpinelli, & Rockland, 2007; McGinn & Roth, 1998). Thus, the minimal research that does exist demonstrates teachers’ struggles with engineering design in terms of unknown content, unfamiliar practices, and not being comfortable with the open-ended nature of engineering design. Taking this research into account, it is important to consider how to support science teachers as they seek to integrate engineering design into their classrooms. Thus, the next section describes a specific engineering curriculum; *Engineering is Elementary (EiE)*, which was designed to help teachers integrate engineering design into the elementary science classroom. The *EiE* curriculum was used by the teachers in my study.

**Engineering is elementary (EiE).** *Engineering is Elementary (EiE)* is a K-6 engineering curriculum that was developed by a team from the Boston Museum of Science (2003). This curriculum has a clearly stated purpose of being an engineering curriculum that can be integrated into science. The *EiE* development team states that “*EiE* units do not explicitly teach science content. However, because science concepts are often referenced, reviewed, and applied as students complete their engineering design challenge, it is important that students have the appropriate science content knowledge before engaging in an *EiE* unit” ([http://www.eie.org/content/how-use-it](http://www.eie.org/content/how-use-it), 2013). The *EiE* curriculum seeks to foster engineering
and technological literacy for all elementary students (EiE, 2003). The EiE curriculum team explains that its core values include: design that is open-ended with multiple solutions possible; design that is situated into a larger real-world context; design that allows for collaborative problem solving; design that fosters creativity and innovation; and design that is scaffolded to support student-directed exploration and learning (www.eie.org, 2013).

The EiE curriculum centers around the engineering design process (EDP) with five iterative steps: Ask, Imagine, Plan, Create, and Improve. Figure 2.1 shows the five stages of the engineering design process (EiE, 2003).

![Engineering Design Process](image)

*Figure 2.1. Engineering is Elementary (EiE), Engineering Design Process (EDP)*

*Reprinted with permission
Developed by EiE, Boston Museum of Science (2001)*

Students as they engage in a design are supposed to: 1) Ask questions to define the problem; 2) Imagine possible solutions to the design challenge; 3) Plan how they are going to make their design; 4) Create and test their design solution; and, 5) Improve their designs to make them more effective (EiE, 2003).

There are currently 20 stand-alone curricular units, including such topics as windmills, water filters, bridges, plant packages, and solar ovens. Each unit is organized with the same structure. Every unit has four lessons. The first lesson always begins with a story about a child somewhere in the world that has a problem that needs to be solved. This first lesson sets the
stage for the design challenge and situates the problem into a larger context. For instance, in the first lesson of the *Designing Windmills* unit, Leif and his cousin Dana have a problem; they need to figure out how to get oxygen into a fish pond. Leif’s mother is an engineer and helps the two children work through the engineering design process in order to successfully design a windmill that is attached to a paddle that oxygenates the pond for the fish.

The second lesson in every *EiE* unit explores a type of engineering. In the *Designing Windmills* unit, students explore mechanical engineering. They do this by examining several common machines such as mechanical pencils, egg beaters, can openers; they diagram how the parts of each machine interact with other parts of the same machine and allow it to function. Students must identify the purpose of the machine as well as identify where you act on the machine and the resulting reaction.

The third lesson in every *EiE* unit is a scientific inquiry that helps the student to learn information they need to know in order to make a more effective design in the design challenge. In the *Designing Windmills* lesson three, students design sails for small boats to explore different materials and shapes that are good for catching the wind. The purpose of this lesson is to give the students more experience with materials, before they design their windmills.

The fourth and last lesson in all 20 *EiE* units is the design challenge. The three previous lessons work together to prepare the student to use the engineering design process to solve the same problem that was foreshadowed in the storybook in lesson one. In lesson 4 of *Designing Windmills*, students use what they learned to design a windmill that will catch the wind and turn a dowel rod connected to a string and lift weights. Figure 2.2 demonstrates the set-up of the windmills. The students’ challenge was to design blades that could be attached to a windmill and
catch the wind. A fan provides the wind to turn the windmill blades. An effective design would be able to catch the wind and lift a small cup full of weights.

Figure 2.2. EiE Designing Windmills Lesson 4

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Developed by EiE, Boston Museum of Science (2001)

The teaching methods recommended by EiE (2003) are based in a constructivist view of learning, in which the prior knowledge, ideas, and skills brought by students to the learning are recognized and valued. Students are encouraged to share ideas about how to solve the problem and to revise their initial ideas based on new information and experiences gained (http://www.eie.org/content/design-principles, 2013).

Summary

In this chapter, I described the literatures that help to understand my research. The first body of literature in this chapter, teacher change, informed my study. Specifically, Guskey’s model of teacher change provided the conceptual framework for my study. Additionally, I used this framework for the pre-determined codes to be used in the analysis of research question 3. The literature on engineering and engineering design provided information to understand how it is defined and its promise as an instructional strategy in the K-12 classroom. Using this literature, I
pre-determined codes to be used during my analysis for research questions 1 and 2. My first research question was “How do two fifth grade science teachers implement an engineering design activity?” My second research question was “How do these same two fifth grade science teachers’ instructional practices change as they implement the same activity during a second instructional cycle?” The literatures concerning engineering design and teacher change are both critical in framing the other chapters in this dissertation. These literatures provide the lens to view my methods which will be described in the next chapter as well as my findings and conclusions. In the next chapter, I describe my research methods in terms of research context, my roles in this study, participant selection, data sources, data analysis, and the strengths and limitations of my research design.
Chapter 3

Methodology

The purpose of my research study was to describe two science teachers’ implementation of an engineering design activity over two academic years and to explore what factors the teachers identified as to why their classroom practices changed. In chapter one, I established the rationale and significance for my research study. In chapter two, I discussed the literature on engineering design. I also reviewed the literature on teacher change in practice and explained the conceptual framework for my research. In this chapter, I describe my research methods including a justification of why I used a qualitative research design in my study. After providing this justification, I describe the research context, my roles in this study, participant selection, data sources, and data analysis. Additionally, I discuss the strengths and limitations of my research.

Research Methods

The research questions for my study included:

1) How do two fifth grade science teachers implement an engineering design activity?

2) How do these same two fifth grade science teachers’ instructional practices change as they implement the same engineering design activity for a second time the following academic year?

3) What factors do the teachers identify as to why their practice changed?

My research was constructed as a qualitative study. The purpose of qualitative research is to describe understandings, meanings, and processes (Merriam, 2009). This was the most appropriate design for my study in that I wanted to be able to describe the instructional practices of two science teachers’ as they implemented an engineering design activity as well as explore their understandings of why change occurred in their practice. My research questions can best be
understood by exploring the instruction of these two elementary science teachers as they implemented the engineering design activity over two instructional cycles. Exploration of these teachers’ experiences and their practices is descriptive in its nature. Qualitative research has a distinct purpose; it can help us to understand the world around us in a more holistic way (Eisner, 1991). Qualitative research is different from quantitative research in that qualitative research seeks to provide “detailed views” of both the research and the participants (Creswell, 2007, p. 15). My study sought to capture the perspectives and insights of the two science teachers involved in my study, as well as observations of their teaching in the natural setting of their classrooms. This fits well within the purpose of naturalistic research in that this type of research seeks to address questions concerning how “social experience is created and given meaning” (Denzin & Lincoln, 1994, p. 82). Thus, qualitative research was the best choice for the design of my study in that it allowed me to more fully understand how the teachers involved interpreted, made meaning, and acted upon the engineering design instruction and the changes in their instructional practice (Lincoln & Guba, 1994).

In addition to framing my research as a qualitative study, I chose to approach my research as a case study (Merriam, 2009). Two reasons why a case study methodology is appropriate for my research: (a) a case study is a good way to answer ‘how’ and ‘why’ questions; and, (b) a case study is particularly appropriate for research that is interested in process as opposed to product (Merriam, 2009). My research questions are ‘how’ questions: How did the teachers implement the activity? Additionally, my research questions explore the process of teacher change: what factors do the teachers identify as to why their teaching practice changed? More specifically, I used an exploratory design in order to understand beginning knowledge and practice and to be able to generate more specific hypotheses for future research (Marshall & Rossman, 2010).
Merriam (2009) defines a case as a bounded system, which may be bound by time, space, or component parts. Additionally, the bounded system has a defined starting and ending time. For my study, the bounded system included the instructional practices of two elementary science teachers in the defined timeframe of a two-week period in May 2012 and a second two-week period in June 2013. I examined the components of the bounded system to better understand how engineering design was implemented in the context of the upper elementary science classroom; and how the instructional practices of these two teachers changed as they implemented the activity for a second instructional cycle. By focusing on the engineering design instruction, I was able to describe in-depth the instructional practices of these two science teachers, as well as the changes in their practice.

**Research Context**

Goodward City School District is located in a suburb near a mid-size city in the Midwest. The city of Goodward has a population of 8,500. The school district is categorized as high needs in that 80% of the students come from homes that are at or below the poverty level. The 3,360 students are a diverse population: 74% Black, 22% White, 3% Hispanic, and 1% Asian. The district has two elementary schools, one junior high, and one high school. The school has constantly struggled with state test scores and rankings of ineffectiveness. Additionally, the district has continually struggled with getting school levies passed, which makes for high levels of financial tension with frequent cuts of teachers and programs.

For the last four years, Goodward City Schools has been in a partnership with the local University. All science teachers in the district in grades 5-12 have participated in two different grant-funded efforts with the University. The first effort was funded by the state Department of Education and sought to improve teacher content knowledge and teacher inquiry practice through
professional development (PD). This PD consisted of monthly all-day workshops facilitated by a team of science faculty members for the three years of the program. Expert modeling in the teachers’ classrooms also occurred monthly in which a member of the PD team would go into teacher’s classroom and teach a lesson to their students while the teachers observed. This was followed up by a teacher-PD team member debriefing after the teaching session.

The second grant-funded effort was funded by the National Science Foundation (NSF), which sought to investigate engineering design integrated into the science classroom. The NSF project only included 5th and 6th grade teachers who taught both math and science. All 5th and 6th grade math and science teachers met as a learning team with the University faculty and staff bi-monthly from October 2011 until June 2013. These learning teams focused on continued learning through formal training provided by the University team, as well as the development of additional teaching lessons and resources that were needed to allow for better curriculum integration of engineering design into the district-mandated science curriculum. These 5th and 6th grade science teachers, with support from the University team, implemented new curricula which included Seeds of Science / Roots of Reading (SSRR), Full Option Science System (FOSS), and Engineering is Elementary (EiE). EiE is a curriculum developed by the Boston Museum of Science for elementary students (grades K-6). The curriculum is designed to be integrated into existing science instruction in schools. The goals of the curriculum are to increase students’ understanding of engineering and the engineering design process and increase science content knowledge related to the engineering topic (Engineering is Elementary, Boston Museum of Science, 2004). Teachers were supported with the implementation of these curricula through professional development workshops, expert modeling, team teaching, and learning team lesson
development. Each teacher participated in 120 hours of PD each year for each of three years (2011-2013).

My dissertation study took place within one of the two elementary schools in the Goodward City School District, Thomas Elementary. Thomas Elementary includes grades preschool through sixth and has approximately 1,000 students and 40 teachers. Thomas Elementary is representative of the demographics of the district. There were 12 5th and 6th grade teachers who participated in the grant-funded efforts. Each teacher taught math and science to two different classes of about 30 students each. They represented a range of teaching experience: only one teacher was a new teacher, the teacher with the most experience had been teaching for 26 years, and the rest of the teachers had experience in the 10-15 years range. All of the teachers had a K-8 certification. Ten out of 12 of the teachers had a Master’s degree in education. All of the teachers had taken only 6-12 hours of post-secondary science. None of the teachers had been involved in any coursework or professional development concerning engineering or engineering design.

Role as Professional Development Team Member and Researcher

My role in the project was multifaceted. It included serving as the primary researcher, a member of the PD team, co-PI for the grants, and over time a colleague with my participants. As part of the PD team, I organized and facilitated all of the PD workshops. Additionally, I led learning team meetings as well as taught lessons with and in the teachers’ classrooms. As the researcher, I also had multiple roles: classroom observer, video recorder, interviewer, and data analyst. The multiple roles I played in this research study allowed me to develop a deep understanding of both the context and the teacher participants involved in the study. However, my closeness to this research also affected how I have come to understand the teaching of engineering design and of the teacher change process. I was still an outsider and can only
provide an interpretation of how engineering design was implemented in the science classroom and why the teachers involved changed their teaching practice. Though this was a complicated relationship, I took measures as a researcher to ensure I was representing the study participants’ views and actions, rather than evaluating them. These measures included: acknowledging my complex role and potential biases; checking for internal triangulation though an iterative research design; and member checking to ensure validity of my interpretations. These measures worked together to increase the trustworthiness of my interpretations.

**Participant Selection**

I purposefully selected teacher participants for this study based on five criteria: (a) 5th grade teachers, (b) who were teaching at the same school, (c) had participated in the same professional development with the University, (d) were teaching the same *Engineering is Elementary (EiE)* unit; and, (e) had a willingness to participate in the research. Details about the participants are provided with the cases in Chapter 4.

**Data Sources**

Multiple data sources were collected to address my research questions: 1) How do two fifth grade science teachers implement an engineering design activity; 2) How do these same two fifth grade science teachers’ instructional practices change as they implement the same engineering design activity for a second time the following academic year; and 3) What factors do the teachers identify as to why their practice changed? Data for this study were collected over two years (May 2012 and June 2013) using classroom observations, written reflections, and a final interview. This variety of data sources were used not to capture an external reality but to construct understandings and meanings of the participant’s lived experiences (Denzin & Lincoln, 1994). Data used to answer question 1 included observation field notes and audio transcriptions.
of the teachers during the engineering design units in year one. Data used to answer question 2 included observation field notes and audio transcriptions of the teachers during the engineering design units during year two. Merriam (2009) stated that observations allow for direct experience with the phenomenon being studied. In my study, classroom observations were critical to address my first two research questions. It was important to first identify and describe, through classroom observations, what teaching behaviors or classroom instructional practices were exhibited in each of the two years of implementation of the engineering design activity. These two years of observations allowed changes in practice to be identified over the two instructional cycles. My research was iterative in that interview questions were derived from an analysis of the observation data over these two years. This iterative process of data gathering and interpretation was described by Lincoln and Guba (1994) as critical in naturalistic inquiry research. Changes in teaching over the two enactments were used to create the interview protocol (see Appendix D).

