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Elementary Teachers Committed to Actively Teaching Science and Engineering

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ELEMENTARY TEACHERS COMMITTED TO ACTIVELY TEACHING SCIENCE AND ENGINEERING

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A DISSERTATION

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An Abstract of the Dissertation Presented
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Committed elementary teachers of science and engineering, members of a professional learning community called Collaborative Conversations in STEM, were studied to elicit their perceptions of experiences that influenced their commitment to, and their pedagogical content knowledge of, STEM teaching and learning. The hermeneutic phenomenological interviews enabled the teachers to express their beliefs in their own words. Data analysis employed a theoretical framework that investigated teacher epistemology and knowledge in light of their experiences. Findings revealed a web of lifelong experiences unique to each individual, and evidential of the committed elementary scientist-teachers' present day values, teaching epistemology, lifelong learning, and emotional and intellectual engagement. Scientist-teachers are individuals whose teaching and learning characteristics reflect those of scientists and engineers.

Evidence indicated that no single transformative learning experience resulted in those elementary teachers' commitment to STEM teaching and learning, but recent professional development activities were influential. Formal K-16 STEM learning was not uniformly or positively influential to the teachers' commitment to, or knowledge of, STEM.

Findings suggest that ongoing professional development for STEM teaching and learning can influence elementary teachers to become committed to actively teaching STEM. The Collaborative Conversations in STEM provided intellectual and emotional engagement that empowered the teachers to provide STEM teaching and learning for their students and their colleagues overcoming impediments encountered in a literacy-focused curriculum. Elementary teachers actively committed to teaching science and engineering can undergo further transformation and emerge as leaders.

Key Terms: STEM, committed, elementary teachers, engineering, professional development, professional learning community, experience, hermeneutic phenomenological, science, scientist-teacher.

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Dedication

This dissertation is dedicated to my family. They have loved, encourage and inspired me John R. Opperman, my husband; Peter Paul Radkowski, my father; Julianne L. Radkowski, my mother; Peter P. F. Radkowski, Ph.D., my brother; Paul Opperman, my son; and Lucas and Susan Opperman, my son and daughter-in-law.

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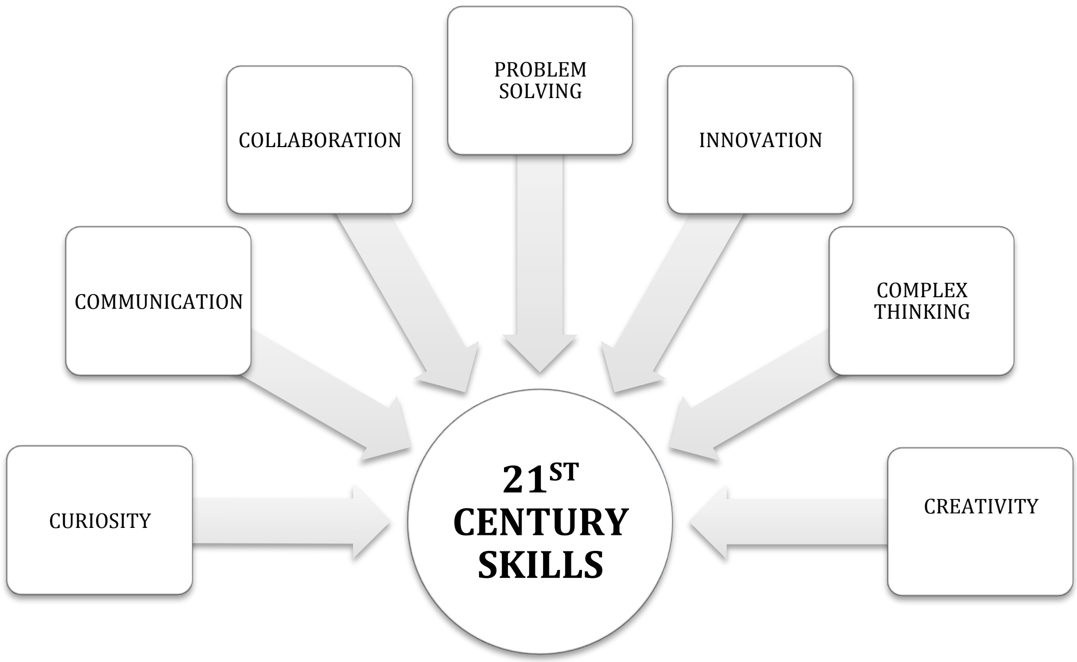
Chapter One: Rationale of the Study

Innovation is a primary driver of global growth and prosperity. Human capital is the source of innovation. Business and government investment in physical capital also supports economic development, but investments in education produce rates of return equal to or higher than returns on physical capital investments (Becker, 1993). Innovation is one of the non-routine cognitive skills essential to the 21st century workforce (Adkins, 2012; Levy & Murnane, 2004). Figure 1 shows a selection of the knowledge and skills needed for economic growth and prosperity (Zhao, 2015). According to the Congress of the United States, investments in human capital require Americans to be equipped with science, technology, engineering and mathematics (STEM) knowledge and skills (2014). Furthermore, education can provide those skills because it increases the innovative capacity of the economy (Hanushek & Wößmann, 2011).

Acquiring the 21st century skills. The required 21st century knowledge and complex thinking skills are acquired in a progression of learning that begins in the elementary school years. Researchers have concluded that to enhance the new basic skills (cognitive, personal, and inter-personnel competencies including complex problem solving, expert thinking, and complex communications) in *all* students, cognitive process practice must begin early and be encouraged throughout each student's education. The National Research Council study, *Taking Science to School,* reported research indicating children have the capability to learn complex reasoning at much earlier ages than previously thought (Klahr, 2005; Wieman, 2012). Furthermore, it is recognized that students develop their life interests at a very early age (Ray & Smith, 2010). While the progression of learning begins before kindergarten, the true manifestation will be seen in an individual's secondary and post-secondary education and in the workplace (Dejarnette, 2012; Klahr, 2005; National Research Council, 2012).

Figure 1: Skills for a 21st Century Citizen



Impediments to acquiring the 21st century skills. Despite evidence that STEM disciplines have a positive impact on elementary school students' learning, much of STEM education, particularly science, is disappearing in the lower grades, in part as a result of the No Child Left Behind (NCLB) reform initiatives. The legislation requires the reporting of Annual Yearly Progress K-12 in English language arts and mathematics but only three times in science during the same twelve years (Judson, 2013; Lynch, 2011). Griffith and Scharmann (2008) surveyed 164 elementary teachers who indicated that the English language arts and mathematics assessments from the NCLB legislation have redirected teaching time to those subjects, while science and social studies learning is diminished or eliminated (Marx & Harris, 2006,).

Facilitating acquisition of the 21st century skills. Elementary school teachers are the first formal educators responsible for teaching the 21^{st} century skills through the STEM content areas. With or without contextual support, elementary teachers are trained as generalists who are required to teach a wide range of subject matter. Elementary teachers are dedicated to student learning, and teacher commitment is necessary to teacher effectiveness (Day & Gu, 2007;Ware & Kitsantas, 2007). Based on the *Next Generation Science Standards*, the science content they must be prepared to teach are the earth, space, physical, and life sciences. Elementary teachers are expected to help students construct their own understandings of natural phenomena, while fielding student questions, correcting misconceptions, and responding effectively to unique and varied student ideas (Nowicki, Sullivan-Watts, Shim, Young, & Pockalny, 2012). Unfortunately, most elementary teachers are uncertain of their own abilities to teach even the most basic STEM concepts such as forces, energy, and earth systems (Hudson, McMahon, & Overstreet, 2002; Milner, Sondergeld, Demir, Johnson, & Czerniak, 2012; Ramey-Gassert, Shroyer, & Staver, 1996; Smolleck & Yoder, 2008).

Teacher commitment and STEM learning. Teaching science and engineering in an education environment that minimizes the teaching and learning of those content areas is difficult, and requires teachers be committed to STEM. Teacher commitment is the whole-hearted dedication to the various aspects of teaching. Measures of teacher commitment have addressed commitment to a school organization, commitment to the profession, and commitment to the personal aspects of teaching (Coladarci, 1992; Day & Gu, 2007; Ware & Kitsantas, 2011). Greater teacher commitment increases student engagement and learning (Collie, Shapke & Perry, 2011).

Day, Elliott and Kington (2005) studied experienced Australian and English primary teachers and identified four key factors that those teachers believed described commitment:

(1). A clear enduring set of values and ideologies which inform practice regardless of social context.

(2). A clear sense of standards: the active rejection of a minimalist approach to teaching (to just doing the job).

(3). A continuing willingness to reflect upon experience and the context in which practice occurs and to be adaptable.

(4). Intellectual and emotional engagement (Day, Elliot &Kington, 2005, p 573).

Teacher commitment characteristics provide a lens to assess the possibility of student growth and learning of STEM content and 21st century skills.

Statement of the Problem

High stakes testing to measure student achievement aligned with No Child Left Behind, and more recently the Common Core State Standards, has caused elementary schools to emphasize reading and mathematics curricula. Many elementary students are receiving little or no instruction in science and engineering.

Nonetheless, there are elementary teachers who actively incorporate science and engineering content into their students' curricula despite school policies that downplay such content. Elementary STEM teachers who are committed to actively teaching science and engineering are needed to help establish foundational STEM learning for the 21st century learners. Understanding the knowledge and beliefs of those teachers, and the experiences that may influence their commitment and pedagogical content knowledge may help other elementary teachers develop as knowledgeable, STEM teachers.

Purpose of the Study

The purpose of this qualitative study was to understand the phenomenon of elementary STEM teachers committed to actively teaching science and engineering. The study focused on science and engineering, the core content areas addressed in the *Framework for K - 12 Science Education*. This researcher investigated the perceptions and beliefs of three elementary teachers who are committed to actively teaching and learning STEM independent from any school policy initiative.

Research Questions

The following research questions were addressed in this study: What are the beliefs and knowledge of elementary teachers committed to actively teaching science and engineering? What experiences do elementary teachers describe as important to their knowledge, beliefs and commitment to actively teaching science and engineering?

Operational Definitions

Committed is an adjective that describes whole-hearted dedication.

Elementary teachers are those teachers who teach in kindergarten through fifth grade in self-contained classrooms.

Engineering is the body of knowledge and system of practices to design and create a means to solve a problem, or to meet a need.

Formal learning of science encompasses the academic school traditions of lecture, library and laboratory.

A *generalist teacher* is one who must teach a wide range of content including, but not limited to, reading, mathematics, social studies, science, and writing.

Hermeneutic phenomenology is interpretive analysis of phenomena based on the words and patterns of words used in written documents or oral dialogue.

Inquiry activities consist of the activities and thinking processes of scientists embedded within a foundation of deep conceptual understanding. Canonical, procedural and experimental, and nature of science knowledge can be considered representative of goals for inquiry.

Phenomenology is a holistic philosophy and methodology that seeks to understand how a person perceives his or her own life experiences.

Science is the body of knowledge and the system of practices to discover and understand nature.

A *self-contained classroom* is one in which a generalist teacher is responsible for academic content.

Self-efficacy is the belief that one has or does not have the ability to produce an intended effect.

STEM is an acronym for science, technology, engineering and math. In general, STEM comprises life sciences, physical sciences, mathematics and statistics, computer science and engineering.

Teacher beliefs are the internal system of perspectives and values that affect a teacher's attitudes and teaching.

Teacher experiences are the summation of a lifetime of exposure to and involvement in activities and actions that affect a teacher's teaching.