Data used to answer question 3 included both the final interview and monthly written reflections. These data sources were necessary to answer research question 3, in that these sources allowed me to directly capture the voices of my participants (Merriam, 2009). An interview and written reflections allowed me to describe what factors the teachers identified as to why their teaching practice changed. All of my data sources and their functions within my study are specified in my methodology table (see Appendix E) and will be described in detail below.

**Classroom observations.** The primary data source for research questions 1 and 2 were classroom observations. During the classroom observations, I took the role of observer as participant (Merriam, 2009). In this role, my major focus was to gather and record information. Field notes were taken each day. Creswell (2003) emphasized that observation as a data
collection method has limitations, including the researcher’s ability to accurately view and capture data. For this reason, I also audio recorded the teachers during their engineering design instruction. Teachers were audio recorded through the use of a digital recorder and a lapel microphone that the teacher wore during their classroom instruction. Recordings were transcribed by a professional transcriptionist. I double checked the accuracy of the first five transcripts in their entirety and then checked portions of the remaining transcripts. These transcripts, in addition to my field notes, were used to identify engineering design instructional practices as well as changes in these practices between the two instructional cycles. Observations occurred for a two week period during May 14-25, 2012 and for a second two week period during June 3-14, 2013. Each teacher taught 2 classes, so I observed each teacher teach the same lesson twice each year. Each teacher was observed for approximately 20 hours for each of the two years.

**Final interview.** A final interview served as the primary data source for research question 3. I interviewed the teachers to explore the factors they identified as to why their teaching practice changed. Both teachers were interviewed at the end of the two years after data from observations were coded and changes in practice from year 1 to year 2 were identified. These changes in practice were used as topics of conversation in a semi-structured interview (see Appendix F). The interviews were conducted in person and audiotaped. The interviews lasted about one hour for each teacher. The audios were transcribed by the same professional transcriptionist as the teacher audio recordings. I reviewed transcripts for accuracy.

**Written reflections.** A secondary data source in my study included written reflections. At the end of each monthly learning team meeting, teachers went to desktop computers and typed a reflection and emailed it to me before leaving the meeting. Over the two years, 14
written reflections were gathered. The prompt for all of the reflections was the same: “Today’s reflections.” Teachers were instructed to reflect on their current thinking about their teaching. The written reflections were used to elaborate on ideas seen in the observations and interviews in order to search for either confirming or disconfirming evidence.

Data Analysis

According to Bogdan and Biklen (2007), analysis is “working with the data, organizing them, breaking them into manageable units, coding them, synthesizing them, and searching for patterns” (p. 159). In order to accomplish the general process of analysis described by Bogdan and Biklen (2007), I conducted two specific types of analyses on my data sets: typological analysis (Hatch, 2002; Lecompte & Preissle, 1993) and inductive analysis (Hatch, 2002; Merriam, 2009). Typological analysis uses pre-determined codes from the literature, researcher experience, or research objectives for initial data analysis (Hatch, 2002). Inductive analysis allows codes to emerge from the data (Hatch, 2002; Merriam, 2009). Typological analysis of my data consisted of four steps (Hatch, 2002). The first step was to pre-determine the codes to be used. The second step was to read the data and code them using the pre-determined typological codes. The third step was to review the data by typological code and develop main ideas and supporting excerpts for each category. The fourth step was to analyze main ideas across typological codes for patterns or themes. Hatch (2002) suggests that inductive analysis can be used to “fill in the gaps” (p. 161) after completing a typological analysis. After completing the typological analysis described above, I re-read the data and identified emergent codes. These were codes that emerged during analysis that were important to the research questions, but outside the pre-determined typological codes. In this section, I explain how typological and
inductive analyses were used to analyze the data sources within each of my research questions. This information is also described in my Data Analysis table (see Appendix G).

**Typological analysis for research questions 1 & 2.** I first used typological analysis to answer research questions one and two, “How do two fifth grade science teachers implement an engineering design activity”; and “How do these same two fifth grade science teachers’ instructional practices change as they implement the same engineering design activity for a second time the following academic year”. In the first step of typological analysis, I used the pre-determined codes in three areas: science content connections, core engineering principles and science and engineering practices. These codes were pre-determined using the literature on engineering design. For science content connections, I coded for scientific concepts, scientific patterns, and scientific principles. The core engineering principles, I coded for were: (a) systems; (b) modeling; (c) specifications and constraints; (d) optimization; and (e) trade-offs. For science and engineering practices, I coded for: (a) defining problems; (b) developing and using models; (c) planning and carrying out investigations; (d) analyzing and interpreting data; (e) using mathematical and computational thinking; (f) designing solutions; (g) argumentation; and (h) communication. Additional information is also described in my Pre-determined Codes table (see Appendix H).

Codes explicitly labeled by the teachers during their instruction were coded first. For example, if a science content connection was stated by the teacher with a concept label (i.e. anemometer, force, electricity, etc.) during her instruction, then that section of the data was coded with “explicit science content connection – concept”. A second level of coding followed to identify implicit references that were made to the code, meaning the teacher did not label the concept of the engineering practice, analysis, but still discussed analyzing the effectiveness of...
student designs. The process was the same for all of the pre-determined codes. An example of the process is shown in the data set represented below in Figure 3.1. The codes are shown below highlighted in either blue or yellow. The blue codes identify implicit references to the pre-determined codes. The yellow codes reference explicit pre-determined codes. The supporting data follows the code in different highlighted colors according to code. In this example, gray represents the engineering practice of analysis; light green represents the core engineering principle of improve; dark green represents the engineering practice of defining problems; and teal represents science content connections.

![Figure 3.1. Coding with Pre-determined Codes](image)

In the third step, I reviewed the data by typological code and analyzed each code separately to look for main ideas and supporting excerpts. An example of a main idea that emerged for science content is the scientific concept of force. Another example of a main idea that emerged for science content is the scientific pattern of the ‘angle of the blades affect how much wind you
catch’. Additional examples of science concept codes can be found in Appendix I and additional examples of scientific pattern codes can be found in Appendix J. The fourth step was to analyze main ideas across typological codes for patterns. Some examples of patterns that were identified include: most of the science content that was integrated by the teachers was in the form of concepts; some of the science content connections were in the form of patterns, but these were not pointed out explicitly as patterns; and no formal principles were made known to students during any of the lessons during either year. These patterns were used in later stages of the analysis to identify themes.

**Inductive analysis to answer research questions 1 & 2.** While completing typological coding using the pre-determined codes, emergent codes were discovered. Thus, after completing my first series of coding, I re-coded searching for emergent codes using inductive analysis. Emergent codes arose in one major area, instructional practices important for engineering design. Sub-codes included within the instructional practices important for engineering design were troubleshooting, brainstorming, questioning, real-world connections, engineering design process, and materials discussions. Troubleshooting was defined in my study as procedures to identify what is wrong with a design. Brainstorming was defined as procedures to come up with ideas for different solutions to solve a problem during a design activity. Questioning included questions asked by the teacher to understand and guide student thinking and choice during a design activity. Real-world connections included teacher connections made during the design activity that ties to the real-world in a way that will help the students better understand things about the design activity. The materials code was defined as properties of materials important to the success of a design. Additional supporting data excerpts of the emergent codes can be found in Appendix K.
Typological analysis for research question 3

In order to answer research question 3, I employed typological analysis on the final interview and written reflections. Typological analysis was conducted using the pre-determined codes from my teacher instructional change conceptual framework. Guskey (2000, 2001) identified three interacting influences on the process of teacher change: change in teacher classroom practices, change in student outcomes, and change in teacher’s attitude and beliefs. These influences served as the pre-determined codes during my analysis for research question 3 (What factors do the teachers identify as to why their teaching practice changed?).

After categorizing the factors that teachers identified as to why they did or did not change from the final interviews into pre-determined codes, the data was re-read for patterns. The patterns were analyzed and themes of the teachers’ change in practice were identified. Chapter 4 elaborates on the findings and themes identified during this analysis.

Written reflections. I analyzed the written reflections after the observational and interview data to search for both confirming and disconfirming evidence (Hatch 2002). Examples of patterns or themes that emerged from the analysis of the written reflections included the importance of open-endedness and explicit connections, the value of the engineering design process, and the improving phase in design activities.

Strengths and Limitations

The major strength as well as the major limitation of this study was my prolonged engagement and observation of four years in the research setting. The strength in this is that it allowed me to more deeply understand the broader context as well as the teachers involved in my study. The limitation in the prolonged engagement is that it moved me from an outside observer to a more of an insider. In order to minimize the effects of my position of “an insider” in this
study, I worked to take multiple measures to increase the trustworthiness of my findings. The first measure to increase trustworthiness was to gather multiple sources of data (Hatch, 2009). In my study, I conducted classroom observations using both field notes and audio recordings. I also conducted a final interview as well as monthly written reflections to capture my participant’s voices (Merriam, 2009). A second measure to increase trustworthiness was that the analysis of this data was analyzed through an iterative process (Lincoln & Guba, 1985). My data analysis was iterative in two ways: (a) observation field notes and audio transcriptions were coded to identify changes in practice that served to guide the interview; and (b) written reflections were analyzed after the observational and interview data to search for both confirming and disconfirming evidence (Hatch 2002). The last measure that I took to increase the trustworthiness was that I checked all interpretations with the teachers by member checking throughout the research process (Lincoln & Guba, 1985).

**Summary**

In this chapter, I explained my research methods as a qualitative exploratory case study. This framework lent itself well to research questions in that it helped uncover the instructional practices of two elementary science teachers as they implemented engineering design over a two year period and provided an understanding of what factors the teachers identified as to why their instructional practices changed. In this study, I collected three sources of data: observation field notes and audio transcripts, a final interview, and written reflections. Two types of data analysis were used including typological analysis with pre-determined codes and inductive analysis with emergent codes. In Chapter 4, I present the findings of my study that emerged through analysis of the data.
Chapter 4: Findings

This chapter describes real teachers struggling with real reform efforts as they tried to make learning relevant and real for their students. The findings in this chapter details the emerging themes that can be used to answer my research questions:

1) How do two fifth grade science teachers implement an engineering design activity?
2) How do these same two fifth grade science teachers’ instructional practices change as they implement the same engineering design activity for a second time the following academic year?
3) What factors do the teachers identify as to why their practice changed?

The observations, interviews, and reflections of Sara and Leslie have been synthesized to provide an overall description of how two teachers new to engineering and engineering design implemented an engineering design activity for the first time; and how their practices changed as they enacted the same activity again during a second time the following year. As the two teachers integrated the unit into their science classroom, commonalities in their implementation emerged that might provide valuable insight for teachers and teacher educators as we move to implement engineering and engineering design into the K-12 curriculum. Thus, the findings in this chapter will focus on the instructional actions, as well as the changes in those instructional actions, that Leslie and Sara had in common.

This chapter is organized using the themes that emerged in my study. This chapter is divided into three major sections. The first section explains both teachers’ backgrounds including: their teaching story, their philosophy of teaching, and their feelings about change. The second section explores their teaching practices during the engineering design activity during year one and a description of changes from year one to year two. This section is organized by the
following themes that addressed research questions 1 and 2: opportunities for explicit connections; instructional disposition, management and strategies important in design; questions that guide process or probe for explanation; and design as a conduit for exploration of materials.

The last section describes the factors the teachers identified as to why their practice changed. This section is organized around the following themes: students as the primary driver of teacher change in practice; Teaching experience changes practice; and, professional development can empower changes in practice.

Sara

Sara grew up in Goodward and went to Goodward City Schools. She had been teaching for 26 years, all of those years at Goodward. She had taught everything from kindergarten to fourth grade; this was her first time teaching 5th grade. Her undergraduate degree was elementary education with a K-8 certification and her Master’s degree was in educational foundations. Sara described herself as a person who always loved kids. However, she explained in her interview that she NEVER [emphasis added] wanted to become a teacher, because she so frequently felt so disconnected to her own teachers while in school.

“I always loved kids and kids loved me. Even when I was a teenager, I would have a big following of younger kids all around me. When I was in high school, I started a babysitting business and was quickly booked three months in advance. In a year, I had saved $1,000 even though I only charged $1 an hour. However, I NEVER wanted to be a teacher. In school, I always felt disconnected from most of my teachers. I hate to say it, but I felt as if mostly they weren’t very smart people and I couldn’t understand why so many of them didn’t get me. When I went to college, I thought I was going to be a
pediatric nurse, until I realized that kids died. That was the end of that, so I had to figure out what else I might do. That’s when I decided to become a teacher” (Sara, int, 6-25-13).

Sara pointed out these past experiences made her a teacher who was “student-focused” (Sara, int, 6-25-13). She explained being student-focused meant she “teaches kids, not worksheets” (Sara, int, 6-25-13). She continued saying she was not the kind of teacher who did the same thing every single year. She did not “go to her file drawer and pull out the same exact lesson that she had taught for the last 10 years” (Sara, int, 6-25-13). She prided herself on being the type of teacher who “reflects and improves her teaching every day and every year” (Sara, int, 6-25-13). Sara explained that in her 26 years of teaching, she always tried to start with where her kids were and figure out how to get them where she wanted them to be.

In a written reflection, Sara’s passion was strongly felt when she wrote, “I want my students to have EVERY opportunity that is POSSIBLE open to them, and I want to HELP open up those POSSIBILITIES for them!!” (Sara, yr 1, refl 2, Nov. 2012). When asked how she felt about change, Sara responded she “loved change” (Sara, int, 6-25-13). She explained one of the reasons she loved teaching was every day and every lesson was different. She said it best when she said, “Teaching is all about change…changing lives one child at a time” (Sara, int, 6-25-13). In summary, Sara saw herself as a student-focused, reflective teacher who embraced change.

Leslie

Leslie grew up on a farm about an hour from Goodward. She came to teaching as a second career and had been teaching for 11 years. She had taught two years at a neighboring school and had been teaching at Goodward for the last 9 years. Her undergraduate degree was also in elementary education and she had just finished her Master’s degree in curriculum and instruction with a focus on inquiry education. Like Sara, Leslie exclaimed that she had NO
intention of becoming a teacher. She continued by explaining she went to a local college to study nursing, but after a semester she knew nursing was not for her.

“So, 14k in debt I went to a community college in town and started studying computers.

For a couple of years, I worked three jobs: programming, at my parent’s farm, and also at their bakery. One day I was standing in a store line with my mom and I blurt out that I think I am going back to school to become a teacher. Three years later, I walked into my very own classroom” (Leslie, int, 6-25-13).

When asked about her philosophy of teaching, Leslie expressed she wanted to make a difference. Leslie explained that she thought that her own struggles in life helped her understand her student’s better and how from her own experiences she realized the importance of people who care about you.

“I know life isn’t easy, and some of my students have really hard lives. More often than not, the kids who are the hardest in class are the ones who have no support at home. They only have us here at school to care about them. It is important to have people in your life who care and support you” (Leslie, int, 6-25-13).

When asked about her feelings about change, Leslie described herself as an “old dog” and it is “hard to teach old dog new tricks”. She continued by saying she “adapts… if she has to”.

“I don’t prefer change. As they say, it’s hard to teach old dog new tricks. When a new principal comes in and says, hey, now we are going to do this, I almost have a heart attack. But, I do adapt when I need to and in time can often see the value in those changes, especially if I believe it’s the right thing to do for my kids” (Leslie, int, 6-25-13).
In summary, Leslie saw herself as a teacher who wanted to make a difference in her students’ lives. Even though Leslie expressed resistance to change, she was always willing to try something for the good of her students.

**Teaching Engineering Design in Year 1**

Even though engineering content and practices were new to Sara and Leslie, they were open and even excited to try it out in their classrooms. Of the 12 teachers involved in the project, Sara and Leslie were the only two teachers to implement the *Designing Windmills* EiE unit in this first year. Sara described it as “jumping in with both feet” (Sara, int, 6-25-13). Both teachers taught the unit during the last month of school before summer break. They allotted two weeks for the unit and extended their science time to a full hour for each of the ten days of instruction. Both teachers were provided with the *EiE Designing Windmills* teacher guide and a full kit with all of the supplies that were necessary for the activities. They were not given professional development on this unit. In the following sections, the teaching of the engineering design activities are described according to the themes that emerged during data analysis.

**Theme 1: Opportunities for explicit connections.** An explicit connection is when the teacher labeled and explained the relationship between a science or engineering concept, process, or strategy to the engineering design activity. The *Engineering is Elementary (EiE)* curriculum is explicit that its purpose is not to teach science, rather to teach engineering and engineering design. The developers of *EiE* from the Boston Museum of Science do not intend *EiE* to replace science curriculum but to supplement them by adding in engineering and engineering design. Because of this clear purpose, it is up to the individual teacher to make connections between the *EiE* unit and her science classroom. During an *EiE* unit, there are numerous opportunities a teacher could take for making explicit connections: to science, to science and engineering
practices, and to the real world. The connections Sara and Leslie made in their first implementation are discussed below.

During the first experience implementing *Designing Windmills*, both Sara and Leslie made four kinds of explicit connections: 1) to the engineering design process (EDP); 2) to the core engineering principle of optimization; 3) to student’s prior knowledge through real world examples; and, 4) to science content.

When connecting to the engineering design process, both teachers repeatedly had students define the problem that needed to be solved, explained the purpose of the windmill, and emphasized that the students were trying to create and test a solution to their problem. In the following teaching moment, Leslie reviewed the engineering design process (EDP) and used this to introduce their design task for the day.

Leslie: So, what is the engineering design process?

Student: What you use to solve a problem

Leslie: Good. What is the purpose when using the engineering design process?

Student: To make a technology that solves the problem.

Leslie: Perfect. So, we have defined our problem. We need to make a windmill that lifts weights. You have made a plan. So, now you’re going to create your solution or your design (Leslie, yr 1, trans 5-17-12, p. 7, lines 138-144).

Both teachers had posters in their rooms of the *EiE* EDP and constantly referred to the poster. Both teachers repeatedly asked students where they were in the EDP process. This EDP process was used to frame the work in which the students were engaged throughout each part of the engineering design unit. In the teaching moment below, Sara explicitly talked to a group of
students about the engineering design process not being a one-time process, but a continual process.

Sara: When you came up, I asked you where you were in the EDP, and also whole bunch of questions, and you went back and you reworked it using the engineering design process. And then you came up with something else. I asked some more questions and each time, what happened to your windmill?

Student: It lifted a little more weight.

Sara: OK? So, is it a one-time process? Or do I need to continually go through the different steps of the EDP?

(Sara, yr 1, trans 5-23-12, page 2, lines 54-60)

In addition to making explicit connections to the EDP during the lessons, both teachers made connections to the core engineering principle of optimization. In the EiE unit, optimization is called ‘improve’. In this sample teaching moment, Leslie reminds the students as they were designing their windmills, every one of them had needed to improve their designs. She also connected what the students were doing to the work of real engineers.

“I like what Abi said over here. She said there were lots of things you had to think of when you built your windmill. How many of you the first time you tried it, it was perfect? Perfect? You didn’t go back; you didn’t go back to the drawing board? It was perfect. If you wanted to go take it to a toy company, they would say alright? No, I think everybody went back. I think Anthony and, if I’m wrong, I think the first time Anthony and, and was it Reggie? OK. Their windmill lifted 3 washers, and the next time they lifted 6 washers and then you made it even better and what happened? It lifted 25 washers. So that was kind of interesting. They realized, they kept trying to improve.
Students iteratively worked on improving, or optimizing, their designs. Both teachers helped their students to figure out how to make their designs more effective. Sara and Leslie asked questions, gave suggestions, and pointed out successful designs of other students in order to stimulate ideas for how students could improve their windmills. This can be seen in the teaching moment described below; as Sara helped a group of students improve their design.

Sara: What did you change?
Student: I changed the tissue paper because it was too weak.
Sara: You thought the tissue paper was too weak? Okay. Interesting. All right. Let's see what happens here. Okay. So here – tell me what you observed. What happened? One, it's probably not heavy enough so we'll put – let's put some more weight in it, right? What else? What did you notice about your dowel rod?
Student: It got pushed back.
Sara: It started to go back. So you need to do what? How do you need to improve?
Student: We need to stop it from moving back

(Sara, yr 1, trans 5-25-12, p. 16-17, lines 467-476).

A third connection was providing real-world examples that connected students’ prior knowledge to the design of the windmills. A good example of this was when Sara asked her students about what types of things they knew could ‘catch the wind’. The students’ examples included such things as: kites, pinwheels, airplanes, balloons, paper, and flags. Most of Sara’s students had never seen a sailboat or a windmill, but they had seen the things on this list, things
that could ‘catch the wind’. Another example of this connection to the student’s real world can be seen in this next teaching moment, in which Sara tries to give the students an idea of the size of the blades of a wind turbine. When Sara asked how big was 100 yards, no students raised their hands.

Sara: Wind turbine blades can be 100 yards long. How many of you can tell me something else that is 100 yards long? [No student hands are raised].

Sara: How long is a football field? [No student hands are raised].

Sara: A football field is 100 yards long. So, wow! The blade of a wind turbine can be as long as a football field. Okay? That’s big (Sara, yr 1, trans 5-16-12, p. 4, lines 68-74).

The lessons of both Sara and Leslie were filled with frequent questions and examples that connected what the students were learning to things they knew about from their real world.

The fourth area where both Sara and Leslie made explicit connections was science content. In the following teaching moment, Sara pointed out that energy was the ability to do work and that the students wanted to catch the wind’s energy in order to do the work of lifting weights.

“It’s not catching the wind, is it? OK. So, let’s think about yesterday. Remember, the whole point of the windmill is it has to catch and harness the wind in order to do work. What is energy? It is the ability to do work, right? So, we want to harness the wind’s energy in order to do the work, to lift the weights” (Sara, trans. 5-23-12, p. 10, lines 237-241).

Like Sara, Leslie made an explicit connection to the science concept of energy. In the teaching moment below, Leslie questions her students in order to help them figure out that the windmill uses the wind’s energy to spin.
Leslie: Tell me what a windmill is. Kristi?

Kristi: A machine with blades that spin.

Leslie: Yep. How does it spin? Malachi?

Malachi: Energy.

Leslie: What kind of energy? Where does that energy come from? Anthony?

Anthony: The wind.

Leslie: Wind. There we go. OK. A windmill uses the wind’s energy to turn, to spin

(Leslie, yr 1, trans 5-22-12, p. 3, lines 23-34).

In summary, it is not surprising that both teachers made explicit connections to the engineering design process or to improving student designs. The EiE curriculum places a heavy emphasis on both of these areas. However, it is interesting that both teachers took them on so completely and used the EDP to guide and direct the students’ processes during every part of the engineering design activity. In an email reflection after teaching the unit for the first time, Leslie talked about the value of the engineering design process in that it provides a guide to support more student-directed learning.

“We as teachers, sometimes feel as though we need to fill our students' brains with facts, information, and the right answers... however, learning through "working it out" may be a more beneficial attribute in the learning process. I like the engineering design process in that it allows more student involvement and investigation on the part of students rather than teacher direction. Students can use the engineering design process as their guide for more independence in their own learning”. (Leslie, yr. 1, refl 7, June 2012)

In a second email reflection, Sara said that one of her favorite parts of the EiE unit was the improve phase. She talked about how infrequently students were expected to go back and
improve something they had produced either in school or at home. She thought that having students improve their design was a wonderful way to incorporate a skill or an attitude that would help her students in life; that it could build persistence so they didn’t give up as easily when things got hard (Sara, yr. 1, refl 7, June 2012).

Although the EiE curriculum did emphasize the EDP and improving the design, it did not emphasize making real-world connections or science content. These are two areas that both Sara and Leslie added in to their teaching of the EiE Windmills unit. The two science concepts elaborated in the sections above of wind is a form of energy that makes the windmill’s blades spin and that wind energy could be used to do work were the only two science connections made during year one of teaching the EiE Windmills unit. Even though the connections to science content were limited, real world examples were interwoven frequently throughout the unit. When asked why she made such explicit real-world connections in an interview, Leslie and Sara both talked about the limited experiences of their students. They expressed that their students had very little experience with creating real objects and little to no experience with things like windmills or sailboats. They explained that these examples allowed students to connect things they hadn’t experienced to things they knew in their own real world (Leslie, int, 6-25-13; Sara, int, 6-25-13).

**Theme 2: Instructional disposition, management and strategies important in design.**

Along with the opportunity for making explicit connections that add to the depth of student learning in an engineering design activity, there are important dispositions, management, and strategies that are needed to support effective instruction in engineering design. These dispositions, management approaches and teaching strategies include: comfort-level with open-endedness and the possibility of multiple solutions; system for the management of materials and supplies; and facilitation of brainstorming and troubleshooting. Leslie and Sara did not appear
uncomfortable with the open-endedness when observing their classroom instruction. During the design activity, both teachers frequently pointed out that there were no right answers, that there were lots of ways to solve the problem and build an effective windmill. For example, in the introduction to the windmill activity, Leslie asked her students, “Is there one way to build a windmill? Then, continued by telling her students that this might be one of the only times in school that there was not a “right answer” (Leslie, yr 1, trans 5-14-12, p. 2, line 7), that there were lots of right answers. Sara expressed very similar views to Leslie. In an email reflection, Sara wrote about the value of open-endedness for her students.

“When you start the engineering design process, you start by asking questions. You have an open discussion; you give students a problem and let them figure out where they want to go. They kind of take it in their own direction, so that they can get to their end product. They struggle with the asking questions and deciding how to figure out a good design. But the whole open-ended process is good for our kids; it’s probably one of the only times in school that there’s not one answer, a right answer” (Sara, yr 1, refl 7, June 2012).

A second important instructional management approach was when facilitating engineering design the teachers needed a system for management of materials and supplies. During the first year of teaching the EiE unit, Sara and Leslie did not formalize a system for managing materials. Materials were placed on a table in the back of their rooms and student groups were allowed to go and get what they needed when they needed it. Lots of materials were used by the students and lots of materials were wasted by groups as the students were not made accountable for their choices and use of materials.

Two additional instructional strategies emerged as important for facilitating engineering design activities: brainstorming and troubleshooting. Students must engage in these activities as
they seek to create the most effective solution to a design challenge. Sara and Leslie both explicitly labeled the process of brainstorming, but were not observed actively facilitating it. They put students into groups and told them to brainstorm ideas. They asked them to draw pictures of the groups’ ideas on their paper. They asked the students to decide which design they wanted to build. In all cases, the students did as they were told by drawing the design they wanted to build, then drawing a second design to meet the teacher’s expectations. Even when the students were questioned by the teacher or other students, a group tended to stick with their first design. Neither the teacher nor the students appeared to know how to get ‘unstuck’ and use the brainstorming phase to open up new possibilities.

Compared to brainstorming, both teachers more actively facilitated troubleshooting. Leslie and Sara asked questions to help their students solve their problems. In the teaching moment below, Leslie helped students troubleshoot things that weren’t working with their designs. She didn’t use the term troubleshooting. Instead, she used the word ‘problem’.

Leslie: So, your blades aren’t turning. What do you think the problem is?
Student: They’re not catching the wind.
Leslie: What can you do to solve that problem? Why don’t you think about putting some more material on them to help your blades catch more wind? (Leslie, yr 1, trans 5-24-12, p. 21, lines 233-236).

In summary, both teachers remained open to multiple solutions and projects with no one right answer. Neither teacher had a system for the management of materials. Additionally, neither teacher actively facilitated brainstorming or explicitly labeled the process of troubleshooting.

**Theme 3: Questions that guide process or probe for student explanation.** The next theme to emerge was that teacher questioning could be used to guide students through the design
process or to probe into student thinking about their design choices. In year one, Sara and Leslie asked questions that were very directed in helping students solve their design problems.

Questions like, “Why isn’t your windmill catching the wind?”, “What’s the problem?”, or “Why do you think it’s not working?” were heard repeatedly during the design activity. Additionally, numerous suggestions were also provided by the teacher to students as they were having design problems: “Is it working? I think you might need to make your blades bigger, so they can catch more wind.” or “So, what’s the problem? I think your dowel rod is not moving easily against the milk jug; you need to make it looser.” Table 4.1 shows examples of questions that were asked by Sara and by Leslie in year one.