Significance of the Study

A community of 21st century workers ready to take on a changing economic environment begins developing long before the individuals are of an age to be productive. Thus elementary school teachers have the responsibility to begin the process of creating a 21st century workforce (Hargreaves, 2003; Weiman, 2012). Knowing the teaching epistemology and knowledge of a committed elementary STEM teacher who actively teaches science and engineering is critical to establishing educational policies that enable good teaching and learning for students (Banilower, 2013). Pre-service teacher educators may find the teachers' reflections on their preparation in STEM content and pedagogical content knowledge useful for designing effective programs. The committed teachers' comments on their early in-school and out-of-school experiences may identify particular experiences that encourage positive STEM interests that carry into adulthood. Early childhood, elementary and secondary educators might apply that information when they design curricula. Professional development providers can use the teachers' perceptions of effective practices to create meaningful programs for in-service teachers. Furthermore, school districts might use the research findings to gain insight into the beliefs, knowledge and pedagogical content knowledge of elementary STEM teachers committed to actively teaching science and engineering. This new knowledge would assist school districts in providing opportunities for teachers to develop their teaching skills so that all students may acquire the 21st century skills needed for their future.

The ultimate hope is that future generations of students learn STEM subjects from more committed, knowledgeable teachers.

Chapter Two: Literature Review

The purpose of this study of elementary teachers was to investigate elementary teachers who are committed to actively teaching science and engineering. The following research questions were addressed in this study: What are the beliefs and knowledge of elementary teachers committed to actively teaching science and engineering? What experiences do elementary teachers describe as important to their knowledge, beliefs and their commitment to actively teaching science and engineering?

Studying an elementary teacher's commitment to teaching science and engineering requires an understanding of teacher beliefs and the knowledge of the science and engineering that elementary teacher would explain to students. Research that describes elementary teachers and their teaching of STEM content is examined. Literature discussing the science experiences that elementary teachers typically encounter, the epistemologies and beliefs that influence their science teaching, and pedagogical content knowledge for teaching of the nature of science is presented. Finally, theories that explain how experiences can transform elementary teacher knowledge and beliefs are articulated.

Beliefs

Belief is " a strong feeling that something/somebody exists or is true; confidence that something/somebody is good or right"(Stevenson, A., 2010). Irez (2006) combined and summarized several authorities' work, and defined beliefs as "psychological constructs that: (a) include understandings, assumptions, images, or propositions that are felt to be true; (b) drive a person's actions and support decisions and judgments; (c) have highly variable and uncertain linkages to personal, episodic, and emotional experiences; and, (d) although undeniably related to knowledge, differ from knowledge in that beliefs do not require a condition of truth"(p17). Those researchers remarked on the important role personal perspectives of learning have on teaching and learning.

Such personal perspectives are part of a teacher's epistemology, or theory of knowing. According to Schommer (1990), personal epistemology is a belief system that is composed of several more or less independent dimensions. Beliefs about the nature of knowledge are far too complex to be captured in a single dimension (Schommer, 1990, p1). Two epistemologies prevalent in education are constructivism and positivism, also known as empiricism (Lortie, 1975; Schommer, 1990). Those belief systems are distinguished by the structure, certainty and source of knowledge.

Positivism philosophy is the epistemological belief that reality can be known objectively. There is a single certainty, a reality independent of a learner, which can be determined empirically. In science, there is a source of knowledge that is to be discovered; in teaching, knowledge is to be shared or dispensed. Constructivism promotes the idea that knowledge is purposive, and a variety of possible interpretations of reality can coexist (Bunge, 1997). Piaget's theory of children's cognitive development, and Vygotsky's work on thought and learning align with constructivism. Social creativity, creating concepts together, is an aspect of Dewey and Vygotsky's constructivism (Tan, 2007). Piaget's ideas set developmental limits on the potential of early elementary students' abilities. Contrary to that, researchers have found young students to have more sophisticated capabilities (Ray & Smith, 2010). Positivism and its closely related philosophy, empiricism, hold that knowledge is based on sensory evidence provided from scientific methods of discovery, and can be demonstrated. B.F. Skinner's comments give a sense of positivism in education. "The natural logical outcome from the struggle for personal freedom in education is that the teacher should improve his control of the student rather than abandon it "(Skinner 1973, p 16). No one learns very much from the real world without help. "Formal education has made a tremendous difference in the extent of the skills and knowledge that can be acquired by a person in a single lifetime "(Skinner 1973, p15). It is efficient to dispense knowledge.

Epistemology's effect on teaching and learning.

Schommer (1990) found that student epistemologies and teacher epistemologies affect learning. Conflicts arise from competing epistemologies. Multiple learning experiences can affect teacher beliefs and create a lack of understanding of science knowledge and practices. Losh and Nzekwe (2011) discovered that pre-service teachers, including elementary teachers and science education majors, were inconsistent in their knowledge and critical evaluations of evidence-based science, and of pseudoscientific beliefs such as astrology, extraterrestrial creatures and intelligent design. Bryan (2003) found a teacher's beliefs about the value of science and science teaching, the nature of science, and the management of an inquiry science structure classroom, were "nested." One set of beliefs arose from the teacher's experience as a science learner, the other set of beliefs were "learned" but not experienced. Years of positivist, didactic training conflicted with the constructivist inquiry approach embraced during the pre-service teacher experience. Positivism and constructivism collide in science and science education for the typical elementary teacher.

LaPlante (1997) also found that teachers' epistemological beliefs strongly affected their students' "school science" experience. His study showed that positivist teaching, that is the sharing of knowledge, did not permit students to acquire the language of science, or to develop the cognitive capability of independently creating science knowledge. Unfortunately, the mismatch of beliefs can be perpetuated from teacher to teacher, and from teacher to student (Lortie, 1975). Murphy (2004) observed how the apprenticeship of observation that takes place in schools begins early. Elementary teacher beliefs about science and science education are transmitted to students, and those insider beliefs will influence future generations of educators. The transmission of beliefs is not always bad. In his study of students in third through sixth grade, Beghetto observed that elementary students' willingness to take intellectual risks in science learning was directly correlated with their teachers' support and interest in science (2009).

Epistemology and the nature of science.

Hanuscin, and colleagues (2009) studied elementary teachers of science with a focus on the nature of science (NOS). They summarized NOS as the awareness that scientific knowledge is both reliable and tentative; there are multiple approaches to science methods; and, creativity is critical to scientific progress. Moreover, science brings observations and laws together with inferences and theories, objectivity with an element of subjectivity. That description of the nature of science is more compatible with constructivist epistemologies. The dualities in the NOS contrast with Rushton, Morgan and Richards' (2007) findings that order, unambiguity and concrete problem-solving are characteristics of a large proportion of elementary schoolteachers' pedagogy. Their findings imply that a more positivist epistemology is common in elementary school teachers.

Knowledge

Hanuscin et. al. (2009) found that teacher beliefs determined the amount and content of science taught in elementary school, and that knowledge affected teacher beliefs. According to Crawford "knowledge and beliefs about teaching are entangled, since what one believes about teaching necessarily hinges to a large extent, on one's knowledge of his or her discipline, as well as on one's beliefs about how children learn" (2007, p4). Thus elementary teachers' epistemic view of science and engineering will influence their acquisitions of the content knowledge and pedagogical content knowledge they are asked to teach.

Science and Scientists, Engineering and Engineers.

Content knowledge of science and engineering includes knowledge of who does science and engineering, and how are they done. According to Shulman, science includes the facts, theories and practices that are to be learned or taught in disciplines such as life sciences, physics, chemistry, environmental systems, astronomy, meteorology, geology and oceanography (1998, 2005). Knowing the processes of the scientific method and inquiry is important knowledge for elementary science teachers (Hagevik, Veal, Brownstein, Allan, Ezrailson & Shane, 2010).

The National Academy of Engineering and the National Research Council have defined engineering as "both a body of knowledge—about the design and creation of human-made products—and a process for solving problems"(2009, p7); and, "in a very broad sense to mean any engagement in a systematic practice of design to achieve solutions to particular human problems" (2012, p 21). Disciplines within engineering include mechanical, chemical, environmental, materials, acoustical, agricultural, electrical, and industrial. “Engineering habits of mind are aligned with what many believe are essential skills for citizens in the 21st century. These include (1) systems thinking, (2) creativity, (3) optimism, (4) collaboration, (5) communication, and (6) ethical considerations” (Cunningham, 2009). Content knowledge related to the nature of science has been seen as appropriate for all ages, including elementary students. As previously stated, Hanuscin, Lee and Akerson studied elementary teachers of science and defined the nature of science (2009).

In 2011, the National Science Teachers Association (NSTA) in collaboration with the National Research Council of the National Academies of Science produced The Framework for Science Education. brings together scientific and engineering practices, crosscutting concepts and disciplinary core ideas in age appropriate learning progressions. It conceptualizes a research-based emphasis of teaching and learning science and engineering:

> Scientific and engineering practices; crosscutting concepts that unify the study of science and engineering through their common application across fields; and core ideas in four disciplinary areas: physical sciences; life sciences; earth and space sciences; and engineering, technology, and the applications of science (National Research Council, 2012, ES-1).

The framework emphasizes learning as a developmental progression; learning science and engineering in depth is more effective than a shallow coverage of topics; and science and engineering content and practices must be integrated across the disciplines of science. The science and engineering practices are similar to Hanuscin’s criteria for the nature of science: asking questions (for science) and defining problems (for engineering);

developing and using models; planning and carrying out investigations; analyzing and interpreting data; using mathematics and computational thinking; constructing explanations (for science) and designing solutions (for engineering); engaging in argument from evidence; and obtaining, evaluating, and communicating information. Social and cultural contexts are entwined with scientific endeavors (Hanuscin, Lee, & Akerson, 2009).

The framework guided the formation of the Next Generation Science Standards (NGSS) that were released in 2013. The standards identify disciplinary domains: physical sciences, the life sciences, the earth and space science, and engineering, technology and applications of science (NGSS Lead States, 2013). The NGSS contains a learning progression of concepts, content standards, and practices for students beginning in kindergarten. Physical science, life science, earth science and engineering (motion and stability, forces and interactions, energy, from molecules to organisms, structures and processes, Earth's systems, Earth and human activity, and engineering design) are NGSS topics which will be developed in appropriate learning progressions throughout a student's primary and secondary education (NGSS Lead States, 2013).

Thus, the Next Generation Science Standards require elementary teachers to be knowledgeable in many science disciplines. While the framework for science education can be demonstrated when elementary teachers use constructivist methods effectively integrating several subject areas, the NGSS is not a curriculum. Elementary teachers may independently develop curricula and strategies that reflect their abilities to integrate knowledge and use knowledge building pedagogy (Nowicki, Sullivan-Watts, Shim, Young, & Pockalny, 2012; NGSS Lead States, 2013).

The nature of science reveals the nature of scientists. Getting into the spirit of science, engaging intellectually and emotionally, includes the knowledge of what scientists do. (Table 1 outlines a scientist's or engineer's characteristics.) In the first chapter of *Science for All Americans,* the American Association for the Advancement of Science describes scientists as investigators, creative modelers, data analysts, and interpreters of phenomena. "Scientists strive to make sense of observations of phenomena by constructing explanations for them that use, or are consistent with, currently accepted scientific principles"(AAAS, 1993).

Scientists are visionaries interested in exploring the next new phenomenon. Scientists predict and hypothesize in order to discover the unknown. Astronomers look for new stars, and predict their behavior. Atmosphere scientists extrapolate the past and the present into the future to predict the state of the air on earth, and the future of the planet. Epidemiologists hypothesize the public health issues of the future. Engineers seek to develop new technologies that will be tools to explore, predict, and remedy the needs of society. Rogers and Portsmore set forth the steps in engineering practices as:(1) identify and formulate a problem, (2) design a solution, (3) create and test a solution, (4) optimize and re-design, and (5) communicate and disseminate the solution(2004). That parallels the science practices, and is combined with those in the Framework for K-12 Science Education (2011). The authors (2004) suggest a progression of engineering topics that increases in complexity for kindergarten through grade 5 students. Katehi, Pearson and Feder support engineering in elementary education .