Table 4.1

*Example Questions Asked by Sara and Leslie in Year 1*

<table>
<thead>
<tr>
<th>Examples of Questions Asked</th>
<th>Sara</th>
<th>Leslie</th>
</tr>
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<tbody>
<tr>
<td>• What is going to catch the wind?</td>
<td>• Is it working? I think you need to fix the…</td>
<td></td>
</tr>
<tr>
<td>• Why isn’t it catching the wind?</td>
<td>• What do you need to do to make it work? How about try…</td>
<td></td>
</tr>
<tr>
<td>• Why do you think it is not working?</td>
<td>• Why won’t it move? I think it might be…</td>
<td></td>
</tr>
<tr>
<td>• What do you want to adjust?</td>
<td>• So, what’s the problem? It looks like it might be…</td>
<td></td>
</tr>
<tr>
<td>• Is your sail big enough?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• What’s the problem?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• What do you see your materials doing?</td>
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</tbody>
</table>

Much of the interaction between teacher and student during a design activity is in the form of teacher questions-student responses. Both teachers’ questions engaged students in a dialogue about their designs. However, in year one, most of the questions were more directed and did not ask students to explain their thinking or defend their choices in their designs.
Theme 4: Design as a conduit for exploration of materials. Design activities emerge as a valuable conduit for exploration and discussion of properties of materials. Leslie and Sara asked students about the properties of the materials throughout the design activity. They asked students about the sturdiness, size, and shape of the materials they chose for their windmill blades. In the teaching moment below, Leslie questioned a group about their choice of materials and the properties of those materials chosen.

Leslie: So, tell me what materials you chose to make your blades out of.
Student: cardboard.
Leslie: Okay, why did you choose cardboard?
Student: It seemed to be light but strong.
Leslie: So, you chose the cardboard because it was light and strong?
Student: Yes, when we built the blades we thought about size, shape, and especially if it was strong enough. (Leslie, yr 1, trans 5-24-12, p. 32-33, lines 386-392).

Much of the interaction between students in their groups as well as between teacher and student groups was in discussion around properties of materials. Design as a conduit for valuable exploration of properties of materials has not previously been mentioned in the existing literature.

Summary of Teaching in Year One

As Leslie and Sara navigated a new instructional strategy, they had to figure out not only new content and processes, but how to integrate this strategy into their classroom instruction in a way that taught science more effectively. They knew that the EiE curricula did not explicitly teach science content and that it was their job to figure out how to both implement and integrate it most effectively. As they implemented engineering design as an instructional strategy for the
first time, the engineering design process as defined by *EiE* provided an organizing framework for both the teacher and the students. The EDP was used to structure and guide the learning during the design activity. Additionally, the engineering principle of optimization, or improve, provided a driving focus during the design activity. In effect, the driving purpose was to make a design that was better and better over iterations of design improvements. Both teachers created a learning environment that supported open-endedness in the design activity. Additionally, Sara and Leslie facilitated discussions of the properties of materials and asked questions throughout the design activity to help students solve their design problems. In the next section, I describe the changes that were made in Sara’s and Leslie’s teaching of the engineering design unit during year 2.

**Teaching Engineering Design in Year 2**

Leslie and Sara were excited to teach the *Designing Windmills* unit again. They felt positive about using this type of instruction in their classrooms. During learning team meetings, Sara and Leslie vocally advocated for the inclusion of engineering design instruction in science to the other 5th and 6th grade teachers in the district. They shared stories of student engagement, the benefits to struggling learners, and making science more real for students. Both Sara and Leslie presented at educator conferences about engineering design experiences in the science classroom. The following sections explore the commonalities between Sara and Leslie and their teaching of the windmills unit using the same themes as was detailed for year one.

**Theme 1: Opportunities for explicit connections.** During the second experience of implementing the *EiE Designing Windmills* unit, both Sara and Leslie continued to make explicit connections to the engineering design process (EDP), to the core engineering principle of optimization, to student’s prior knowledge through real world examples, and to science content.
Except for connections to science content, the other areas of explicit connections that were
continued from year one looked very much the same as what was observed during the first
implementation of the *EiE Designing Windmills* unit. Thus, in this section, I provide description
of the commonalities new in this second year as compared to the first year of implementation.
Both teachers made many more science connections through both science concepts as well as
scientific patterns. In addition to the increased science connections, Leslie and Sara made
explicit connections to math content, to the science and engineering practices of modeling and
argumentation, and to the core engineering principle of modeling and systems.

In the second implementation of the *EiE Designing Windmills* unit, both Sara and Leslie
made many more explicit connections to science content in terms of both concepts and patterns.
Throughout the design activity in year 2, both teachers constantly gave explanations and asked
questions to students concerning definitions of science concepts as they related to the designing
of windmills. In the teaching episode below, Leslie asked a student to define friction which was
taught in a previous unit. She proceeded to point out to her class possible issues with friction in
the designing of their windmills.

Leslie: Friction. We heard that word before. Rashawn, what is friction?
Rashawn: When two things rub together?
Leslie: Good. Friction is a force when two things are rubbed together. What do we need
to watch out for with friction in the design of our windmills? Aniya?
Aniya: That the dowel rod isn’t rubbing again the milk jug.
Leslie: Good. Let’s get back to designing our windmills. (Leslie, yr 2, trans 6-6-13, p. 4,
lines 22-27)
Other examples of making explicit connections to science concepts can be seen in the teaching moments of Sara when she told the students that they were “going to capture the wind energy, and convert that wind energy into mechanical energy, so that the blades and dowel would spin and lift the weights in the attached bucket” (Sara, yr 2, trans 6-11-13, p. 9, lines 148-152) or when she asked the students what could wind energy be used for, and the students answered to make electricity (Sara, yr 2, trans 6-12-13, p. 2, lines 74-75). In year one, explicit connections were made only to the concepts of work and energy. In year two, explicit connections were also made to the science concepts of force, energy transformation, renewable energy, friction, and electricity. When asked why she had made explicit connections to many more science concepts in year 2, Leslie proclaimed that she realized that the first time she taught the unit she actually taught very little science. She went on to reflect that it was surprisingly easy to feel as if you are teaching science when you are simply using science vocabulary words or doing a hands-on activity (Leslie, int, 6-25-13).

In addition to including many more science concepts, both teachers made connections to emerging scientific patterns during the design of the windmills. All of the patterns that emerged during the EiE instruction were related to the scientific pattern that ‘the greater the force, the more quickly an object will speed up’. This pattern or the supporting observations were not explicitly pointed out to students. In the teaching moment below, Sara was working with a group as they tested their windmill. During this moment, two observational patterns were discussed: 1) the less weight of an object, the more the object will speed up, and 2) the less friction of an object, the more the object will speed up.

Student: It is important for your blades to not be too heavy.

Sara: Why is that important?
Student: You get more speed.

Sara: You get more speed because you have less what?

Student: Weight.

Sara: Less weight? Yes, that’s right.

Sara: And you can also get more speed if you have less…

Student: Friction?

Sara: Yes, that's right. You get more speed when you have less friction

(Sara, yr 2, trans 6-13-13, p. 19, lines 488-499).

In year two, three additional patterns emerge: 1) number of blades affects how much wind you can catch; 2) surface area of blades affect how much wind you can catch; and, 3) angle of blades affect how much wind you can catch. Neither teacher explicitly labeled any of these as patterns to the students during the engineering design activity.

Two other areas in which Leslie and Sara made explicit connections in year 2 was in science and engineering practices and core engineering principles. Specifically, they made explicit the practices of modeling, mathematical thinking, and argumentation, as well as the core engineering principles of models and systems. Both teachers began to use the word ‘model’ and ‘modeling’ for the student’s work in designing the windmills. They frequently asked student to look at the model of their windmill and to consider their windmill as a system. Both teachers made some connections to math content by showing the relationship of symmetry and also of surface area to the effective design of windmill blades.

Both teachers facilitated a teaching moment that included the science and engineering practice of argumentation. They had the students make a claim and provide evidence for their claim. Both teachers facilitated other students to agree and provide further evidence or disagree
and make a counter-claim with supporting evidence. In the teaching moment below, Sara has set up a scenario that she has given them a pinwheel and they take that pinwheel outside into a field. She tells them they can hardly wait to watch it spin. She adds to the story by saying that they could “feel the wind brushing your hair against your face, your pants and skirt and your shirts are blowing in the wind” (Sara, yr 2, trans 6-10-13, p. 13, lines 485-489). She proceeds to tell the students that when they go to watch their “pretty pinwheel that your teacher gave you, you are deeply saddened because it's not working” (Sara, yr 2, trans 6-10-13, p. 13, lines 496-497). After setting the stage with this story, Sara asked the student to provide a scientific explanation of why their pinwheel was not working.

Malachi: I claim the wind is not blowing on the pinwheel.
Sara: Because the wind is not blowing on the blades, and you're basing that on?
Malachi: My evidence is that the pinwheel is too low and the wind is not being able to hit it.
Sara: Because it's too low? Okay. Okay. Brea? Agree or disagree?
Sara: I claim he is wrong because -
Brea: I claim he is wrong because if you have the pinwheel a little bit up from the - above the grass and the grass is moving it means the pinwheel should be.
Sara: Okay. So now give me an explanation as to why the pinwheel's not working. He says - he said the reason why it's not moving is because the wind isn't blowing that far down there. Okay. Come on, Michael, tell me.
Michael: I claim the pinwheel is not moving because the wind is not hitting it at the right angle (Sara, yr 2, trans 6-10-13, p. 14-17, lines 532-567).
This teaching moment continued with students agreeing and disagreeing as well as providing evidence for their claims and counter-claims. Sara ended this argumentation activity by pulling out common themes that emerged in the student’s discussions. She pointed out that angle and direction of the wind was very important to the movement of a pinwheel and that angle and direction of the wind would also be very important for their windmills.

Making explicit connections emerged as important over the two years of teaching the engineering design activity. At the end of the second time teaching the EiE unit, in an interview, Sara explained that just because her students were low SES and lacked prior knowledge didn’t mean they couldn’t get it. She continued by saying that this lack of opportunity and knowledge meant that she needed to make sure they got it. She described the need to create and find other ways to make sure her students were able to get the knowledge they needed. She finished by explaining, “We need to help them make explicit connections, explicit connections to content and explicit connections to processes” (Sara, yr. 2, refl 14, June, 2013).

In Leslie’s interview, she talked in particular about making changes based on whether things worked or not. Leslie talked about how she did “a poo-ey job” in year one on making connections to science content because her students didn’t do such a good job on the final assessment. This forced her to change in year two and make more explicit connections to science, so she could make sure her students learned more (Leslie, int, 6-25-13).

**Theme 2: Instructional disposition, management and strategies important in design.**

During the second time of the teachers’ implementation of the EiE Designing Windmills unit, both teachers continued to be comfortable with the open-endedness and the possibility of multiple solutions in a design activity. The changes in the instructional management and strategies in year two were: 1) both teachers created a system for the management of materials
and supplies and 2) both teachers began to use the term ‘troubleshooting’ when helping their students solve problems in their designs.

In year 2, both Sara and Leslie created systems for management of materials. Groups of students had to get their designs and list of materials approved by the teacher before going to get their materials. If during the process the students needed more materials, they had to give a reason and get approval from the teacher for use of additional materials. Both Sara and Leslie pointed out in their interviews that this way of managing materials reduced waste and forced students to have good reasons for the need of more materials.

In year two of Sara’s and Leslie’s teaching of this design unit, they both continued to explicitly talk about brainstorming, but did not actively facilitate it (as in year one). However, in year two both teachers began to explicitly label efforts to solve the problems in a design as ‘troubleshooting’. In this teaching moment below, Sara asks a student to troubleshoot the problem that they were having with their design.

Student: It's lighter.

Sara: It's lighter. Okay. Well, but see what happens. Okay. So tell me – troubleshoot for me.

What's the problem that you're running into? (Sara, yr 2, trans 6-12-13, p. 17, lines 117-119).

Like science content as well as science and engineering practices, troubleshooting became an explicitly labeled process in year two in both teachers’ instruction. When asked why the term ‘troubleshooting’ was explicitly used in year two, neither teacher could answer specifically why they started using the term. However, both Sara and Leslie explained that through the experience gained by having taught the engineering design unit previously, it was obvious to them that much of the instructional time was spent solving problems with student designs. Thus, they explained
that it made sense to them in year two to label the process, so that students understood more clearly what they were trying to accomplish.

**Theme 3: Questions that guide process or probe for explanation.** In year two, Leslie and Sara continued to ask lots of questions. However, the types of questions that were asked pushed students to explain their reasoning and defend the choices of their designs. The questions asked by Sara and Leslie in year 2 drove deeper levels of student explanation. Questions that asked students to explain their thinking were frequently heard. Questions like, “Explain to me your reasoning of why you made your blades that way?” were typical in year two. Table 4.2 shows examples of questions that were asked by Sara and by Leslie in year two.

Table 4.2

*Example Questions Asked by Sara and Leslie in Year 2*

<table>
<thead>
<tr>
<th>Types of Questions Asked</th>
<th>Sara</th>
<th>Leslie</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• Explain to me your reasoning of why you made your blades that way.</td>
<td>• What material did you choose?</td>
</tr>
<tr>
<td></td>
<td>• What problem are you running into?</td>
<td>• Why did you choose that material?</td>
</tr>
<tr>
<td></td>
<td>• Why do you think that is happening?</td>
<td>• Tell me your thinking on the choices of your design.</td>
</tr>
<tr>
<td></td>
<td>• So, troubleshoot for me…what is happening? Why do you think that</td>
<td>• I notice your blades are…Why did you do that? Tell me about your</td>
</tr>
<tr>
<td></td>
<td>might be happening?</td>
<td>reasoning behind those choices.</td>
</tr>
<tr>
<td></td>
<td>• What do you think needs to change? Tell me why you think that.</td>
<td>• So, are you catching the wind? Why aren’t you catching the wind?</td>
</tr>
<tr>
<td></td>
<td>• How do you think catching the wind is affected by surface area?</td>
<td>What do you think you need to change?</td>
</tr>
<tr>
<td></td>
<td>• So, troubleshoot for me. As you observe your windmill, tell me</td>
<td>• Tell me about your design and why you chose to use the materials</td>
</tr>
<tr>
<td></td>
<td>what you think is going on?</td>
<td>you chose.</td>
</tr>
<tr>
<td></td>
<td>• What things might you try to fix the problem?</td>
<td></td>
</tr>
</tbody>
</table>
Tell me about the properties of the materials you chose. Why did you make those choices?

What’s the idea here? What’s your thinking?

What did you change? Why did you make those changes?

These questions were much more targeted to get to student thinking than questions that were asked in year one of the engineering design instruction. In year two, the types of questions asked specifically asked students to make explicit their thinking and their choices. These questions drove a much deeper discussion between the students and the teacher.

When asked about the changes in the types of questions asked, Leslie answered that was easy to explain. She identified that it was experience with another curriculum that helped her ask deeper levels of questioning that affected how she now asked deeper questions in any and everything she did.

“In the other curriculum we use, deep levels of questioning are used. The Seeds of Science, Roots of Reading (SSRR) curriculum gives question prompts and as I used them, I realized how well they worked to drive students’ thinking to deeper levels, so I started using that strategy in everything I do in my class” (Leslie, int, 6-25-13).

Additionally, when I asked Sara about her changes in making her questioning more open-ended, she replied that she didn’t know why she made those changes. Sara went on to say that she guessed it came from her experience as a teacher.

“Wow, I don’t know. I guess it was my teaching experience. After I taught the unit the first time, I realized that the purpose was to give students freedom to create, and that it was my questioning that could drive my kids’ thinking” (Sara, int, 6-25-13).
Theme 4: Design as a conduit for exploration of materials. Leslie and Sara continued to engage students in discussions of materials throughout each of the lessons. In addition to discussions of the properties of materials, they also discussed criteria of effective materials. In the teaching moment below, Sara talked to her class about criteria that could be used to determine the effectiveness of materials.

Sara: Your sails are going to be extremely important when you construct your windmills. What are some of the key points that we learned about materials when we constructed those? What do we need to think about to choose materials that are most effective?

Student: Make sure that they’re not too heavy.

Sara: Okay. What happens if it is too heavy?

Student: They wouldn’t move.

Sara: What – what else did we find was important about materials to make them more effective in catching the wind?

Student: They had to be big enough to catch the wind. They had to have a good amount of surface area. (Leslie, yr 2, trans 6-13-13, p. 33-34, lines 768-775).

When asked about the changes in how they talked about materials in year two, both teachers again pointed to the experience they gained teaching the unit for the first time. Because neither of them had taught using engineering design as an instructional strategy, they did not realize the importance of materials. However, after trying out this type of instruction once, it made sense to both of them that generalizing the discussion to criteria of effective materials versus just properties of materials was a good idea. Sara explained in her interview that her students had very little experience ‘messing with’ materials to build for a purpose. That she thought that the experience with materials provided students great real world experiences that she could use when
she taught other things in her science classroom (Sara, int, 6-25-13). In her interview, Leslie explained that she thought being able to judge the criteria of the effectiveness of ‘anything’ was a valuable skill and one that could be practiced through engineering design.

**Summary of Changes with Experience**

The changes in Leslie’s and Sara’s practice from years one to two included: more connections to science content in terms of concepts and patterns; more explicit links to modeling, systems, argumentation, and troubleshooting; more open ended questioning that drove student explanation; and deeper discussions of materials including criteria for effective materials. Table 4.3 summarizes the findings for Sara’s and Leslie’s teaching practices in year one and two. Important areas of change are in bold, italicized font.

Table 4.3

*Changes in Teaching Practice from Year 1 to Year 2*

<table>
<thead>
<tr>
<th>Category</th>
<th>Year 1</th>
<th>Year 2</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Science Content</strong></td>
<td><em>Little science connections – two examples related to energy</em></td>
<td><em>Lots of science connections – Force, Work, Energy, Friction, etc.</em></td>
</tr>
<tr>
<td>Concepts</td>
<td><em>No emerging patterns</em></td>
<td><em>Emerging patterns</em></td>
</tr>
<tr>
<td><strong>Science Content</strong></td>
<td><em>Implicit modeling and systems</em></td>
<td></td>
</tr>
<tr>
<td>Patterns</td>
<td>Explicit optimization (called Improve)</td>
<td>Explicit optimization (called Improve)</td>
</tr>
<tr>
<td>Core Engineering</td>
<td><em>Implicit developing and using models</em></td>
<td><em>Explicit developing and using models</em></td>
</tr>
<tr>
<td>Principles</td>
<td>Explicit Defining Problem</td>
<td>Explicit Defining Problem</td>
</tr>
<tr>
<td></td>
<td>Implicit specifications and constraints</td>
<td>Implicit specifications and constraints</td>
</tr>
<tr>
<td></td>
<td>Missing trade-offs</td>
<td>Missing trade-offs</td>
</tr>
<tr>
<td><strong>Science &amp; Engineering</strong></td>
<td><em>Explicit Defining Problem</em></td>
<td><em>Explicit Defining Problem</em></td>
</tr>
<tr>
<td>Practices</td>
<td><em>Implicit developing and using models</em></td>
<td><em>Explicit developing and using models</em></td>
</tr>
<tr>
<td></td>
<td>Explicit Plan &amp; create investigations</td>
<td>Explicit Plan &amp; create investigations</td>
</tr>
</tbody>
</table>
Why Change?

The commonalities in what Sara and Leslie identified as factors of why they changed their teaching included: their students, their teaching experience, and the professional development with the university. In the following sections, I describe each of these factors in terms of the themes that emerged during data analysis for my third research question: What factors do the teachers identify as to why their practice changed?

Theme 1: Students as a primary driver of teacher change in practice. Both Leslie and Sara identified their students as a primary reason why they changed their teaching practices. In her interview, Sara said that her students strongly impacted whether she changed.
“My students probably play the biggest part of whether I make changes or not in my teaching. As a teacher, I have to try to see things through my kids’ eyes to understand how they view and feel about learning. I have to know where they are, where I want them to be, and how do I bridge that gap; how do I get them to where they need to be. I change my teaching from year to year and even class to class based on the students who are in my room. I have to adjust based on a class or even a student’s learning style, their behavior, or their ability. I don’t teach ‘the packet’; I teach kids and that requires constant adaption, constant change if I want to truly meet their needs and help them to learn”
(Sara, int, 6-25-13).

Leslie also stated that her students were the main reason she made changes in her teaching. Leslie stated that she changed to adapt to her students’ needs.

“Well, it worked or it didn’t work. And, if it didn’t work, I change it. I adapt to the needs of my kids. I want my students to feel successful, to feel important. I want to affect each student’s world. To do this, I have to change my teaching if something isn’t working. I change depending on how my students respond to the learning activities. For instance, my morning class this year is very aural, so I include more listening and talking activities for them. In my afternoon class, they are more tactile so I make sure I keep them moving. I think that most of the changes I make in my class are driven by the needs and actions of my students” (Leslie, int, 6-25-13).

At first glance, Sara and Leslie both pointed to their students as a primary driver of their change in practice. However, with a deeper level of analysis differences began to emerge. Sara referred to understanding where her students were affectively, cognitively, and also in terms of their behavior. She specifically described “seeing things through her kid’s eyes” as well as adjusting
her teaching due to her students’ ability and behavior. On the other hand, Leslie focused mostly on judging whether a teaching activity worked based on the behavior of her students. Additionally, her hoped for outcome was an affective one for her students; she wanted them to “feel important”.

**Theme 2: Teaching experience changes practice.** As a second reason why they changed their teaching, Sara and Leslie both pointed to their teaching experience as another major factor for their change in instructional practice. Sara explained that her experience as a teacher led her to make either intuitive or decided changes.

> “You know, I have been teaching for 26 years, which gives me a bank of experience to draw upon and helps me know when change is necessary. I have had lots of experiences to be able to observe my students and know if students understand or if they are struggling. I pay close attention to not only the grades on the test or quiz, but also to how they are interacting in class and how they are responding emotionally to the challenges. I use these things to know when to make a change. Sometimes those changes are conscious and sometimes I guess intuitive” (Sara, int, 6-25-13).

Leslie talked about experience as her greatest teacher from a different angle than Sara. Leslie described the learning she gained through trying out specific teaching strategies or curriculum and seeing how they worked. She identified that sometimes the use of one curriculum impacts what she does in a different curriculum. Leslie gave the example of the *Seeds of Science/Roots of Reading (SSRR)* curriculum, in which there is a strong emphasis on content literacy and scientific practices like argumentation. She explained that experience with these strategies allowed her to transfer those strategies to other parts of her science and math instruction, because they worked so well with her students.
Once again, Leslie’s and Sara’s answers are very similar but in digging deeper differences can be found. Sara talked about how she considered student learning, as evidenced by grades, as well by their classroom behaviors, to figure out what was working and what needed to change. Leslie talked about experience being her greatest teacher in a much more concrete manner. As Leslie tried instructional strategies and if they were successful, she changed her teaching based on this learning.

Theme 3: Professional development can empower changes in practice. Both Leslie and Sara gave credit to the professional development with the university as empowering of their change in teaching practice. Sara thought the professional development with the university was one of the most effective and empowering experiences that she had been involved in during her teaching experience.

“Overall, most of the professional development that I have been in has been a waste. I sit there and I don’t get anything out of it: it doesn’t give me more background knowledge; it doesn’t make my teaching better; it doesn’t give me something I can take back to my class and use. Probably one of the most effective and empowering PDs that I have been in was the work I did with the university these last couple of years. That PD helped me get deeper science knowledge of what I am teaching and improved my instructional skill; and it really helped my confidence as a teacher. I felt valued by the university team; that I was smart and that I was a reasonably good teacher. I loved the collaboration with the university and the other teachers. For the first time, we were a team. It has definitely made me a better teacher” (Sara, int, 6-25-13).

Leslie also pointed to the professional development with the university as valuable. She explained that she had not been involved in much PD, previous to the university PD. She talked
about the value of the PD in that it forced her into the role of a learner. Leslie discussed how much she gained in both her own learning as well as gains in her understanding of how her students must feel during difficult learning activities. She came through the PD understanding her students better, especially their feelings of frustration and success and felt empowered to become a more effective teacher.

“Before the university PD, my PD involvement was pretty minimal. The university PD was really good in that it put me in the role of a student. I gained deeper knowledge, but also understood feelings of frustrations and successes that my students feel. It made me remember the challenges of being a student. The university PD was empowering, because it not only put the teacher in the student role but had good outcomes. It improved my teaching skills and knowledge; it helped me improve student learning” (Leslie, int, 6-25-13).

Both teachers considered the professional development from the university valuable and empowering. Sara talked much more about the value of the structure of the professional development. Specifically, she talked about how the PD allowed her teacher expertise to be valued and how control of learning was shared among teachers and University researchers. On the other hand, Leslie talked more about the value of the PD in terms of mechanisms. The teacher-as-learner workshops and the professional learning community were PD mechanisms that Leslie found valuable. She appreciated learning more herself, and especially, understanding her students better due to the PD.

The factors identified by Leslie and Sara for why they changed their teaching practice are not single or simple answers, but a complex interaction of multiple factors: student, teacher, and professional development. The teaching behaviors and the changes in teaching behaviors of both
Leslie and Sara during the engineering design activity were remarkably similar. Additionally, their reasons for change were remarkably similar. However, the underlying reasons for each of the factors of teacher change held notable differences when comparing the two teachers.

In conclusion, the findings presented in this chapter address my research questions and give insight into supporting teacher reform and changes in teacher practice. During the first year of implementation of the engineering design activity, the engineering design process served to organize the instruction and learning. Additionally, the instructional strategies of brainstorming, troubleshooting, questioning, and materials discussions emerged as important in engineering design instruction. During the second year of implementation, both teachers made many more explicit connections to science concepts and patterns as well as connections to engineering principles and practices. In addition, teachers’ questions caused students to explain their thinking and defend their choices in their design solutions versus just helping them solve their design problems. As can be seen by these examples, the experience gained by the teachers with engineering design instruction supported a deepening of implementation over the two years. When asked why they changed, both Leslie and Sara pointed to the same factors: students, teaching experience, and professional development. In the next chapter, I present the discussion and implications of these research findings as well as recommendations for future research.
Chapter 5

Discussion, Implications, and Conclusions

In my dissertation study, I sought to answer these research questions: (a) How do two fifth grade science teachers implement an engineering design activity; (b) How do these same two fifth grade science teachers’ instructional practices change as they implement the same engineering design activity for a second time the following academic year; and (c) What factors do the teachers identify as to why their practice changed? The analysis of my data helped to develop understandings about these three research questions, which will be discussed in the following section of this chapter. First, I discuss the findings in terms of opportunities for explicit connections, instructional dispositions, management approaches, and strategies important in design, questions that guide process or probe for explanation, and design as a conduit for exploration of materials. Then, I discuss the findings in terms of students as a primary driver of change in practice, experience in teaching changes practice, and professional development can be empowering for changes in practice. In addition, I make connections between my findings and the literature; reflect on the limitations of this research study; and finally consider the implications of these findings on policy, practice, and educational research.

Discussion

For my first research question, “How do two fifth grade science teachers implement an engineering design activity?” I came to four understandings based on the findings of this study. First, in the initial implementation of the engineering design activity, both teachers made explicit connections to the engineering design process, to the core engineering principle of optimization, to students’ prior knowledge through real-world connections, and to science content. The engineering design process emerged as an organizer of the learning activities for both teachers...
and students. The EDP provided a common language and a common process. Second, there were two instructional strategies that emerged as important during the engineering design instruction: brainstorming and troubleshooting. Brainstorming was explicitly labeled by the teachers, but not actively facilitated. Troubleshooting was actively facilitated, but not explicitly labeled. Third, questioning also emerged as a critical practice for teachers to use during an engineering design activity. In year one, teacher’s questions helped students solve their design problems. Finally, exploration of properties of materials played a major role in engineering design activities. Teachers and students discussed the properties of the materials that were used in the student designs.

For my second research question, “How do these same two fifth grade science teachers’ instructional practices change as they implement the same engineering design activity for a second time the following academic year?” I came to four understandings based on my findings. First, both teachers’ practices changed by making many more connections to science content. Science connections were made to both scientific concepts (i.e. force, work, energy) and to scientific patterns (i.e. greater force=quicker things speed up). In addition, both teachers increased making explicit connections to science and engineering practices. Some examples of the science and engineering practices included in year two were: modeling, connections to mathematical concepts, and argumentation. Second, both teachers’ practices changed in that they began to explicitly label the process of troubleshooting. The teachers asked students to “troubleshoot” their problems in order to create better functioning designs. Third, with more experience, both teachers asked types of questions that facilitated student explanation. Specifically, the questions forced students to explain their thinking and defend their design choices. Finally, both teachers’ practices changed, by not only discussing properties of materials,
but exploring and discussing criteria of effective materials. Teachers led students to analyze what makes a material the best one for the job it needs to perform in a design solution.