The design process, the engineering approach to identifying and solving problems, is (1) highly iterative, (2) open-ended, in that a problem may have

> many possible solutions, (3) a meaningful context for learning scientific, mathematical, and technological concepts, and (4) a stimulus to systems thinking, modeling, and analysis (2009, p 6).

Scientists and engineers seek knowledge. They ask the questions that will lead to new discoveries and new technologies. Observations are fundamental to science (Noris, 1984). Models are created to explain phenomena. Scientists create models that will help develop, test and explain new knowledge and technologies. Inquiring and visualizing are central to scientific theories. “They must be logically sound and incorporate a significant body of scientifically valid observations. The credibility of scientific theories often comes from a model’s ability to show relationships among phenomena that previously seemed unrelated. But knowledge and creative insight are usually required to recognize the meaning of the unexpected. Aspects of data that have been ignored by one scientist may lead to new discoveries by another”(AAAS, 1993). Scientists must analyze and interpret new information in light of previous knowledge.

Scientists are collaborative communicators. Discourse among scientists helps them judge the merit of information, and visualize new models and theories. Scientists look to the future. Asking the right questions propels scientists into investigating the unknown (Moore, 1993). The direction of scientific research is affected by informal influences within the culture of science itself, such as prevailing opinion on what questions are most interesting or what methods of investigation are most likely to be fruitful (AAAS, 1993). Engineers design to meet the needs of society.

Table 1. Characteristics of Scientists and Engineers.

Visionary	Scientists look to the future. Asking the right questions propels scientists into investigating the unknown (Moore, 1993). Engineers consider the possibilities beyond the present (NAE, 2010)
Dedicated investigator and problem solver	Scientific questions are distinguished from other types of questions in that the answers lie in explanations supported by empirical evidence, including evidence gathered by others or through investigation. (Lead States, 2013, p4) Scientists strive to make sense of observations of phenomena by constructing explanations for them that use, or are consistent with, currently accepted scientific principles" (AAAS, 1993) Engineers solve problems within constraints (NAE & NRC, 2009).
Creative modeler	Modeling is a process of representing phenomena and processes in a logical way. Modeling is essential to scientists and engineers who move forward by constructing models and creating connections between phenomena (modified from AAAS, 1993).
Critical analyst and imaginative interpreter	Scientists and engineers who create meaningful models of phenomena review, retest and rethink previous models. (AAAS, 1993).
Collaborative communicators	Science and engineering are social practices. Engineers serve the needs of society. Scientists and engineers obtain information and communicate ideas to evaluate the merit and validity of claims, methods and designs. (AAAS, 1993; Latanision, personal communication, 2015).

Constructing the knowledge of science and scientists, engineering and engineers.

Elementary teachers must reconstruct the knowledge of science so it is more than just lists of facts delivered to students. They must make it meaningful and useable in different contexts. Pedagogical content knowledge (PCK) in science is essential to science teaching and learning; it encompasses the specific understanding necessary to deliver content to a learner. Researchers have found that intellectual and emotional engagement with PCK occurs in the classroom with students. PCK includes the knowledge of what makes learning a concept difficult, and how to reorganize and transform the preconceptions and misconceptions of the learner to permit assimilation of the content. PCK is the ability to make sophisticated science content accessible to the students (Shulman, 1986; 1987). As mentioned above, teacher beliefs determined the amount and content of science taught in elementary school (Hanuscin et al, 2009). A constructivist teacher will interact differently with students than a positivist teacher. According to Mishra and Koehler (2006), PCK exists at the intersection of content and pedagogy. Thus it goes beyond a simple consideration of content and pedagogy in isolation from one another. PCK represents the blending of content and pedagogy into an understanding of how particular aspects of subject matter are organized, adapted, and represented for instruction (p. 1).

"Knowledge-in-action" is how Park and Oliver's (2008) characterized PCK. They indicated that effective teachers respond immediately and appropriately when they encounter an unexpected and challenging teaching and learning situation. PCK is "an active and dynamic process" (Park and Oliver, 2008, p. 8). That active and dynamic process has been associated with constructivist pedagogy in science. Loughran has written extensively regarding constructivist pedagogy (Loughran, 2013; Loughran, Mulhall, & Berry, 2004; Nilsson & Loughran, 2012).

Pedagogical content knowledge is not refined for all science disciplines and engineering. Identifying PCK for elementary engineering has not been studied extensively, although researchers have developed curricula (e.g.Lego Mindstorm) for K-12, and are studying student and teacher characteristics related to engineering (Bethke Wendell & Rogers, 2013; NAE & NRC, 2009; Rogers, 2012; Roth, 1996; Siler, Klahr, Magaro, Willows, & Mowery, 2010; YaSar, Baker, Robinson-Kurpius, Krause, & Roberts, 2006).

Elementary teachers' beliefs and knowledge of science, engineering and science and engineering education are developed over a lifetime of experiences.

Teacher experiences

Teacher experiences are the summation of a lifetime of exposure to and involvement in activities and actions that affect a teacher's teaching.Table 2 describes the experiences discussed in this section of the chapter. Science experiences may be informal or formal. Informal science experiences include exploring nature while walking with friends or family, visiting a science museum or an aquarium, gardening, stargazing and bird watching. Formal experiences include science experienced in a classroom, library or laboratory where an instructor guides the activity.

Early experiences, both formal and informal, provide opportunities to engage emotionally with science, and to develop standards for teaching science. Later experiences provide opportunities to engage intellectually with science, and to increase knowledge of science content and practices.

Informal experiences

Early informal life experiences can influence the teaching and the career choices in science. A National Science Foundation survey of 254 individuals who had science-related careers found that more than 90 percent of the respondents indicated that their most memorable childhood experience was visiting a planetarium, zoo or aquarium. "Direct observation at nature centers led to [my] first feeling of intense interest and curiosity; I developed a need and an interest in 'knowing' and 'exploring' for answers" Career Scientist (COSMOS, 1998, p. 8).

Ray and Smith (2003) studied two very similar neophyte elementary teachers, and observed a relationship between their personal experiences learning science and their methods of teaching science. One teacher gathered her science knowledge informally from experience on a farm and her personal investigation of the environment, while the other teacher gained most of her knowledge in traditional lecture and fact-memorization schooling, even though she also lived on a farm. The researchers found that the early experiences with science defined their pedagogy and beliefs about science.

***Table 2*: Teacher Experiences with STEM**

Experience	Definition
1.Early Informal	Exploring nature while walking with friends or family, visiting a science museum or an aquarium, gardening, stargazing and bird watching.
2.Early Formal	Science experienced in a classroom, library or laboratory where an instructor guides the activity
3. Pre-service	Teacher training
4. In-service	Teacher as a professional
a. Professional Development	"A comprehensive, sustained and intensive approach to improving teachers' and principals' effectiveness in raising student achievement (NSDC,2015).
b. Professional Collaboration/ Learning Communities	Professional learning communities (PLC) "ongoing groups of teachers who meet regularly for the purpose of increasing their own learning and that of their students"(Lieberman & Miller, 2008. p. 2).
5. Transformative	Education should leave us different, understanding more, seeing differently, and willing to act in accordance with these differences. (Girod, 2010, p 804)

The traditional teacher followed her experiences and taught science through lectures and supportive positivist activities. The investigating teacher used constructivist techniques to help her students explore from their own perspectives (Ray & Smith, 2003, p 1078).

Teacher educators recognize the importance of science informal experiences to teacher development. Riedinger, Marbach-Ad, McGinnis, Hestness and Pease (2011) investigated pre-service teacher attitudes in a science methods course that incorporated informal science experiences. The three class sections were inquiry, small group, and questioning activities. Two of the sections also contained informal science with guest speakers and a virtual field trip. There was a notable difference between the teacher candidates' responses on the attitudes and beliefs survey on item 9, ''I like science.'' The number of teacher candidates answering positively to the item changed from 70.8 percent to 95.8 percent in the treatment group, and from 69.2 percent to 80.8 percent in the comparison group (p 63).

However, the effect of informal science on in-service elementary teachers' knowledge and practice has not been articulated.

Formal experiences

An elementary teacher's formal experiences occur in a school setting or in a defined course of study. Elementary teachers' K-12 school experience with science is related to where they attended school. Their own elementary schooling would typically include reading, mathematics, physical education, social studies, art, music and science (Dougherty, 2015). A highly regarded high school in the middle of the United States includes the following science guidelines in its course requirements.

> Students must have a minimum of 48 credits to graduate. The required distribution of credits includes … 6 credits in both science and social studies. …. The only specific courses that are required … General Science (2 credits, typically taken in grade nine)….Thus, on paper, there is a considerable amount of flexibility in the range of courses that students are able to enroll (Ferrare, 2013, p 144).

Consequently, a typical future elementary school teacher might graduate from high school with one to three courses in science.

Pre-service teacher experiences.

Students enter teacher-preparation programs with some emotional engagement with the teaching profession, but there are different paths to becoming an elementary teacher. Banilower et al. (2013) found that most elementary teachers (61percent) received their certifications to teach through a bachelor's degree program and certification courses. Twenty-five percent were certified within a master's degree program. In the 2000 National Survey of Science and Mathematics Education (Weiss, 2001), 86 percent of the K-4 teachers' degrees were in elementary education, two percent of the K-4 degrees were in science, two percent were in science education, and no mathematics degrees or mathematics education degrees were reported. Only four percent had degrees in natural science or engineering. One percent of elementary teachers report that they have taken a college course in engineering, and ninety percent have taken at least one course in biology or life science. Elementary teachers by and large take only the introductory course in physics, chemistry, or earth science, whereas thirty-four percent of elementary teachers report taking advanced biology courses such as genetics, zoology, botany or anatomy and physiology

Elementary teachers, as generalists, need to know a wider range of subject matter than do their middle school or high school peers. Typical coursework for a bachelor in elementary education includes professional courses in education theory, methods courses in reading, science, mathematics, art/music, and technology. Prospective elementary teachers also take general education courses in mathematics and psychology, as well as a distribution of courses or a concentration in literacy, science or social science. In some cases, they will teach more than ten different content areas: reading, spelling, writing, mathematics, social studies, science, physical education, music, art, information, foreign language and citizenship. Their academic backgrounds tend to be broad rather than deep (Yore, Shymanski and Anderson, 2005).

Pre-service elementary teacher commitment to teaching science is unclear. Studies of teacher commitment have been focused on teacher retention in the profession. It has been noted that pre-service elementary teachers are, in large part, committed to teaching in general because of emotional engagement with their charges (Evans & Trimble, 1986). Watt, Richardson and Wilkins found that while commitment to teaching remains steady in teacher training, commitment to teaching varies markedly once a teacher is in the classroom (2014). An inquiry-based methods course during teacher training does improve some pre-service individuals' self-efficacy to teach science (Avery & Meyer, 2012).

In-service teacher experiences.

Elementary teachers interact with students, teachers, administrators and community members. Among those interactions that may affect a teacher's commitment are professional development and professional learning communities.

Professional development. Professional development for teachers has many definitions, some more explicit than others. The National Staff Development Council's detailed definition begins "a comprehensive, sustained and intensive approach to improving teachers' and principals' effectiveness in raising student achievement (NSDC, 2015). NCLB Title IX defines professional development in great detail and includes:

- Are not 1-day or short-term workshops or conferences
- Are high quality, sustained, intensive and classroom-focused in order to have a positive and lasting impact on classroom instruction and the teacher's performance in the classroom
- Improve and increase teachers' knowledge of the academic subjects taught and enable teachers to become highly qualified
- Include instruction in the use of data and assessments to inform and instruct classroom practice. (NCLB, Sec 9101(34))

Science professional-development for elementary teachers is not common, or extensive. Elementary teachers reported that 41 percent have not had any science-focused professional development in the previous three years, and only 12 percent had more than 15 hours of professional development in science or science education. The professional development topics are varied and include discovering student thinking and learning how to use manipulative resources for science instruction. The distribution of professional development methodology among college courses, short courses. or one-time sessions was not articulated in the national science study. More than 70 percent report that the professional development had some impact on their science content knowledge (Banilower, 2012).

Goodnough and Hong's (2009) study of elementary teachers as they developed project-based learning curricula indicated that professional development for teachers is critical if the teaching and learning process is to improve, and new innovations are to be assessed for their potential to improve education. Furthermore, the purpose of teacher learning should be to support teachers in examining, understanding, and changing their beliefs, attitudes, and classroom practices. Teaching stances and intellectual engagement will be impacted through emotional engagement.

Providing reflective professional develop experiences is a multifaceted process. In their studies of elementary teachers' professional development for acquiring science content, Schibeci and Hickey (2002) articulated three dimensions required for effective teacher learning: (1) scientific dimension, including science concepts theories and practices to broaden teacher knowledge, (2) professional dimension that incorporated the content to be taught to the elementary students, and (3) personal dimension related to the teachers' everyday life.

Elementary teachers are adult learners who are actively involved in their teaching careers while participating in professional development opportunities. Their learning experiences do not occur in isolation from students and teacher colleagues as they might in pre-service instruction. To understand teachers as professionals, Park and Oliver (2008) studied pedagogical content knowledge's role in teacher growth. PCK is the ability to make sophisticated science content accessible to the students. Their findings indicated that: pedagogical content knowledge was developed through reflection-in-action and reflection-on-action within given instructional contexts; teacher efficacy emerged as an effective affiliate of PCK; students had an important impact on PCK development; students' misconceptions played a significant role in shaping PCK; and, PCK was idiosyncratic in some aspects of its enactment.

One approach that has been shown to contribute to success of professional development (PD) is an increase in the level of personalization of the PD experience. Emotional connections support teacher commitment (Collie, Shapka & Perry, 2011). Recognizing the diversity of teachers' knowledge and experiences, and to address the emotional and intellectual engagement of the teachers, more effective PD has moved away from involvement in large-scale, compulsory courses, to experiences that are embraced by teachers as individually relevant (Schibeci & Hickey, 2002).

Zembylas and Barker (2002) believed there were multiple methods for developing good teaching and learning, since teachers and student have different interests, attitudes, dreams and preferences. "At the core of our approach lies the epistemological stance that learning how to teach science is a deeply emotional activity in which the individual concerned has to deal with his or her prior emotions and attitudes in the light of their past and present experiences" (2002, p.346).

Among those more effective personal professional development offerings, informal science experiences have been identified as influential and memorable to novice elementary teachers (Katz, McGinnis, Marbach-Ad, & Dai, 2013).

Falk and other researchers (2012) suggest that professional development that encourages an elementary teacher to develop the commitment to teach science must address more than a particular program or curriculum. Recognizing the teacher as a learner resonates with Dewey's work, "The most important attitude that can be formed is that of desire to go on learning" (Dewey, 1938, p. 20).

Professional collaboration/learning communities. Lieberman & Miller (2008) describe professional learning communities (PLC) as a new source of professional development. They define a PLC as "ongoing groups of teachers who meet regularly for the purpose of increasing their own learning and that of their students"(p. 2). Educational reform advocates have encouraged professional learning communities as an effective avenue to change. They have adopted Senge's (1990) idea of a learning organization "where people continually expand their capacity to create the results they truly desire, where new and expansive patterns of thinking are nurtured, where collective aspiration is set free, and where people are continually learning how to learn together" (p. 3).

Professional learning communities enable teachers to learn together, and nurture new and expansive patterns of thinking. That takes time. The 2009 Met Life Survey of the American Teacher stated that teachers spend on average 2.7 hours per week collaborating with other teachers (twenty minutes per day). The 2012 survey indicates that teachers and principals do not believe that time has increased; rather it has stayed the same or decreased. The survey findings show that fifty-eight percent of all teachers spend less than two hours per week collaborating, and thirty percent spend less than one hour. The study describes the meetings as leadership-sharing responsibilities with the teachers,

teachers discussing student-specific achievement and some experienced teachers working with novice teachers on basic skills.

Collaborative professional development is not identified as a priority. Research suggests that trend is counterproductive. According to Kohm and Nance (2009), a climate of working together will accelerate positive change in schools. Professional learning communities in science have been found to increase teacher content knowledge and improve teacher attitudes (Fulton & Britton, 2011). Shinohara and Daehler (2008) describe a community of elementary teachers in which the researchers presented formal lessons in science. Studies suggest that well-developed PLCs have positive impact on both teaching practice and student achievement (Vescio, Ross, & Adams, 2008). According to the report "Team up for 21st Century Learning" well-developed PLCs have six characteristics:

- shared values and goals with a specific problem they come together to solve,
- collective responsibility,
- authentic assessment - hold themselves accountable because it is important,
- self-direct reflections goal setting planning and evaluations,
- stable setting dedicated time and space, and
- strong leadership support – empowered to make decisions based on student needs.

(Fulton & Britton, 2011; Carroll, Fulton & Doerr, 2010)

Vescio, Ross and Adams' (2008) review of the literature identifies persistent dedication to improving student learning and achievement as a key feature of professional learning communities. Members of PLCs collaborate to analyze and improve classroom practice in an ongoing process that promotes deep team-learning (Dufour, 2004).

Transformative Experiences

Committed elementary teachers' beliefs and knowledge might not be consistent throughout their lifetimes of experience. Research has show that changing perspectives and epistemologies is not trivial. Pre-service academic instruction in constructivist pedagogy and science content has not always produced teachers who understand and utilize information. Ucar's (2012) study of pre-service elementary teachers found that over time within the program the pre-service teachers pictured teaching to be more student-centered rather than teacher-centered, showing a shift to constructivist from positivist pedagogy. However, the pre-service teachers did not change their views of science or scientists, and remained steadfast in the positivist viewpoint.

Adult learners have years of experience and instruction that can support or impede learning. Accessing new information may involve unique experiences such as those described by transformational learning (Mezirow, 1997). It may also require settings that foster adult learning such as professional learning communities (Kohm & Nance, 2009). Moreover, transformational learning theory may be a window into developing an elementary teacher into a committed science and engineering teacher.

> There is transaction between person and world; between experiencer and experienced. This is a departure from our current and overwhelmingly common cognitive, rational perspectives on teaching and learning. Attention here is beyond just the mind of the learner and is extended to include emotions, actions, and perceptions. A person who truly learns exits transformed, not just of mind, but of heart, eye, and body. Education should leave us different, understanding more,

seeing differently, and willing to act in accordance with these differences. (Girod, 2010, p 804)

Transformation of an in-service teacher requires professional development. As previously referenced, Schibeci and Hickey (2002) articulated three dimensions required for effective teacher learning in science professional development. Palmer (2011) speaks of mastery as a classroom-based experience in which teacher's self-efficacy is improved, but he also says: "there is another form of mastery experience, which for the sake of comparison will be referred to in this paper as 'cognitive mastery' This occurs when teachers perceive success in *understanding* science concepts or pedagogical concepts" (p. 579).

Becoming a science educator involves transformative learning (Wieseman & Weinburgh, 2009; Yeotis, Klein, & Weaver, 2009). Change is a very personal experience. As Goodenough and Hung's (2009) study identifies, each teacher becomes a science teacher with a different knowledge base. In other words, each teacher has a unique PCK profile,. and how it changes as a result of new experiences will depend on prior experiences, contextual factors (e.g., support for engaging in teacher development, availability of resources), and readiness to adopt new teaching approaches. (p. 239)

DiBiase (2000) has written about the implications of Mezirow's theory of transformative learning for science educators. He suggested that knowing how to facilitate adult learning based on transformative theory is necessary for science-education reform and creation of environments in which males and females feel comfortable and successful, and that leaders in science education must understand the need to change the thinking of adults (teachers and teacher educators). Having been apprenticed into traditional or positivist science teaching and learning in their own educational experiences, elementary teachers who become committed teachers of science inquiry-based learning undergo a change in epistemological views and pedagogical content knowledge. The process may involve fear and discomfort. As previously mentioned, it will involve reflective practice, collaborative experiences and a supportive environment.

Mezirow (1997) identifies the phases of transformative learning as: involvement of a disorienting experience; reflection on feelings; assessment of assumptions; recognition that it is shared experience; exploration of options; determination of a course of action; acquisition new knowledge and skills; practice of a new role; building competence and self-confidence; and reestablishing oneself with a new perspective. Being in the classroom can be a transformative learning experience as described by Falk (2012) who characterized the reciprocal relationship between elementary school teachers' formative assessments of students and the teachers' developing PCK.

A 1995 study of pre-service teachers determined that very strong positive and negative feelings about school figured prominently in the students' memories. They remembered when they felt good, or proud, or confident about their abilities for the first time (Blake, 1995, p5). The study suggests that pre-service teachers' intuitive and subjective frameworks for education derive from their own K - 12 school experiences. Elementary teachers who identify themselves as unprepared to teach science content may undergo the transformative learning that changes that belief while participating in science professional development. Yeotis, Klein and Weaver (2009) described experiences related to "enculturation into science education." They identified mentoring and collaboration as important democratic and participative pathways for women in science education. Akerson and Khalick found that a "nature of science" (NOS) knowledgeable fourth-grade teacher required socially mediated support and explicit modeling to achieve PCK in her classroom (2003).

Mezirow's transformative learning theory suggests an elementary teacher who is actively committed to teaching science could become a leader in science education. The literature presents many theories and styles of leadership. Northouse (2013) perceives leadership "as a complex process having multiple dimensions" (p.1). Leadership roles in a professional learning community or school community can be formal (school principal), or informal. Current leadership definitions have four central components: it is a process; it involves influence; it occurs in groups; and it involves common goals. One form of leadership considered in this study is emergent leadership that results from the actions of an individual and the support provided by a group. Within that context transformational leadership results in an elevation of the motivation and morality of the members of a group individually and collectively (Northouse, 2013).

Collaboration is a key feature of emergent leadership. Gabriel, Day and Allington (2011) described teacher development including teacher leadership. In addressing the role of collaborations they insist it must not be "contrived" and "mandated." "Collaboration must be a genuine sharing of ideas, question, and frustrations" (p 41). Finally, Danielson (2007) believes teacher-leaders "mobilize their closest colleagues" to achieve the best for students and the school.

Summary

Teacher commitment has been recognized as important to student learning, including science learning. Learning about science and scientists has an orientation best understood with constructivist epistemology. However, research has shown that most elementary teachers have a positivist epistemology. Change of epistemology is a transformative experience. Professional development has been shown to increase a teacher's science-content knowledge and pedagogical-content knowledge. Collaboration is an effective form of professional development. This study will further investigate elementary teacher epistemologies and knowledge that are associated with elementary teachers actively committed to teaching science and engineering. Those teachers' experiences that may have influenced their commitment, beliefs and knowledge of science and engineering and transformed the teachers' characteristics will be explored.

Chapter Three: Research Methods

The purpose of this study of elementary teachers was to investigate elementary teachers who are committed to actively teaching science and engineering. The following research questions were addressed in this study: What are the beliefs and knowledge of elementary teachers committed to actively teaching science and engineering? What experiences do elementary teachers describe as important to their knowledge, beliefs and their commitments to actively teaching science and engineering?

Context

This qualitative study arose during the research design phase of a quantitative study of elementary teachers of STEM when the researcher organized meetings with a group of elementary teachers interested in STEM. They were a professional learning community called Collaborative Conversations in STEM. The members of the PLC included teachers from within the same school district as the researcher.