Three understandings emerged from the findings for my third research question, “What factors do the teachers identify as to why their practice changed?” First, both teachers identified students as a primary driver of their change in teaching practice. The teachers changed or didn’t change based on how their students reacted to lessons, what they thought their students needed in order to learn more, or how to help their students feel successful. Second, both teachers identified their own experience as a great teacher. It was their experience in teaching, with students or with specific instructional practices that allowed them to decide if they needed to change or not change. Third, both teachers identified the professional development with the University as empowering. The teachers described it as empowering in that it valued their teacher expertise through shared collaboration or allowed them to take the role of learners in order to understand their students better.

At first glance, the factors identified by Leslie and Sara appear practically the same in that they identified the same three or four factors as to why they changed. However, differences emerged with deeper analysis. Leslie focused strongly on her change in teaching practices as based on an affective “it worked or it didn’t work” (Leslie, int, 6-25-13). She tied her change to her students’ behaviors and their feelings of success and importance. She most certainly wanted students to learn, but cognitive gains were not the primary factor for her reasons for change. Leslie felt the professional development from the University was valuable. She focused on the mechanisms of the PD as most empowering in that it helped her understand her students better (an affective teacher outcome).
On the other hand, Sara focused on changing her teaching practices based on the cognitive, affective, and behavioral influences of her students in making decisions of whether to change or not. She described her practice of reflection and her lengthy teaching experience as important in knowing when to make these change decisions. Sara described the PD with the University also as valuable and empowering, but focused on the structural aspects of the PD. She emphasized the collaboration of the PD, and a feeling that her expertise as a teacher was valued. Figure 5.1 summarizes the influences identified for both Leslie and Sara. The influences that appear in bold were influences directly identified by the teacher. The influences that are grayed did not emerge as important in my study.
Figure 5.1. Factors Influencing Teacher Change: A Comparison of Leslie & Sara
Figure 5.1 demonstrates an interesting profile of each teacher and the influences that emerged as important in the reasons they identified as to why they changed. Both Leslie and Sara emphasized all three factors of change suggested by Guskey (2000, 2001) including teacher practices, student, and professional development. It was in the influences of the factors that the two teachers differed. In the teacher factor, Leslie talked about affective and teacher practice influences; Sara described all three influences within the teacher factor. Within the student factor, once again Leslie described the importance of the affective and learner behavior influences; and Sara once again talked about all three influences within that factor. Finally, in the professional development influence, Leslie focused on the mechanisms of the professional development and Sara identified the structures of the professional development as having the greatest influence. In the next section, I tie my findings back to the existing research. This section is organized into two parts: discussion of engineering design in the K-12 science classroom and discussion of teacher change in practice.

**Engineering design in K-12 science classroom**

The research that currently exists on teachers’ implementation of engineering design in the K-12 science classroom is sparse (Brophy, Klein, Portsmore, & Rogers, 2008; Crismond, Lo, & Lohani, 2006). This exploratory study sought to begin to expand this research base. Opportunities for explicit connections, instructional disposition, management and strategies important in design, questions that guide process or probe for explanation, and design as a conduit for exploration of materials are four themes that can inform the implementation of engineering design instruction in the K-12 science classroom. The minimal research that does exist demonstrates teachers’ struggles with engineering design in terms of unknown content, unfamiliar practices, and not being comfortable with the open-ended nature of engineering
design (Brophy et al., 2008; Kimmel, Carpinelli, & Rockland, 2007; McGinn & Roth, 1998). My study did not address what teachers knew about engineering design, but instead looked at their teaching practices and the changes within those teaching practices. As stated in Chapter 1, the research demonstrates that many teachers are uncomfortable with the open-endedness and possibility of multiple solutions during design activities (Brophy et al., 2008; Kimmel, Carpinelli, & Rockland, 2007; McGinn & Roth, 1998). My findings do not support this research. Both teachers relied heavily on the engineering design process as a guide even during the first year of implementation. My findings demonstrated that both teachers structured and supported the view of engineering design as an open-ended, iterative process (Atman et al., 1999; Crismond et al., 2009). Additionally, the research conducted by Brophy et al. (2008) found that teachers are not comfortable teaching content that they do not understand and will often avoid teaching this unknown content. The teachers involved in my study did not avoid teaching the engineering design activity even though they did not know the content. Perhaps, the engineering design process provides a way to access and approach the unknown content of engineering and engineering design. The EDP gives teachers a structure to depend on as they are learning about engineering and engineering design.

Both teachers spent instructional time helping students troubleshoot problems in their designs. Crismond and Adams (2013) discussed the importance of troubleshooting for students during a design activity, specifically the need for teachers to help focus students on what is going wrong in their designs. They suggested a four step process for troubleshooting that should be actively facilitated by teachers: observing, diagnosing, explaining, and fixing (Crismond & Adams, 2013, p. 76). This process should be an explicit and intentional process for students to engage in when they are creating and testing a design solution (Crismond & Adams, 2013). As
the teachers involved in my study gained more experience with engineering design, they
approached the level of “informed designers” (Ahmed, Wallace, & Blessing, 2003, p. 32).
Informed designers are better at identifying issues in designs as compared to beginning designers
(Ahmed, Wallace, & Blessing, 2003; Crismond et al., 2006). This was observed with the
teachers’ facilitation of troubleshooting in my study; they were able to help students more
effectively in troubleshooting during the second implementation of the engineering design
activity. The primary means for facilitation of effective troubleshooting was through deeper
levels of questioning that asked students to explain their thinking and defend their designs.

In addition to troubleshooting, brainstorming also emerged as important in engineering
design. The research shows that beginning designers have a tendency to fixate on the first design
they come up with and have trouble considering other possibilities (Crismond et al., 2006). The
teachers in my study did not actively facilitate brainstorming. Students were simply instructed to
brainstorm and were left to complete the assigned task on their own. Thus, what was observed
was that students more often than not made a single design and could not be swayed to consider
other options.

Another area that emerged in my research was that design allowed for discussions of
properties of effective materials. The research on students’ understanding of materials suggested
that classifying materials based on what they are made of, and of comparing properties of
materials, can be difficult for elementary-school students (Russell, Longden, & McGuigan,
1991). In addition, elementary-school students may have limited understandings or hold
misconceptions about the origins or transformations of materials (Russell, et al., 1991). My study
demonstrated that teachers and students engage in discussions about properties of materials and
criteria for effective materials. Thus, engineering design provides a potential conduit to address
the gaps shown by the research on elementary students’ limited understandings concerning materials (Russell, Longden, & McGuigan, 1991).

In summary, my research adds to the limited research base on teachers’ implementation of engineering design in the upper elementary science classroom. This study demonstrated that as these teachers first implemented engineering design instruction into their classrooms, there were numerous missed opportunities and a lack of explicit connections. However, the engineering design process (EDP) did provide a valuable framework to organize the instructional and learning activities. THE EDP provided a common language and a common process for teachers and students. Additionally, four strategies or approaches to engineering design instruction emerged as important in year one: brainstorming, troubleshooting, questioning, and materials discussions. With experience, these teachers made many more explicit connections to science concepts and patterns and to engineering principles and practices in year two. These teachers also more actively facilitated questioning to drive student explanation, discussion about the properties and criteria for effectiveness of materials, and explicitly engaged in troubleshooting to solve design problems.

**Teacher change in practice**

The literature on teacher change identified a focus of the relationship between teacher beliefs (affective factor) and teacher practices (Green, 1971; Guskey, 2000, 2001; Franke, Fenam, & Carpenter, 1998; Novak & Knowles, 1992; Powell & Birrell, 1992; Raths, 2001; Richardson, 1996, 2003). Additionally, it has been found that beliefs are heavily dependent on past and present experiences (Novak & Knowles, 1992; Powell & Birell, 1992). Richardson (1996) identified three sources of teacher beliefs: personal experience, school and teaching experience, and experience with content and pedagogical content knowledge (p. 913). Both Sara
and Leslie pointed to the role of experience in their decision to change or not change. Sara talked more about her school and teaching experience; she said that her 26 years of teaching experience helped her know when change was needed. She explained this by saying that sometimes those decisions were intentional, and other times were intuitive. Leslie talked more about experience with content and pedagogical content knowledge; specifically, she talked about her experience with one curriculum influencing what she did in another curriculum. One example she gave was transferring what she learned about the facilitation of argumentation in the *Seeds of Science/Roots of Reading* Curriculum to her instruction in the engineering design unit.

The research on teacher change enabled through professional development suggests that effective PD should allow teacher expertise to be valued and that control of learning should be shared among teachers, researchers, and professional developers (Richardson, 1994b). This was illustrated in my study by Sara, as she found the professional development from the university empowering in that it valued her expertise as a teacher. Additionally, the research on teacher change caused by PD confirms that teachers learn best when the pedagogy of the PD requires teachers to be active and learn in ways that is reflective of how they should teach their own students (Borko & Putnam, 1997; Darling-Hammond & McLaughlin, 1999). This is exactly the reason Leslie gave in my study for the value of the University PD; it allowed her to be a learner again.

The role of the student in driving teacher change is surprisingly quiet in the literature. The conceptual framework for my study provided by Guskey (2000, 2002) described the process of teacher change as complex interactions among three interconnected variables: change in teacher classroom practices, change in student outcomes, and change in teacher’s attitude and beliefs (p. 231). Teachers need to be able to see that an instructional practice has immediate
impact on student learning outcomes. Moreover, it is the experience of successful implementation and the results of such efforts that ultimately transform teacher’s attitudes and beliefs. Both teachers identified students as a primary driver of their change. Sara referred to understanding where her students were affectively, cognitively, and also in terms of their behavior. She specifically described “seeing things through her kid’s eyes” as well as adjusting her teaching due to her students’ ability and behavior. Leslie focused primarily on judging whether a teaching activity worked based on the behavior of her students. Leslie’s hoped for outcome was an affective one for her students; she wanted her students to “feel important.” Leslie and Sara were both self-defined “student-focused” teachers. Greensfeld and Elkod-Lehman (2006) demonstrated that the interaction between student and teacher was central to change in teacher practice. The major conclusion of this study by Greensfeld and Elkod-Lehman (2006) was that teachers, who identified themselves as more ‘student-oriented,’ participated more frequently and actively in professional development and made more changes in their teaching practice.

Two additional studies are informative for my study. Both of these studies looked at the types of changes that teachers made as they were implementing new instructional practices (Abkus & Hand, 2012; Adamson, 2013). Abkus and Hand (2012) showed that teachers’ implementation levels of new practices gained through professional development differed, but all teachers showed an improvement in the skill of questioning first. Both Sara and Leslie greatly improved in questioning from year one to two. Their questioning evolved into the type of questioning that drove student explanation in that they were asked to explain their thinking and defend their choices. The second study, conducted by Adamson (2013), showed that all teachers in the study, regardless of grade level, consistently identified similar strategies to promote
science learning: making connections to prior knowledge, making real-world connections, engaging in hands-on activities (p. 567). However, none of the teachers reported more sophisticated inquiry strategies such as designing original science investigations, making predictions or hypotheses, asking questions that could be answered using science experimentation, or using models to construct explanations. This was definitely reflected in the implementation of the engineering design instruction for both Leslie and Sara. The first year of their implementation was focused on connections to prior knowledge, real-world connections, and engineering design through a hands-on activity. During the second year of implementation, both teachers moved toward more sophisticated engineering design and science strategies: modeling, argumentation, and deeper troubleshooting.

Overall, this study contributes to research about teacher change in practice by re-conceptualizing teacher change as a system of interacting influences that is a dynamic and complex (Chapman & Heater, 2010). It recognizes that transformation requires shifts in multiple factors and influences (Kegan, 1994). These systems of teacher change are considered “interdependent and reciprocally influential” (Opfer & Pedder, 2011, p. 379). This interdependence and reciprocity means that to consider teacher change as a system, “one must consider what sort of local knowledge, problems, routines, and aspirations shape and are shaped by individual practices and beliefs” (Opfer & Pedder, 2011, p. 379). In my study, both teachers identified all three factors from my conceptual framework as affecting their change in practice: teacher, student, and professional development. Using the factors that the teachers identified as to why their teaching practice changed provides insight into the complexity of factors involved in change. My study demonstrated that teacher change in practice is not an isolated event, but is a complex interaction of influences. Furthermore, the study showed that individual teachers
change because of different combinations of factors and influences. Additionally, it illustrated that students do indeed play an important role in whether a teacher changes or doesn’t change.

**Implications**

There are numerous limitations that affect the scope of this study; and it is these limitations that provide opportunities for further research. These limitations include a narrow focus on specific domains within my teacher change conceptual framework, short duration of engineering design instructional episodes, and a focus on two teachers within the same teaching context. With regard to the first limitation, I did not study each domain from my conceptual framework in its entirety. I focused primarily in this study on the teaching practices of the teacher factor in my conceptual framework. This narrow focus was due to the lack of existing research on teacher’s implementation of engineering design, which caused me to choose a focus on the teacher practice domain as an exploratory study. The second limitation was the short duration of each of the engineering design enactments. Each episode was only for a period of two weeks. Extended time or additional episodes could add to our understanding of teacher implementation of engineering design instruction. The third limitation was that my study involved only two teachers from the same teaching context. The teachers taught the same grade, same curriculum, and were at the same school. This brings to question if other teachers in other contexts would respond in similar ways to what was observed in my study.

Each of these limitations suggests next steps for further research in order to add to the research base on engineering design in the K-12 classroom. Continuing to study teacher implementation of engineering design longitudinally will add to our knowledge and allow us to understand continued teacher implementation trajectories. Additionally, conducting studies in different contexts will add to our understanding of how these implementation trajectories are
similar or different in a variety of settings. Research on what teachers know and learn about core engineering principles and science and engineering practices would be beneficial to the field. Furthermore, research that looks more closely at the instructional strategies like brainstorming, troubleshooting, and questioning that emerged in this study would be worthwhile. In terms of teacher change, research that considers teacher change as a system is much needed. We must move past viewing teacher change as an event and toward viewing teacher change as a system of interacting factors and influences. Additionally, research that looks at the interaction between and among factors and influences of teacher change would be immensely valuable.