The school district administration agreed to the initiation of the professional learning community in order to provide the opportunity to discuss the state of STEM education in the district at the elementary level. Furthermore, the school district supported the group by providing access to professional development opportunities outside the district for those in the Collaborative Conversations in STEM. While there were a number of individuals who came to meetings and professional development from time to time, a core of teachers emerged.

The collaborative conversations professional learning community's goal was to become knowledgeable in the Next Generation Science Standards. After a few months, the group members thought they would try to provide some professional development opportunities to excite the other teachers about teaching science and engineering. They wanted to initiate a grass roots movement to increase science and engineering teaching.

The teachers' perception of their commitment and actions related to teaching science and engineering to their students became the focus of the study.

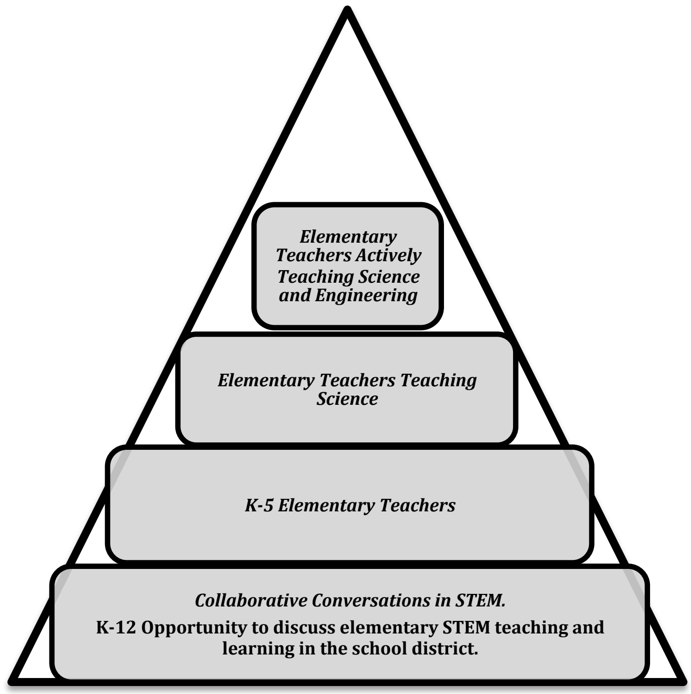
Methodological Overview

Hermeneutic phenomenology was determined to be the best method for collecting data and analyzing it. Hermeneutics focuses on the phenomena of conscious descriptions of experience and seeks the essence and underlying meaning of the account. Sensitive listening to the teachers' perceptions leads to a correct interpretation of their words. The researcher sets aside her bias by reflectively interpreting the data looking for underlying structure and meaning (Merriam, 2009; Moustakas, 1994). According to Roth and Jornet (2013), experience is a category of thinking that includes the intellectual, affective and practical characteristics of the people involved as well as their interactions with others in a particular environment. Table 3 describes the framework used to interpret the teachers' perceptions. The teachers' complex, emerging, and integral interpretation of life experiences were uncovered in the reasoned, rational phenomenological qualitative methodology that recognized the subjective and objective aspects of collecting and interpreting data (Creswell, 2009).

Sample Selection

The Collaborative Conversations in STEM members were the population from which the participants were selected. The three participants were a convenience sample. (Figure 2 outlines the selection process.) While the professional learning community members included teachers K-12 and administrators, only the K-5 teachers were initially considered for the study, all of whom were generalists who taught in self-contained classrooms. Among the elementary teachers were those that were PLC members to obtain professional development in STEM education. Of those teachers, some teachers were supportive of STEM in their classes, but did not give evidence of actively teaching science and engineering content during the Collaborative Conversations in STEM meetings. Those who indicated that they were actively teaching science and engineering were the initial sample selected. Evidence of teaching science and engineering at this stage of participant selection included discussion of specific examples of science inquiry and investigation, such as plant observations, and motion studies, and examples of engineering design and test activities, which included bridge building, circuitry design and catapults. Elementary teachers who represented themselves as going beyond the allotted time for science and engineering teaching and learning, thus demonstrating their whole hearted dedication and commitment, were the final sample. Three of those elementary teachers were able to participate in the research study. All members of the Collaborative Conversations in STEM signed release forms to permit the researcher to ensure trustworthiness of interview data by triangulation with recordings of the meetings.

Figure 2: Decision Tree for Participant Sample Selection



Participants

The participants in this study were chosen from members of a professional learning community (PLC) called Collaborative Conversations in STEM. The PLC began at one of two elementary schools in a suburban school district in New England. Seven teachers attended the first meeting of that group, and three of those participated in this study. They were chosen for their apparent commitment to actively teaching science and engineering as expressed by their willingness to teach those disciplines and “the active rejection of a minimalist approach to teaching (to just doing the job)” despite the “social context” of colleagues who taught little or no science in their school (Day, Elliott & Kington, 2005, p573). The individuals had between ten and twenty-five years of experience teaching in various elementary schools. Two of the teachers taught in self-contained K-3 classrooms, the other taught science in fourth grade, and shared responsibility for subject matter with one other teacher. Their pseudonyms for this study are Kelly, Ann, and Gwen.

Table 3: Framework for Analysis of the Epistemologies and Experiences of Elementary Teachers Committed to Teaching Science and Engineering.

Visionary	Teachers look to the future, aware of their students' future needs and those of society. Teach children to be inquisitive, curious and creative. Teachers strive to increase their students' interest in science and engineering.
Dedicated investigator and problem solver	Teachers ask questions of themselves and their students. Teachers are inquisitive and look for evidence regarding what they should know, what they should teach, how they should teach, and how effective their teaching is. Teachers are problem solvers by making time for science in their classrooms and in the school and overcome obstacles that might stop them from learning and teaching STEM.
Creative modeler	Teachers create models to help their students visualize and understand STEM. Teachers perceive learning as creating knowledge and they design activities that foster conceptual change in a way that is meaningful for their students.
Critical analyst and imaginative interpreter	Teachers are reflective. Teachers investigate the ideas of other educators, analyze those theories and interpret them in the light of their own experiences.
Collaborative communicator	Teachers interact with each other and their colleagues to share and evaluate their teaching and learning experiences. The opportunity to collaborate was key to the increase STEM teaching and learning in their classrooms.

Teacher background.

The teachers were females between the ages of 40 years and 65 years. They were full-time general elementary teachers of children in kindergarten, first, second and fourth grades working in the same suburban public school district.

Kelly was a reserved individual who had been teaching in public schools for about 20 years in first through fourth grades. She was born and raised in the same state where she currently works, but traveled across the country to a very different geographic environment to go to a public university and graduate school. Her undergraduate and graduate degrees were in elementary and special education. She did not have a minor in another discipline. She was certified by the state to teach in grades K-8, and was awarded National Board Certification.

Ann had been teaching kindergarten for a little over ten years in public schools, and had some prior pre-school experience. She was born, raised, educated, and taught in the same state. Her undergraduate degree was obtained at a private liberal arts college. Her academic major was in art history and she minored in education because it interested her. She decided to teach after a few years of pursuing another career. Besides her interest in education, she was planning on have a family and the convenience of working on the same schedule as her children appealed to her. She was certified by the state to teach in grades K-8, and was awarded National Board Certification.

Gwen is an outgoing, bubbly individual who had been teaching grades K-6 in public schools for more than thirty years. She had lived all over the United States because of her father's work. Her undergraduate degree in education was from a public university in the state in which she worked. She had extensive coursework in psychology, but changed her major to elementary education her senior year. Her graduate degree in teaching and curriculum was obtained from an Ivy League university. Her affinity for teaching was evident to others when she was quite young, but she realized its appeal as a young adult.

Kelly, Ann, and Gwen have pre-service training in science and mathematics methods. Gwen has experience in computer-technology education, and has taught programming to fifth grade students in a previous teaching position. Like most elementary **teachers, none** of them had formal training in engineering or engineering methods during their pre-service studies.

Collaborative Conversations in STEM

The professional learning community included K-12 educators and an administrator. The school district curriculum coordinator facilitated the first two meetings of the Collaborative Conversations. An elementary teacher facilitated the succeeding meetings. The administrator, two high school teachers (one technology teacher and one science teacher, the researcher), and a middle-school science teacher were also present as resource providers for the elementary teachers. For three years, Collaborative Conversations met six to eight times during the academic year and twice during the summer.

Data Collection

This study's phenomenological qualitative research sought to understand the elementary teacher's view of her experiences. There were four methods for collecting data: individual interviews with three of the elementary teachers in the Collaborative Conversations in STEM; a card-sort activity with each teacher; observation and auditory taping of the Collaborative Conversations in STEM meeting; and artifact collection.

Interviews

The elementary teacher participants shared their beliefs and experiences candidly in two extended semi-structured interviews. Each teacher's understanding of how she developed her commitment to teaching science, what kind of learning might have transformed her perceptions, and the meanings of the experience that guide her teaching and learning were uncovered. The researcher, as the instrument for data collection, encouraged each participant to talk expansively about the personal experiences she perceived influenced her to develop the commitment to teach science in elementary school (Seidman, 2013).

Interview one. The initial interview delved into the teacher's early experiences that may have influenced her commitment to STEM teaching and learning. The context of her introduction to informal and formal STEM learning and teaching was investigated along with her perspective of those experiences. Her early informal and formal learning experiences were of interest in light of current research that shows the significant effect early STEM learning has on children. The teacher's post-secondary experiences with STEM were investigated (see Appendix A).

Interview two. The second interview examined the teacher's more recent and current experiences with STEM teaching and learning. The teacher's perception of the impact of those experiences on her own commitment to teach STEM inquiry and concepts was explored. Her epistemological viewpoint of learning was elicited. In-service professional development, informal STEM experiences, school-based and classroom-based experiences were probed to develop a rich description of the teacher's perception of her professional STEM teacher and learning characteristics. The second interview continued the discussion to ascertain the teacher's viewpoint of how her collaborative experiences had influenced her in her commitment to teaching inquiry science and engineering. Transformative learning experiences that influenced her teaching of science and engineering were uncovered. STEM in the school community at large from the teacher's perspective became part of the discussion of her personal STEM experiences.

Card sort.

In order to elicit the teachers' perceptions, a card-sort activity was performed. Index cards with words or phrases were presented to the teacher. Different sets of cards were presented separately. Science and engineering content, informal STEM experiences, formal STEM experiences, epistemological viewpoint and pedagogical content knowledge were explored with the 3" x 5" index card prompts, ten cards per topic. Teachers were asked to prioritize the science-content knowledge in one selection, and professional development methods in another. Statements reflecting pedagogical content knowledge and epistemological views were presented, and the teacher was asked to agree or disagree with the statements. Table 4 provides examples of the cards.

Table 4: Examples of content knowledge, beliefs, epistemology, and professional development cards used in the study.

Too many theories just complicate things.	The best ideas are often the most simple.	Everyone needs to learn how to learn.	Scientists can ultimately get to the truth.
Matter	Gravity	Astronomy	Force
Motion	Evolution	Electricity	Magnetism
Create knowledge	Share knowledge	Workshop Summer course	Weeklong workshop

Any gaps in the data collection were rectified during an individual-member check of the data. That verification step ensured the consistency of the data collected from the participants thereby increasing the transferability of the study, the reliability of the results and the dependability of the instrument (Merriam, 2009).

Observation

The third method of data collection involved recording the meetings of the Collaborative Conversations in STEM. The researcher was a participant observer in that phase of data collection. As a participant observer, the researcher actively engaged in the

Collaborative Conversations in STEM as a resource person for all meetings over a two-year period "This participation gives them the advantage of being immersed in the culture long enough to understand it from the insider's perspective and distant enough to objectify patterns of behavior in the community, enabling them to share their insights with other colleagues"(Given, 2008, p 376). The Collaborative Conversation in STEM auditory recordings and field notes by the researcher were transcribed verbatim.

Documents

Evidence of STEM inquiry teaching was solicited from the participating elementary teachers. Artifacts included examples of student work, classroom environment, and lesson plans. Teacher-provided photographs of student activity helped to determine if STEM teaching was occurring in the classroom. For privacy concerns the photographs did not permit identification of the students.

Data Analysis

Analysis sought to discover the essence of the teacher's experiences and beliefs about STEM teaching and learning. (The analysis framework is detailed in Table 3.) The individual teacher interview transcripts were read by the researcher several times for evidence of the themes in the framework (Seidman, 2013; Creswell, 2009). After transcribing the sessions verbatim, the researcher coded and identified themes using NVIVO analytic software (QST International, 2014). The data reduction of the first and second interviews were combined and reorganized according to similar topics. Initial coding of teacher perception of experiences, STEM knowledge, collaborations, and epistemologies was performed. Necessary code/recode did occur.

Discrepant events were noted. The individual thematic stories were compared and contrasted. Unifying themes were identified to address the research questions. Specific quotes from participants were incorporated into the assembled story. The Collaborative Conversation in STEM meeting transcripts and artifacts presented by the teachers were analyzed to triangulate the findings (Coffey &Atkinson, 1995).

Trustworthiness

The trustworthiness of the data collection and analysis in this phenomenological qualitative study was ensured in several ways. The phenomenological interview questions were designed to permit the participants to speak at length. The volunteer participants' authenticity in communicating the data was supported by the researcher's observations of the participants' interactions with peers in the PLC. Because the research instrument, the researcher, had an inherent constructivist epistemology and philosophical view of teaching and learning, it was important to know and understand those before interviewing the data-giving participants. The researcher's background in scientific research and science education enriched her understanding of the participants' responses. The researcher did not share those understandings with the participants, however, but used them to probe deeper into the participants' responses. The researcher's perspective was articulated and recorded (Merriam, 2009). The participant teachers were involved in member checking of the original transcripts to ensure the accuracy of the transcriptions. The group meetings were audio taped to triangulate the perceptions of the participants. The data in those isolated interviews were verified, supported, and interpreted in light of the group interactions.

Another doctoral student performed a peer examination of the findings and analysis by reading an early draft of the manuscript (Coffey & Atkinson, 1995). The peer review supported the credibility of the findings and interpretations. To assist the reviewer, all analytical decisions made in the coding, categorizing and interpretation were shared (Given, 2008, p 102).

Triangulating data collected from interviews, group meetings and documents strengthened the trustworthiness of the data collection and analysis.

Report of findings

The research findings were presented so the patterns of experiences and participant interpretations of those experiences were clear. Individual teachers were given pseudonyms. The findings were complied to illuminate the various characteristics and influential experiences shared by the committed teachers of science and engineering (Coffey & Atkinson, 1995).

Delimitations and Limitations

Delimitations define the parameters of a study set by the researcher. This study focused on three experienced elementary teachers in self-contained K-5 classrooms who were committed to teaching science and engineering, and who interacted in the professional learning community, Collaborative Conversations in STEM. The teachers were colleagues in the same suburban school district at the time of the study. Teachers who were not members of the PLC were not considered for the study. Members of the PLC who taught in grades 6-12, or who had an administrative role in the school district, were not interviewed. Recordings of the Collaborative Conversations in STEM were used only to support the interviewed participants' perceptions.

Limitations are existing constraints at the time a study takes place. In this study the researcher was the instrument for data collection. The interview protocol was created for this study and not tested elsewhere. Researcher bias was inevitable, but external peer review decreased its influence by bringing to the researcher's attention potential issues that were corrected. Phenomenological research is not experimental, and statistically significant causal relationships between variables could not be expected. Nonetheless, combinations of influences appeared that **could** inform future research.

Participant Researcher

The researcher in this study has been a college and high school science teacher. Her experience as a research scientist has influenced her own pedagogical content knowledge, and has influenced her to have a constructivist epistemological view. Participants in the study may or may not share that perspective. The researcher's self reflection helped to identify and avoid the participant observer researcher's bias in preparing, conducting and analyzing the interviews.

As a scientist and a high school science teacher the researcher has been concerned with policies that have limited the science teaching in the elementary schools. The researcher's participation in the Collaborative Conversations in STEM provided a window to initiate an understanding of the nature of teaching elementary students, the beliefs and knowledge of elementary teachers.

Chapter Four: Findings

The purpose of this qualitative study was to understand the phenomenon of elementary teachers committed to actively teaching science and engineering. Using the Framework for Analysis of the Epistemologies and Experiences of Elementary Teachers Committed to Teaching Science and Engineering (Table 3) that specifically focuses on a teacher as a teacher of science and engineering, this researcher investigated three elementary teachers who were committed to actively teaching and learning STEM in an elementary school where the traditional foundational skills of literacy and mathematics are strongly emphasized. The teachers' comments suggest that their school apparently downplays science and engineering teaching and learning to accommodate those annually assessed skills. As occurs in many other schools across the nation, the effect of NCLB and Common Core State Standards in English language arts and mathematics and high-stakes testing encourages the school to emphasize those content areas over science and engineering. During this study, the essence of the teachers' life experiences related to STEM teaching and learning was explored. The phenomenological method provided a lens to focus on Kelly, Ann, and Gwen's "natural attitudes" regarding their commitment, knowledge, experiences, and epistemology. Understanding the phenomenon of elementary teachers committed to actively teaching science and engineering resulted from addressing the following research questions: What are the beliefs and knowledge of elementary teachers committed to actively teaching science and engineering? What experiences do elementary teachers describe as important to their knowledge, beliefs and their commitments to actively teaching science and engineering?

The chapter will offer the findings relevant to the beliefs and knowledge of the committed elementary teachers of STEM revealed in their recollection of their STEM experiences. The experiences Kelly, Ann, and Gwen perceived as influential to their beliefs and knowledge will be presented in the second section of this chapter.

Teacher Epistemology and Knowledge

Kelly, Ann, and Gwen outwardly exhibited their commitment, inner beliefs, values, knowledge, and pedagogical skills in their teaching and learning of science and engineering. The analytical framework described in Table 3 (Chapter 3) uncovered the teachers' perceptions of themselves as elementary teachers committed to actively teaching science and engineering. Findings indicate that their individual commitments to STEM was demonstrated in their epistemologies and knowledge, as evidenced by their visions, curiosity, inquisitiveness, problem solving, modeling of the nature of science, modeling of STEM teaching, reflections on experiences, reflections on practice, collaborations with colleagues, and promotion of STEM teaching and learning. This section of the chapter will present evidence of the teachers' perceptions and actions that revealed those characteristics of their commitment.

Visionaries

According to the Framework of the Epistemologies and Experiences of Elementary Teachers Committed to Teaching Science and Engineering, visionary teachers look to the future, aware of their students' future needs, and those of society. Students need to "learn about things that are going to be important for their future and the future of our world"(Ann). Those elementary teachers committed to actively teaching science and engineering in self-contained classrooms did not limit their visions or ideas about what their students will do in the future. Kelly, Ann, and Gwen perceived they had a responsibility to increase their students' interest in science and engineering. Teaching children to be inquisitive, curious and creative was important for the children, and for the larger society. During the card sort each teacher individually identified "Increase student interest in STEM" as her top priority for teaching STEM.

Gwen was dedicated to engaging students in science and mathematics today because she believes it will make them better people. "Because they have to understand the world and be curious about it. You can't be a lifelong learner if you're not curious. And the world is all around us involves science and math everywhere, and if they don't understand that, they are going to be fairly boring people, and not going to think life is as interesting as it is."

Kelly and Ann perceived the problems future generations will face, and wanted to do what they could to prepare their students to solve them. Increasing their students' interest in science and engineering as a step to the students' future careers was a goal for Kelly and Ann. Kelly sees STEM knowledge as a way to expand her students' personal career possibilities. "I think it is important because when they grow up I think there are more options for them if they are enjoying it and know the basics of it. And it can…open a whole bunch of doors for them." Ann opined, "I think students form their opinions about subjects quite early. I think that our priority right now is increased student interest in science." Ann strongly believed that her students must be willing and prepared to be scientists for the betterment of the community. "Because our next generation is going to have a lot of problems to solve that relate to science, and if they are not interested they are not going to go into science." Envisioning their students' future was a priority to all three of the teachers.

Their involvement in the Collaborative Conversations in STEM was evidence of their visions of elementary education in their classrooms and their school. Gwen perceived the need for effective professional development for herself and her colleagues. "Not because they are scared of the science, but because they don't have it.
And we don't get asked to do it and we don't have time to do it. So there is a hole, they don't have it, we don't have science." Her vision of her students' learning matches her vision of her colleagues learning. "I think it is a way for them to see what they can find out. I want them to be curious. I want them to know that they can ask questions. You don't have to go through life accepting what is around you."

Kelly, Ann, and Gwen's collective vision for others was evident in their own inquisitive, problem solving activities with STEM teaching and learning.

Inquisitive problem solvers

According to the Framework of the Epistemologies and Experiences of Elementary Teachers Committed to Teaching Science and Engineering, committed teachers are inquisitive, and look for evidence regarding what they should know, what they should teach, how they should teach, and how effective their teaching is. These inquisitive elementary teachers' commitments fueled their teaching, and framed their creative problem-solving in their professional experiences. Kelly, Ann, and Gwen were investigators devoted to their students and their students' futures. They were resolved to uncover and learn the content and pedagogy of science, technology, engineering and mathematics. They were determined to find ways to overcome obstacles that might stop them from learning and teaching STEM.

Findings showed that Kelly, Ann, and Gwen wanted to know, to learn, and to explore so they could teach, and their students could learn. They wanted to know what STEM concepts they should be teaching, and they made the effort to learn the concepts and the methods of teaching those concepts. They perceived their professional development experiences to be important, and each of them had taken opportunities to attend meetings, conferences, and workshops that addressed science, engineering and mathematics. Kelly revealed

> I teach science and I love learning what I am doing. Anything math or science related I want to go to. So I just want to learn more. I went to Saltrock last summer and that was where I took the physics class. I was afraid of physics in high school, but I took it [now] for motion and stuff. I really enjoyed it. We did a lot of experiments with it.

Gwen acknowledged her own curiosity, and over the years had taken advantage of professional development opportunities to fuel that curiosity. “When we first got computers when I was teaching in the city, it was really important to me to be part of the first people working with computers. I began taking courses at the university when I was there.”

As members of the Collaborative Conversations in STEM, Kelly, Ann, and Gwen participated in workshops by Brett Moulding, one of the architects of the Next Generation Science Standards, to learn about the NGSS, and to increase their content and pedagogical content knowledge. The hands-on investigations, which were part of the workshop, supported their efforts to be knowledgeable.

Ann also investigated new content independently, and described her own learning as a "challenge" to be met. "As a teacher you need to be informed and up-to-date and willing to keep learning because technology keeps changing and the integration piece is important." When the opportunity to increase her understanding of the Next Generation Science Standards was presented, Ann jumped on it, bringing Talk Science and HOT Science, two programs offered to elementary teachers in her state through a partnership with the state university, to her elementary school The professional development provided content and pedagogical content knowledge related to the cross-cutting concepts outlined in the NGSS.

Ann's description of the professional development opportunity revealed how she enjoyed exploring, experimenting, and testing new experiences, particularly when she could share them with her students or her colleagues. "We are trying out a curriculum and many of the people in the building are trying it out now, too. Which is amazing. And we are doing it through cross-cutting concepts, how to take simple science lessons and make them [develop] higher order thinking skills." Curiosity prompted these committed elementary teachers to seek the knowledge they needed to teach STEM.