In addition to the implications for research, this study has implications for policy and practice. This study helps to inform policy as we move towards implementation of the Next Generation Science Standards (NGSS), which includes engineering design as an explicit instructional strategy. Engineering design is new to K-12 classrooms and teachers. Most teachers have not been trained in the content or processes related to engineering an engineering design. Thus, this study also helps to inform practice for both in-service and pre-service education. For in-service education or professional development, this study helps to inform how to support implementation of engineering design instruction. The engineering design process is an important guiding framework that helps to organize student learning even as teachers are navigating a new curriculum and new strategies. Additionally, instructional strategies important in design can be supported by professional development: brainstorming, troubleshooting, and probing questioning strategies.

This study also informs pre-service education. Teacher education programs at colleges and universities serve as the foundation of the teaching profession. It is critical that the best practices of teaching be discussed and modeled at the earliest stages of the development of the
teaching professional. As we are moving into new science standards, these new instructional strategies and practices play an important role in the development of a new teacher, one who is prepared for the teaching that is required for preparation of students for the 21st century. Furthermore, this study has implications for supporting teacher change in practice and understanding that teacher change is a system of interacting influences. We must take this into account when planning professional development, pre-service education programs, and how to enable and support reform efforts.

Conclusion

My research was a qualitative case study of the implementation of engineering design in the upper elementary science classroom over two years, and how two teachers’ instructional practice changed over the two years of implementation. Data from observations, reflections, and a final interview were collected from the two participating teachers. Data were examined to discern themes that emerged to address my research questions. My first two research questions were: “How do two fifth grade science teachers implement an engineering design activity?” and, “How do these same two fifth grade science teachers’ instructional practices change as they implement the same engineering design activity for a second time the following academic year?” For research questions one and two, four themes emerged in my findings: (a) opportunities for explicit connections, (b) instructional disposition, management and strategies important in design, (c) questions that guide process or probe for explanation, and (d) design as a conduit for exploration of materials. My third research question was “What factors do the teachers identify as to why their practice changed”? For my third research question, three themes emerged in my findings: (a) students as the primary driver of change in practice, (b) teaching experience changes practice, and (c) professional development can empower changes in practice.
The findings in this research study provide insight and implication for supporting engineering design instruction in the science classroom. In order to support implementation of engineering design instruction, my research suggests we should: (a) prepare teachers to use the engineering design process as a way to organize engineering design instruction; (b) prepare teachers to make explicit connections between the hands-on design activity and science and engineering content and practices; and, (c) prepare teachers to facilitate the instructional strategies of brainstorming, troubleshooting, probing questioning, and discussions about materials.

The findings in this research study also provide insight and implication for supporting teacher change in practice. This study helps to inform educational reform. In order to understand and support teacher change, my research suggests we should: (a) recognize teacher change is supported by interacting factors and influences; (b) recognize that students play a primary role in whether teachers change or don’t change; and, (c) recognize that individual teachers may change in similar ways, but the underlying reasons for their change may be very different. Thus, in order for educational reform efforts to be successful, we must consider all of the factors and their influences that can support a change in instructional practice. Additionally, we must build in supports in as many of these areas as possible in order to make the needed changes in our educational system a reality for our students.
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Appendix A

Child Assent Form

Child Assent Form for Research
(Ages 8-11 Years)
University of Cincinnati
Department: School of Education: Curriculum and Instruction
Principal Investigator: Kathie Maynard
Faculty Advisor: Helen Meyer, Ph.D.

Title of Study: An Investigation of Effective STEM Curricular Structures and Instructional Strategies

You are being asked to do a learning project. You may ask questions about it. You do not have to say yes. If you do not want to be in this learning project, you can say no.

This learning project might show your teachers and the University of Cincinnati good ways to learn science by using engineering activities in your science class.

About 600 children will take part in this learning project by letting teachers and the University of Cincinnati review their work done in science class. It will take no extra time for you.

- You will take part in regular classroom lessons.
- This will not take any extra time for you.
- Your work will be collected and looked at by your teachers and the University of Cincinnati.
- Your name will be kept private.

If you have any questions you can ask Helen Meyer at 513-556-5115 or email at helen.meyer@uc.edu.

You do not have to be in this learning project. You may start and then change your mind and stop at any time. No one will be upset with you.

To stop being in the learning project, you should tell Helen Meyer at 513-556-5115 or email at helen.meyer@uc.edu.

If you want to be in this learning project, write your name and birthday. If you do not want to be in this learning project, leave the lines blank.

Your Name (please print) ____________________________________________

Your Birthday __________ (Month / Day / Year)

Your Signature __________________________________ Date ___________
Dear Mount Healthy Parent or Guardian,

Your 5th grader will be studying electricity and will be “engineering” a simple electrical circuit using batteries and flashlight bulbs in class in the next few weeks. All 5th grade students will be involved in this unit.

For the last two years, we at the University of Cincinnati, College of Education have been working with your child’s teachers on the science education program at Mount Healthy City Schools. We are interested in learning how to best support teachers in providing interesting and engaging science instruction. In order to do this we need to look at student work to see how kids learn best. We will be conducting a small research study that looks at how well students and teachers understand the work of engineers and scientists and how this helps students learn more science.

We are hoping to get your permission to look at your student’s work that is related to engineering which he or she will do in science class (like in the electricity unit).

In this study, your child will continue learning in their science class as normal. We will only look at work that students are going to do anyway. Student names will not be on the work we are given.

Attached is a permission form. Please sign the form if you agree for your child to participate in this study. If you have questions, please feel free to call or email Kathie Maynard (513-556-2023 or Kathie.maynard@uc.edu) or Shelly Micham (513-378-6559 or s_micham@yahoo.com).
Appendix C

Parent Consent Form

Parent Permission for Child’s Participation in Research
University of Cincinnati
Department: School of Education: Curriculum and Instruction
Principal Investigator: Kathie Maynard
Faculty Advisor: Helen Meyer, Ph.D.

Title of Study: An Investigation of Effective STEM Curricular Structures and Instructional Strategies

Introduction:
You are being asked to allow your child to take part in a research study. Please read this paper carefully and ask questions about anything that you do not understand.

This research is sponsored by the National Science Foundation.

Who is doing this research study?
The person in charge of this research study is Kathie Maynard from the University of Cincinnati. Dr. Helen Meyer will be supporting Kathie Maynard as she studies the process of professional development. Dr. Meyer’s role is to maintain the privacy of your decision for your child to be a participant in the research study. There may be other people on the research team helping at different times during the study.

What is the purpose of this research study?
The purpose of this research study is to pursue the most effective connections among science content, scientific inquiry, and engineering design in upper elementary classrooms (Grades 5 and 6).

Who will be in this research study?
About 600 children will take part in this study. Your child may be in this study if

• S/he is in 5th or 6th grade at Mount Healthy City schools
• S/he will allow their work to be reviewed by the University of Cincinnati

What will your child be asked to do in this research study, and how long will it take?
Your child will be asked to participate normally in class activities and allow the University of Cincinnati to review student work. It will take no extra time for your child.

• You child will take part in regular classroom lessons.
• This will not take any extra time for your child.
• Your child’s work will be collected and looked at by your child’s teachers and the University of Cincinnati.
• Your child’s name will be kept private.
• Your child’s information will be presented as part of the class not as an individual.
Are there any risks to being in this research study?
- The risk for your child’s involvement in this study is no greater than in daily life. It is not expected that your child will be exposed to any risk by allowing their work to be used in this research.

Are there any benefits from being in this research study?
Your child will probably not get any benefit from taking part in this study. But, being in this study may help science teachers understand how to better teach science by connecting engineering activities into the science classroom.

Will your child have to pay anything to be in this research study?
You will not have to pay anything to participate in this research study.

What will your child get because of being in this research study?
Your child will not be paid (or given anything) to take part in this study.

Does your child have choices about taking part in this research study?
If you do not want to take part in this research study you may discard this consent form.

How will your child’s research information be kept confidential?
Information about your child will be kept private by the use of a study participant code on all data gathered from your child. All work from all students in your school will be turned over to the researcher. A copy of the work will be made and all the items will be returned back to the teachers. The researcher will remove your child’s name or other identifiers from the copies and add your child’s study participant code to the data before it is sent on to the research team.

Your child’s information will be kept in a locked file cabinet in a private University office for paper copies of data or in electronic form on password protected computers for the two years of participation. After that it will be deleted from the computers or shredded for paper copies by the PI. The signed consent documents and participants list with code identifier will be kept in a locked file cabinet in my office. In publication and dissemination of the research findings, your child will not be identified by name and results will be reported as class results.

Agents of the University of Cincinnati and the National Science Foundation may inspect study records for audit or quality assurance purposes.

What are your and your child’s legal rights in this research study?
Nothing in this consent form waives any legal rights you or your child may have. This consent form also does not release the investigator, National Science Foundation, the institution, or its agents from liability for negligence.
What if you or your child has questions about this research study?
If you have any questions or concerns about this research study, you should contact Helen Meyer at 513-556-5115 or via email at helen.meyer@uc.edu.

The UC Institutional Review Board (IRB) reviews all research projects that involve human participants to be sure the rights and welfare of participants are protected.

If you have questions about your rights as a participant or complaints about the study, you may contact the Chairperson of the UC IRB at (513) 558-5259. Or, you may call the UC Research Compliance Hotline at (800) 889-1547, or write to the IRB, 300 University Hall, ML 0567, 51 Goodman Drive, Cincinnati, OH 45221-0567, or email the IRB office at irb@ucmail.uc.edu.

Does your child HAVE to take part in this research study?
No one has to be in this research study. Refusing to take part will NOT cause any penalty or loss of benefits that you or your child would otherwise have.

You may give your permission and then change your mind and take your child out of this study at any time. To take your child out of the study, you should tell Helen Meyer at 513-556-5115 or via email at helen.meyer@uc.edu.

Your child will be asked if he or she wants to take part in this research study. Even if you say yes, your child may still say no.

Agreement:
I have read this information and have received answers to any questions I asked. I give my permission for my child to participate in this research study. I will receive a copy of this signed and dated Parent Permission form to keep.

You Child's Name (please print) __________________________________________

Your Child's Date of Birth _____________ (Month / Day / Year)

Parent/Legal Guardian's Signature ___________________________ Date _______
Appendix D

Interview Protocol

Background

1. Tell me about your teacher story.
2. Tell me about your students.
3. Tell me about your school.
4. Tell me about your professional development experiences.

Teacher Change

1. How do you think your teaching changed from years 1 to 2 during the windmill unit?
2. Why do you think those changes occurred?
3. Here is what I saw as changes in your teaching practice from years 1 to 2 using both field notes and audio transcripts... Why do you think those changes occurred?
4. In general, what are reasons you decide to change or not change your teaching?
### Methodology Table - Data Sources and Function in the Research Study

<table>
<thead>
<tr>
<th>Date Collected</th>
<th>Data Source</th>
<th>Function in the Study</th>
</tr>
</thead>
<tbody>
<tr>
<td>5-14-12 – 5-25-12</td>
<td>Classroom Observations</td>
<td>Addresses research questions 1 &amp; 2 (teacher practices in enactment of engineering design in year 1) by providing:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Source for describing teaching behaviors/practices</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Source for identifying changes in teaching behaviors/practices when compared with year 2 observations</td>
</tr>
<tr>
<td>6-3-13 – 6-14-13</td>
<td>Classroom Observations</td>
<td>Addresses research questions 1 &amp; 2 (teacher practices in enactment of engineering design in year 2) by providing:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Source for describing teaching behaviors/practices</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Source for identifying changes in teaching behaviors/practices when compared with year 1 observations</td>
</tr>
<tr>
<td>10-15-11 – 6-14-13</td>
<td>Written Reflections</td>
<td>Addresses research question 1-3 by providing:</td>
</tr>
<tr>
<td>(Monthly)</td>
<td></td>
<td>- Insight into decisions for engineering design instruction</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Insight into possible influencers of teacher change</td>
</tr>
<tr>
<td>6-25-13</td>
<td>Interview</td>
<td>Addresses research question 3 (factors identified by teachers for their change in practice) by providing:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Information concerning what the teachers identified as to why their classroom practice changed.</td>
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</table>
Data Analysis Table (Source, Type of Analysis, and Analysis Steps)

<table>
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<tr>
<th>Data Source</th>
<th>Type of Analysis</th>
<th>Steps in Analysis of the Data Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transcriptions of teacher audio recording during teaching</td>
<td>Typological Analysis</td>
<td>1. Identification of codes using literature on engineering design in the K-12 classroom.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2. Coding data using pre-determined codes.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3. Identify main ideas as well as emerging patterns.</td>
</tr>
<tr>
<td>Inductive Analysis</td>
<td></td>
<td>4. Open coding data to identify emergent codes.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5. Identify main ideas as well as emerging patterns.</td>
</tr>
<tr>
<td></td>
<td>Typological &amp; Inductive</td>
<td>6. Identification of teaching behaviors/practices in years 1 &amp; 2 using both pre-determined codes and emergent codes.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>7. Identification of changes in teacher practice from years 1 to 2 using both pre-determined and emergent codes.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8. Identification of themes.</td>
</tr>
<tr>
<td>Written Reflections</td>
<td>Typological Analysis</td>
<td>9. Coding data using pre-determined codes.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10. Identify main ideas as well as emerging patterns to inform teacher interview.</td>
</tr>
<tr>
<td>Transcriptions of Final Interviews</td>
<td>Typological Analysis</td>
<td>11. Identification of codes using pre-determined codes from my teacher change conceptual framework.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>13. Coding data using pre-determined codes.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>14. Identify main ideas as well as emerging patterns.</td>
</tr>
<tr>
<td></td>
<td>Inductive Analysis</td>
<td>15. Open coding data to identify emergent codes.</td>
</tr>
<tr>
<td></td>
<td>Typological &amp; Inductive</td>
<td>16. Identification of themes for teacher change.</td>
</tr>
<tr>
<td>Written Reflections</td>
<td>Typological Analysis</td>
<td>17. Re-code to look for confirming or disconfirming evidence for themes.</td>
</tr>
</tbody>
</table>
## Appendix G