Kelly, Ann, and Gwen were not only inquisitive about what they should teach and how they should teach, but they also wanted to investigate how effective their teaching was. They wanted to know what their students' know and think. Kelly, " I want to hear their thinking and know their thinking, and know that they understand the process and stuff like that." Ann asked questions to hear her students' reason, "You know I think naturally I have always asked kids to give [reasons]. I've always said to them, 'Tell me what you think. Tell me why.' The why has always been important to me, but now I feel I've defined it more through science really, and literacy, the evidence piece."

Kelly, Ann, and Gwen were problem solvers. Making time for science was a way they showed their commitment to teaching STEM. As Ann put it, "You need to be flexible as a teacher. Maybe a little creative in terms of how to get it into your current schedule type thing. That is more like a logistical thing." Working to give science time in the schedule involved changing the status quo. Gwen described the situation. "We don't get asked to do [science] and we don't have time to do it. Some people do, some people don't. Ann and I tell people where to find the time. We begged and got our schedule changed for that big block. We have a 70-minute block on Wednesday. All of us."

Problem solving in STEM teaching and learning was not just about finding time to teach. These committed teachers believed that the space and STEM lessons must be engaging for students. As Kelly puts it, 'It has to be fun.' Ann believed the responsibility for having fun rests on the students as well as the teachers. When a student approached her about recycling the yogurt containers from their lunches, Ann was faced with a pile of materials. Furthermore, Ann was continually seeking hands-on STEM activities for her students. Her problems were temporarily solved when she combined recycling and engineering design to have her kindergarteners build a pom-pom village.

> So we started a collection of stuff, recyclable stuff. And when the collection grew big enough I decided it was time to give them a challenge, "So I would like to introduce you to the pompom people and they don't have a place to live. ". So I said "We have some things from our recycle bin and I was wondering if you

> wanted to turn our kitchen area into a creation station so we can build a village for the pom-pom people." I gave them the challenge we had to design and plan. They had to brainstorm what we needed to build a village. They were pretty clear. They wanted a hospital. They wanted work buildings for parents, a school, roads, and a sidewalk. We have been planning and designing and re-planning and going back and now have this elaborate pom-pom village.

Ann's photograph of the project showed a compact structure derived from the students' design and built by them from various recycled materials.

Kelly, Ann, and Gwen perceived their roles in STEM teaching and learning were to make it happen despite the impediments of time, space or resources. They accepted the responsibility to acquire the necessary content knowledge and pedagogical content knowledge to teach STEM topics.

Creative Modelers

According to the Framework of the Epistemologies and Experiences of Elementary Teachers Committed to Teaching Science and Engineering, committed teachers are creative modelers. Modeling is a process of representing phenomena in a logical way. Modeling is essential to scientists who move science forward by constructing models and creating connections between phenomena (AAAS, 1993). These elementary STEM teachers committed to actively teaching science and engineering, Kelly, Ann, and Gwen, created models to help their students visualize and understand STEM. That pedagogy reflected a constructivist philosophy. Based upon that philosophy, Kelly, Ann, and Gwen designed activities that permitted their students to create their own knowledge and build their own understandings with assistance from the teachers.

During the car- sorting activity all three teachers described learning as “creating knowledge.” Kelly articulated it, “Well it started with teaching out of a textbook and then moved to more using manipulatives and doing science. And like exploring looking at rocks doing more like doing a lot of drawing and more writing about science. Kind of like that just from reading about it and memorizing words to stuff to doing and writing about it explaining it. With my teaching I would say ‘here are the things you need to learn’, but I am trying to move more into more creating things. More experiments like that, more hands on stuff. That is the direction I am heading in. Do more creating their own knowledge.”

Kelly, Ann, and Gwen applied their pedagogical content knowledge to create conceptual change in ways that were meaningful for their students. Gwen modeled behavior that led to constructing knowledge and creating conceptual change. In her classroom, in front of her students, she observed; she wondered; she posed questions; and she encouraged her students do the same. “We have conversations. The talking is all about the phenomenon. What they think is going to happen, what they saw happen, and what that might mean.”

Ann was committed to a constructivist approach to teaching, and embraced STEM as a venue for that. “I believe education should have a big constructivist and a practical approach for students, and I think they need to be able to make connections for why we are doing this. STEM brings that to the table and so I jumped on it.” Ann demonstrated that in the classroom with the “pom-pom village” design activity, and the colored water and celery modeling of a tree vascular system. Her actions in her kindergarten classroom revealed her commitment to STEM teaching and learning for the very young.

All the teachers perceived that creating knowledge was a personal experience and not always linear. Adjusting, relearning and making mistakes were part of the learning process. In the process of discovery, Kelly found that students might take a wrong turn. She was comfortable going off the beaten path: letting students make mistakes in the process of discovery was not a problem for her.

> I agree it is important to follow specific instruction, but then sometimes if you go off script then you can find out what you did wrong and how did that change. Like when doing an experiment and. "Well you forgot to do step three. So what happened?" Then it can be a learning experience. While I agree you should follow instructions, that sometimes [mistakes] can be a great scientific discovery something wrong. Like with the ivory soap. I guess that was an accident when it got made.

All three teachers created multiple opportunities so students create their own knowledge. Ann put it this way.

> If I feel we are not getting to the learning, that it is distracting I will try to steer the conversation. Or if they or she hadn't come to that place I would probably then looked for another experience to give them that's hands on so she can come to that. I would have probably put out some Unifix cubes and some scales and say, "Let's test it, let's try again." If she didn't agree still or the other kids weren't still getting it I think there would need to be a new experience provided.

By providing multiple opportunities, Ann was persistent as she modeled scientific and engineering practices of test and retest.

Kelly, Ann, and Gwen's commitment was evident in their awareness of the individual and collective developmental stages of the students. Constructing knowledge is a personal activity. Gwen helped her second-grade class design a motion experiment determining cause and effect with controls and a hypothesis. Writing a lab report was an important component of the activity. The students learned to articulate the procedure, the evidence they gathered, and their explanation for the results. Gwen connected the writing to the scientific process. When adjustments to the learning situation were required, such as a different writing format for different students, Gwen modified the learning situation to maximize a student's opportunity to create his or her scientific knowledge.

Kelly helps students understand through visualization. "Sometime I draw pictures if they don't understand it verbally because a lot of times they can see it better if there is a picture. I use the manipulatives to show them, too."

Gwen creatively modeled critical thinking for her students. She applied her pedagogical-content knowledge spontaneously to engage students' thinking. She employed questioning techniques, and evidence-gathering activities to help them build their ideas. She described how it might occur.

> Or we just look outside and say, "Have you been looking at the tree?" We have this awesome tree now that we can see that kept its leaves forever and it was red forever. So cool. We haven't done anything beyond that. We don't formally record anything. We just keep watching it. Those of us who came from another classroom, seven kids and myself, compare this to what we used to see. "What looks different? How come the sky is always so much more colorful over here?" as we are looking through the steam and smoke and stuff. "I don't know." We talk

> about it. “Do you think it has anything to do that we are seeing it in a different direction?” Some figured out that we are looking in a different direction. “So does that have anything to do with it?” So then they wonder about the steam. The question has always been part of it because I think they need to know how to ask questions and answer it.

In those ways Gwen was able to creatively construct investigations and models so all of her students learned how to observe, question, and construct their own knowledge. She was giving her students the curiosity and skills to be lifelong learners like herself.

Despite a lack of time and resources Kelly, Ann, and Gwen persistently modeled their perception of how important science, mathematic, engineering and technology was for their students. They created a venue for learning STEM by engineering their classrooms and their teaching to make STEM an integral part of learning. They made every effort to present science and engineering on an even footing with literacy and mathematics. Providing sufficient time, place and priority for science was one way they demonstrated that commitment.

During one of the Collaborative Conversations in STEM meetings the teachers revealed their perceptions that science was the most explicit way to model thinking and reasoning based on evidence. Traditionally, according to Ann, science and engineering activities had been an extra, an add-on to the curriculum.

> I had always taught science. I loved it as a subject. But I had never really thought about it as much as I think about my literacy instruction or my math instruction. I sort of thought of it as more of enriching stuff to learn. Because I love teaching it that really forced me to look at science education and STEM completely

> differently, as necessary, as equally important and having a progression of learning just like the other subjects. I think I had always thought of it, and I think there are a lot of teachers at the elementary level that still that think of it this way, as a topical thing to teach, but not something that you have to build skills around.

Like Kelly and Ann, Gwen was a proponent of hands-on learning, conversations and questioning techniques to help students take in and process learning. Gwen's style was, in her words, "not stand and deliver. …The question has always been part of it because I think they need to know how to ask questions and answer them."

Creative modeling was not just between the teachers and the students. These committed elementary teachers modeled and created links between different content areas for their colleagues. They were persistent in discovering opportunities to engage their colleagues. Gwen helped other elementary teachers see the links between STEM topics and practices and other disciplines such as literacy or mathematics. Connecting content with which her colleagues are familiar helps them become comfortable with science content.

> People are starting to see. The more STEM talks we have talking about [questioning], the more they are starting to see the same language that we use it across math [and literacy]. It's that people have a comfort level with asking that kind of questions. With some, if they had just started to do Talk Science and had to think about how you ask questions and get at people's thinking in science and math, that's much more scary. Elementary teachers are much more comfortable as a whole teaching literacy. Math is a little less scary. Science is scary.

These teachers integrated content and modeled scientific practice for their students and for their colleagues to increase STEM knowledge in their school.

Reflective analysts

According to the Framework of the Epistemologies and Experiences of Elementary Teachers Committed to Teaching Science and Engineering, committed teachers are reflective, and investigate the ideas of other educators, analyze those theories, and interpret them in the light of their own experiences**.** As elementary teachers committed to actively teaching science and engineering, Kelly, Ann, and Gwen were reflective. They investigated the ideas of other educators, analyzed those theories and interpreted them in the light of their own experiences. During the course of this study it was apparent that Kelly, Ann, and Gwen thought deeply about their practices. They analyzed previous personal experiences to grow in their pedagogical content knowledge and ultimately in their commitments to teaching STEM. They frequently reflected on classroom experiences to continually improve their teaching and their students' learning.

Ann reflected on how her training in art history prepared her to teach STEM. "But I tell you my content taught me how to think." She sees her experience in the classroom as the source of her pedagogical content knowledge. "I think you learn the teaching part by teaching."

Kelly analyzed and appreciated the connections mathematics and mathematical pedagogical content knowledge had for her as a teacher in ways she didn't have as an unengaged elementary student. "It is amazing what you realize you missed growing up and now it's like going back and rediscovering it as an adult like 'oh, that is what that meant'. It was kind of cool." Her analytical, critical thinking mind made the connections and engaged her intellect.

Experiences influenced the teachers to critically analyze their STEM content knowledge and pedagogical content knowledge. The National Board Certification process impressed upon Ann her need to learn more about science. "I realized I had deficit in that [science], and I was seeing it in a brand new way. And I am not someone who really likes to feel that way in my profession. I want to feel like I kind of know the latest or I am doing the best I can with the newest…I don't have the background to do it well, I need to figure it out."

Ann was a lifelong learner who went beyond the norm to investigate ways to be a better teacher of STEM. She reflected on her evolving into a STEM teacher and her feelings about her commitment.

> What drove me; somehow you asked what drove me to get involved, why the science, this STEM work. So I had done a little bit of research for myself that just tried to fill in the gaps of what I thought was missing when I did National Boards. So I feel right now like, I feel committed to keeping the work going but I feel frustrated myself. It feels like I am climbing up a really big hill. Why would I prioritize when I have twenty other things that I have to present data [literacy], to I have to put all my energy into that. Most people are doing it [Talk Science, HOT Science] because its good practice. It's good practice. The work we are doing is good practice.