### Main Ideas for Sub-code of Scientific Concepts in the Science Content Connections Code

<table>
<thead>
<tr>
<th>Science Content Connections – Scientific Concepts</th>
<th>Supporting Data Excerpt</th>
</tr>
</thead>
</table>
| **Force**                                         | SARA: How are windmills powered?  
STUDENT: Air.  
SARA: Air? How?  
STUDENT: They're powered by air.  
SARA: They're powered by air. Can you explain what that means?  
STUDENT: It's a force.  
SARA: It's a force, yeah. And that's a great introduction to the word I want to make sure we - what's a force? Do you know what a force is? Do you know what the definition or a word that we can use to describe what force is? Wind is a force.  
STUDENT: Force is a push.  
SARA: Push. Excellent. It is a push. And sometimes it can even be a -  
STUDENT: A pull.  
SARA: A pull. Yes, sometimes it can be a push or a pull. So wind can act as a force that sometimes can push things along or sometimes we can use it to pull things. Okay?  
(Sara Audio 1, pages 1-2, lines 27-54) |
| **Work**                                          | SARA: How can we distinguish between a good windmill or an effective windmill and one that may be not? What do we want the windmill to do? When the windmills ground grain and when they pumped water, they were all doing -  
STUDENT: Work.  
SARA: Work. They were all doing work, okay? So I want your windmill that you're going to design to do work and the more washers or weight that they can move, the more work they're going to get done. Okay? Does that make sense?  
(Sara Audio 2, page, 8, lines 245-252) |
| **Electricity**                                   | SARA: What are we studying?  
STUDENT: Wind energy.  
SARA: Wind energy. Wind is a type of energy that we do what with? What are some of the things that we talked about that we do with wind energy?  
STUDENT: We can use it to make electricity.  
(Sara Audio 3, page 2, lines 14-20) |
| **Energy**                                        | SARA: So we need to talk about wind is a specific type of -  
STUDENT: Energy.  
SARA: Energy. Okay? And what is energy?  
STUDENT: Ability to do work.  
|
## Energy transformation

<table>
<thead>
<tr>
<th>SARA: So you're going to capture the wind energy, convert that wind energy into mechanical energy, right? Because it's going to spin and pull your bucket and weight up. That makes sense?</th>
</tr>
</thead>
</table>

## Renewable energy

| SARA: Wind is a renewable energy source. Okay? What does renewable mean? So here's another strategy. Do I know - do I just know what it means? Okay. Some of us may. What if I don't? What strategy can I use to help me think through what I'm reading?  
STUDENT: Look it up in the dictionary.  
SARA: I could look it up in a dictionary, but what if I don't have a dictionary? What strategies have we worked on here in class that has to do with that?  
STUDENT: Look at the words around it.  
SARA: Yeah, look at the words around it. Absolutely. Wind is a renewable energy. Let's go back to the other. Wind energy is clean and safe. Do we do anything to create and make wind?  
STUDENT: No. |
|---|
## Main Ideas for Sub-code of Scientific Patterns in the Science Content Connections Code

<table>
<thead>
<tr>
<th>Main Ideas</th>
<th>Supporting Data Excerpt</th>
</tr>
</thead>
<tbody>
<tr>
<td>More blades=Catch more wind</td>
<td>SARA: The more – the more blades, the more wind. Think about what you're saying. The more blades, you're going to get more wind or you're going to – STUDENT: Get less wind. SARA: Are you going to get more wind or are you going to do what with the wind you're going to be able to – STUDENT: Get more wind. The more blades, the more wind it will catch (Sara Audio 2, page 7, lines 202-209)</td>
</tr>
<tr>
<td>More surface area=Catch more wind</td>
<td>SARA: The blades have to be not heavy. What else did we decide? What about the size of the blades? The size of the blades need to be – STUDENT: [INAUDIBLE]. SARA: You can do whatever you want. Absolutely. Well, how do you want to face it? Okay. It's trying to move. How much surface area did you give it to – to catch wind? Not enough. Try the - go back and try. So that's a design change. You started out small surface area. Go to larger and see what happens. (Sara Audio 6, pages 5-6, lines 141-147)</td>
</tr>
<tr>
<td>Angle of blades affect how much wind you can catch</td>
<td>Now I find it interesting – why did you put your sticks inside your Styrofoam at an angle? STUDENT: I don't know. I thought it would catch more wind if the blades were angled. SARA: You thought it would catch more wind if you did it at an angle rather than just straight up and down? Interesting. Well, let's see if that works. Oh, it's fine. Okay. How do you want it to go? Hold it like that. All right. Let's see. There it goes. All right. Really good. (Sara Audio 6, page 6-7, lines 175-180)</td>
</tr>
<tr>
<td>Less weight=More speed</td>
<td>STUDENT: It is important for your blades too not be too heavy. SARA: Why is that important? STUDENT: You get more speed. SARA: You get more speed because you have less what? STUDENT: Weight. SARA: Less weight? Yes, that’s right. (Sara Audio 3, page 9, lines 251-256)</td>
</tr>
<tr>
<td>Less friction=More speed</td>
<td>SARA: And you can also get more speed if you have less… STUDENT: Friction? SARA: Yes, that's right. You get more speed when you have less friction. Very good. (Sara Audio 3, page 9, lines 257-260)</td>
</tr>
</tbody>
</table>
### Appendix I

**Emergent Codes, Definitions, and Supporting Data Excerpts**

<table>
<thead>
<tr>
<th>Emergent Code</th>
<th>Sub-Code</th>
<th>Definition</th>
<th>Data Excerpt Example</th>
</tr>
</thead>
</table>
| Instructional Strategy        | Troubleshooting  | Procedures to identify what is wrong with a design.                                                                                                                                                      | STUDENT: It's lighter.  
SARA: It's lighter. Okay. Well, but see what happens. Okay. So tell me – troubleshoot for me. What's your problem that you're running into?  
STUDENT: [INAUDIBLE].  
SARA: What?  
STUDENT: It faced that way.  
SARA: It's facing that way and it probably should be faced at a different –  
STUDENT: Angle.  
SARA: A different angle. Okay. So go try that and bring it back. Okay? (Sara Audio 3, page 16, lines 443-451) |
| Brainstorming                 |                  | Procedures to come up with ideas for different solutions to solve a problem during a design activity.                                                                                                   | LESLIE: Your job is to - now don’t do this first, because you're going to do the front - you're going to answer those first four questions. That's important. You need to brainstorm ideas for your design. Then on the back you're going to start drawing how would you create this windmill. Okay? All right. First thing, talk in your group. Answer these four questions.  
STUDENT: [INAUDIBLE].  
LESLIE: What?  
STUDENT: [INAUDIBLE].  
LESLIE: No. That one. Why don't you and Michelle work together? That's okay. Don’t touch the material. Okay. So, let's go back here. Where's it at? Have a seat, please. Yes. Okay. So you guys have to talk together. (Leslie Audio 1, page 9, lines 248-269) |
| Questioning                  |                  | Questions asked by the teacher to understand and guide student thinking and                                                                                                                                | LESLIE: So, tell me what you were thinking when you designed your windmill like this?  
STUDENT: We wanted to have big |
choice during a design activity. enough blades to catch the wind.

LESLIE: Why did you choose this material?
STUDENT: We thought it was stiff and light, so would work the best.
LESLIE: Okay so let’s test it out. LESLIE: So, what’s happening? What problems are you running into?
(Leslie Audio 5, lines 378-388, page 13)

| Real-world Connections | Teacher connections made during the design activity that ties to the real-world in a way that will help the students better understand things about the design activity. | LESLIE: A wind turbine’s blades can be 100 yards long. Does anybody know something that big in your daily life?
STUDENT: [INAUDIBLE]
LESLIE: A football field is 100 yards long. How many of you have been on a football field?
(Leslie Audio 1, Lines 7-12, page 1) |

| EiE Engineering Design Process | Improve | An explicit step of the EiE engineering design process that is not clearly represented in the NRC (2011) engineering practices. Improve is an iterative process to go back and make a design better based on what has been learned. | SARA: Why did you change?
STUDENT: I changed the tissue paper because it was too weak.
SARA: You thought the tissue paper was too weak? Okay. Interesting. All right. Let's see what happens here. Okay. So here – tell me what you observed. What happened? One, it's probably not heavy enough so we'll put – let's put some more weight in it, right? What else? What did you notice about your dowel rod?
STUDENT: It got pushed back.
SARA: It started to go back. So you need to do what? How do you need to improve?
STUDENT: We need to stop it from moving back.
(Sara Audio 3, pages 16-17, lines 467-476) |

| Materials | Properties of materials important to the success of a design. | SARA: Your sails are going to be extremely important when you construct your windmills. What some of the key points that we learned about materials when we constructed those?
STUDENT: Make sure that they’re not too heavy.
SARA: Okay. What happens if it |
is too heavy?
STUDENT: They wouldn’t move.
SARA: What – what else did we find was important about materials?
STUDENT: They had to be even.
SARA: Even or balanced. They were symmetrical. What – what kind of problems that you run into? What happened when it wasn't even?
STUDENT: It flopped over.
SARA: Okay. So you actually brought up two points. One, you said it had to be even or symmetrical. But you also said it had – it couldn't be what?
STUDENT: floppy.
(Sara Audio 4, lines 38-52, page 2-3)
Kathie Maynard

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Milford, OH 45150
513-675-3536

Kathie.Maynard@uc.edu

Education
Ed.D. 12/2013  University of Cincinnati, Cincinnati, OH
Department of Curriculum and Instruction: Teacher & Learning:
School Subjects (Science Education)

M.Ed. 05/2007  University of Cincinnati, Cincinnati, OH
Department of Curriculum and Instruction

B. S. 05/1992  Pikeville College, Pikeville, KY
College of Arts and Sciences: Biology & Chemistry

Professional Certifications
State of Ohio: Professional Teaching Certificate 7 - 12 Life Science, 1993 - Present

Areas of Research: STEM education, engineering design in the K-12 science classroom, and
community partnerships for STEM education and career awareness.

Employment History
2009-Present  Academic Director for STEM Research & Community Outreach,
Fusion STEM Education Center, University of Cincinnati

2009-Present  Adjunct Faculty, College of Education
University of Cincinnati

2007-2009  Visiting Professor, College of Education
University of Cincinnati

K-12 Employment
2003-2008  3rd-10th grade Science Teacher (incl. Biology & Chemistry)
Gifted Academy of Greater Cincinnati (for Twice Exceptional Gifted), Cincinnati, OH

1998-2002  Middle Grades Science Teacher
Madeira Junior/Senior High School, Madeira, OH

1997-1998  Middle Grades Science Teacher
Tichenor Middle School, Erlanger, KY

1995-1997  Middle Grades Science/Math Teacher
Escuelas Lincoln, Buenos Aires, Argentina

1993-1995  Middle Grades Science/Social Studies Teacher
Saint Andrews Episcopal School, Jackson, MS
Scholarly Activities

**Refereed Publications**


**Articles Submitted & Under Review**

Israel, M; Maynard, K; Micham, S; Surrette, T. (Under Review). Journal of Research in Engineering Education. Improving diverse learners’ scientific literacy and attitudes about science and engineering.

**Grants Procured**

Ohio STEM Learning Network - (PI) 2013. STEM Regional Professional Development for $28,500.


NSF Noyce TF/MTF Planning Grant DUE-1035262 – (senior personnel) 2010-12. Developing a Master Teacher Training Program for $75,000.

Ohio Board of Regents: Ohio STEM Initiatives – (co-PI) 2010-11. Developing a sustainable STEM network within the SW Ohio region to form new partnerships and local innovations around STEM for $987,000.

Ohio Department of Education – (Senior Personnel and project director) 2005-09. Alternative Educator Licensure professional development. 2 for $268,250.

NSF – Robert Noyce Scholarship Program (Senior Personnel and advisor) 2008-10. Support for STEM career changers for $494,488.

**National and International Refereed Presentations**


Improve Student Science and Math Achievement”; November 2013. (Upcoming Presentation - Already Accepted)

Maynard, K., Castañeda-Emenaker, I. Micham, S., World Council for Curriculum & Instruction: Montreal, Canada., “Partnerships to Support Social Justice for all Learners”; October 2013 (Upcoming Presentation - Already Accepted)

Maynard, K., Micham, S., Castañeda-Emenaker, I. Ethnographic and Qualitative Research Conference; Cedarville, Ohio. “Exploring Literacy Strategies to Improve 5th Grade Students Science Achievement & Attitudes: A Case Study; June 2013.


Fowler, T.W. and Maynard, K.J. (February 2010) Using AAAS Atlas and NSDL to Improve Teacher Content Understanding and Curricular Coherence, NSELA Annual Conf. Phila., PA.

**Regional/State Presentations**


Fowler, T.W & Maynard, K. Developing a STEM Focused Neighborhood School at Taft Elementary School, Ohio RttT Statewide conf., Columbus, OH; Nov. 2011.

**Invited Workshops and Presentations**


Maynard, K. Greater Cincinnati STEM Collaborative: Cincinnati, Ohio. Effects of Engineering Design on Students Science Knowledge & STEM Career Attitudes”; January 2013


Fowler, T., & Maynard, K. Engineering is Elementary - Pilot Professional Development Trainer Workshop (for Boston Museum of Science), Cincinnati, OH; Dec. 2009.
**Paid Consultations**

2011-present  **Co-Director**, Greater Cincinnati STEM Collaborative  
Cincinnati, OH

2012-2013  **Educational STEM Consultant**  
American Association for the Advancement of Science (AAAS)  
Washington, D.C.

2010-2012  **Educational STEM Consultant**  
Boston Museum of Science  
Cambridge, MA

2009-2012  **Educational STEM Consultant**  
Cincinnati Public Schools  
Cincinnati, Ohio

**Courses Taught**

**Graduate Masters Level:**  
Secondary Education Methods: Science  
Science Curriculum  
Effective Instruction in Middle School  
Classroom Management

**Undergraduate:**  
Secondary Education Methods: Science  
Secondary Education Methods: Math

**Professional Service Activities**

Member of the new Ohio Academic Content Standards in Science with a focus on Life Sciences  
Hughes STEM High School, Advisory Board  
Red Team Review RTTT-D Batelle, Columbus, Ohio

**Professional Associations**

Association of Science Teacher Educators (ASTE)  
National Science Teachers Association (NSTA)  
National Science Education Leadership of America (NSELA)  
National Association for Research in Science Teaching (NARST)  
School Science & Mathematics (SSMA)