Gwen spoke of how her graduate work developed her PCK to teach science. "All of the work with her helped me develop [modeling]. Our explanations were poor, very hard to articulate." Explaining phenomena was only part of it. Her instructor modeled questioning, and Gwen came to think, "If you are going to teach people you need to understand how to teach. You need to understand how to get them to think. You do that by asking questions you find out what they know and then you go Ping Ping [continue to ask them for explanations]." Gwen carried that into her classroom asking her students to think, reflect and analyze. "Where is your thought coming from? What gave you that idea in the first place? Where is your evidence to based to support what you say? The talking is all about the phenomenon, what they think is going to happen, what they saw happen, and what that might mean."

Reflecting, analyzing and interpreting phenomena of all types were the ways that these teachers showed their commitment to STEM.

Collaborators

According to the Framework of the Epistemologies and Experiences of Elementary Teachers Committed to Teaching Science and Engineering, committed teachers interact with their colleagues to share and evaluate their teaching and learning experiences. Kelly, Ann, and Gwen were collaborative communicators, interacting with one another and their colleagues to share and evaluate their teaching and learning experiences. Their involvement in the Collaborative Conversations in STEM demonstrated their willingness to collaborate. Kelly, Ann, and Gwen interacted with teachers at all levels of K-12 to brainstorm, initiate, develop, and share ideas for STEM learning. Each of them had indicated that the opportunity to collaborate was key to their efforts to increase STEM teaching and learning in their classrooms. According to Ann:

> There wasn't a catalyst for it [STEM teaching and learning] to go any further or for me to continue doing that after National Boards was done until that opportunity [Collaborative Conversations in STEM] was presented … the collaboration with other teachers, that it wasn't just about me being curious…. Creating this collaboration was hugely a factor for me to do this STEM work."

Ann's collaboration with a university research group outside of the school brought STEM teaching back to her building. Ann and Gwen worked together on several projects, and they collaborated with the building and district administration to initiate and foster STEM learning at the elementary level. Speaking about the new and evolving science program and the related professional development Gwen said, "they [teachers] get to try some STEM activities [and] we already see it [collaboration in science teaching]. People walk around the building joking with each other and saying, 'Oh that would make a good conversation, or 'that would be a good probe.'" Gwen reflected on how time influenced her recent STEM endeavors described an earlier environment before her collaboration with Ann and the administration. "They gave us two things [FOSS kits], but no time teach it. Just you have to teach these two units. But didn't give any planning time or time to do it. But that was more than we had before."

Gwen had a long history of collaborating with her colleagues. She worked extensively with others in mathematics and computer science. Recently, she was a math mentor, and a member of a district K-12 mathematics conversation. She had developed and taught a computer science course with teachers in another school district. Most recently, working with Ann, she developed curriculum and professional development activities in STEM. For many years she had collaborated with another teacher in their multilevel classroom.

Students who are studying science and engineering will collaborate and debate as part of the learning process. Gwen provided a good example of that occurring in her second grade classroom.

> It was a probe. It was with marbles and a piece of tubing. Our tubing was the end of a roll. Someone tried to get it open and you had to hold it in place and have at least one curve [as a spiral]. You had to predict how it would come through the shoot loop, curve left, right or straight ahead. In this group, one [student] was convince it was curving, while the others thought it was going straight. I didn't provide an alternative explanation. It was more, 'what could you do to figure it out.' They decided if it would leave a mark they could track it. So I just said, "Are there any materials?" Literally. [They] got paper. Wet the marble. And it came down. And the darn thing did curve. I know it [tubing] didn't move. So the four of us sat there. We took it back to the group because other groups had been doing their experiments. I asked someone from this group to explain exactly what happened. Big class discussion ensued about that and the conclusion was: that even though we didn't see ourselves do something, we must have done something to influence it. Because it should have gone straight because everyone else's had gone straight.

Gwen found that, like some scientists, the doubting student was not convinced that the ball would go straight and would need to repeat the experiment in the future. "Oh well, I do try to help them when they get it wrong. No point in my telling them. They are not going to believe." Gwen believed that creating knowledge required evidence gathered from personal experience with a phenomenon.

Ann collaborated with members of the community to provide a variety of creative experiences for her students. "I brought in Alice because I don't know anything about gardening. I mean I know about gardening, but she is like an avid gardener. So she has talked to them all about seeds and monarchs. Bringing in people doing real world things, I connect [students] to [science and engineering] professions."

By collaborating among themselves, with colleagues, and encouraging it with their students, Kelly, Ann, and Gwen promoted scientific and engineering practices and reinforced their commitments to teaching STEM. Their activities inspired the parent-teacher organization to host the first STEM night for the elementary student–parent partners who engaged in inquiry-learning together. The school budget began to include curriculum materials because of their advocacy for STEM teaching and learning.

Teacher Experiences

Teachers' epistemology and knowledge develop as they reflect on individual life experiences, which are complex, and influence all aspects of teaching. This section of the chapter will focus on the experiences elementary teachers committed to actively teaching science and engineering describe as influential to their pedagogical content knowledge, and to their commitments to teaching STEM. Kelly, Ann, and Gwen shared their perceptions of their early experiences, both informal and formal, that influenced them to be teachers, and framed their early perceptions of the teaching and learning of STEM. They also shared recent experiences interacting with students within the classroom, as well as experiences interacting with other education professionals that they perceived influenced their commitment to teaching STEM. The evidence revealed the beliefs and knowledge that influenced their commitments.

Early informal and formal learning experiences.

Early informal experiences can influence knowledge and beliefs about STEM. Kelly, Ann, and Gwen's very early personal STEM experiences demonstrated their emotional comfort-levels with science, and particularly with inquiry. Ann spoke of exploring nature, and observing bugs as a child. "The memorable part of my childhood was engaging with outside world and wondering how things worked…You know I wasn't into the sciences. I was an outdoor kid. I spent a lot of time outside… working in the garden with my dad learning about plants what they needed, how they grew, where they grew, how to take care of them. I loved nature."

Gwen had experiences with snakes and bees, fire and magnifying glasses, shells and fossils, computers and fish eyes, and she learned to ask questions about them all. "We always had pets. We had an alligator. Our family was big on historical names. Alexander the great the alligator and Socrates the snake." Gwen made an early connection with scientists on her way to elementary school in Princeton, New Jersey. "I got to walk by Einstein's bench every day!"

Initially, Kelly described her informal experiences as "nothing sciency," but later conversations indicated she enjoyed spending time outdoors. She mentioned an early interest in Legos, Tinker Toys and building things. Her informal interest collided with her formal schooling. "Well, I really feel bad because I failed industrial arts. I didn't really fail, I got a C. Dad is a carpenter so he was really disappointed. But anyway that was more of a class. But for fun I would do those things."

Kelly, Ann, and Gwen presented their perceptions of formal school experiences with teachers who demonstrated high standards for teaching. All three teachers in this study attended traditional K-12 schools in the United States. They spoke of being intellectually and emotionally engaged, while developing their high expectations of teachers and teaching. They also told stories of teachers they perceived had not made the commitment to engage students in inquiry learning, teachers who were boring or mean.

Gwen's science education content and quality varied greatly over her K-12 education, but she spoke of a first-grade science experience where Mrs. Brookes modeled exceptional teaching.

> We had magnifying glasses and we were talking about how they worked. So I asked if we could take it outside and see if we could set something on fire and she let us. So we went outside and we did it. We set a fire on the playground and nobody got in trouble. But that impressed me so much, not only what I learned, but also the fact that we got to do it. She was a great teacher, my first grade teacher, Mrs. Brooks.

Kelly and Ann did not recall positive memorable science experiences in elementary school. They indicated that their pedagogical experiences as children influenced their own STEM pedagogy by illustrating what not to do as teachers. Their STEM experiences were not inquiry-based or student-centered. Ann recalls second grade,

> I remember my textbooks. I remember learning about clouds from a textbook in second grade. I remember opening it up and reading and the teacher would call on one person to read a paragraph. I remember learning about different types of clouds. I don't have a lot of memories of being taught science. All of our field

> trips that I remember were very social studies focused. I don't ever remember going on a science field trip.

Ann was very specific about her previous experiences in learning and described her most influential personal experiences with STEM as those that involved hands on learning.

> You know, I have a very vivid memory of when things started to shut off for me. It was when hands were just writing and my ears just listening. To this day I know about myself that if I want to learn something I have to do it.

Kelly did go on a field trip in sixth grade. "The only field trip I remember taking was the one to Mount Mica, which cemented my hatred of geology. I just didn't like it. It was boring because I didn't understand it. I didn't understand the differences between the rocks. And I just didn't care."

All three teachers mentioned that the hands-on lab activities in high school were among the "best times" in science classes. Dissecting frogs in biology, and creating unauthorized mixtures in the chemistry lab were memorable experiences. However, Gwen expressed frustration at her experience with physics, and the trigonometry class preceding it. She recalled that the boys in the math class received all the teacher's attention. Consequently, she dreaded taking physics.

> I hated trig because I couldn't make any sense of it and nobody was willing to help us try. The whole class was completely frustrated. There was that math teacher. It was like "It's my way. If you don't understand it, too bad"
>
> I don't understand trig. I know enough to know if I don't know enough I am going to have a really hard time [in physics]. We are in the era of slide rules. It

> was horrible. There were only two girls, myself and the smartest kid in the building. Thank God. She was also another reject. So I manage to sit it out. [The physics teacher] kept telling us, “Imagine the flag pole. Imagine a tree.” Imagine everything. We did nothing. No labs. At all.

These committed elementary teachers perceived their personal classroom experiences with hands-on, inquiry learning were influential to their own STEM content knowledge and pedagogical content knowledge.

Pre-service experiences.

Kelly, Ann, and Gwen related college experiences shared by many elementary teachers. Kelly and Gwen majored, and Ann minored, in education in their undergraduate careers. Nationally 90 percent of elementary teachers take a life-science course, but these teachers took geology, which is comparable to 65 percent of elementary teachers (2013). Kelly, Ann, and Gwen did not indicate that formal academic science courses made a positive impression on any of them. Kelly found her mathematics-methods and science-methods courses interesting and useful. But describes her college science course differently.

> I took science once in geology to get it out of the way. Summer session, three weeks. Done. I started taking biology but I didn’t like it. It was too hard even though I liked it in high school. I took the most minimal science course I could. I really liked the science methods classes. It was fun. It was easier to understand because it was at a lower level. It was at the elementary level. It was more basic. More fun. How to teach it and learn how to do these cool activities rather than to read out of a book and memorize.

Gwen completed a bachelor's degree in elementary education with extensive study in child psychology, one semester of geology, and a student teaching experience in an urban setting. " Psychology for three years and the last year education. I have a degree in education, and I was only missing the last couple classes the research classes to graduate with psychology."

Ann earned an art history degree with a minor in education. "I went to a liberal arts college, and I took a variety of courses. I picked a major in art history and along the way I took an education class. It just very much sparked me and resonated with me as a learner. I just found a real passion for how people learn in education, so I continued to take education classes but still majored in art history. I minored in education, graduated and assumed I would do something with my art history." Ann also took geology and biology to fulfill the science requirements in college, and for teacher certification.

Their early STEM experiences, as perceived by these teachers, did not provide a foundation of content knowledge for STEM teaching. Pedagogical content knowledge was influenced by both their positive and negative STEM experiences.

In-service teacher experiences

These committed elementary teachers of science and engineering described several situations when interactions with students were STEM learning experiences for themselves. According to them, learning and inquiry science are "messy." Kelly, Ann, and Gwen acknowledged that they acquired STEM pedagogical content knowledge (how to present material so others can learn) in student learning experiences.

Classroom experiences. Ann described a lesson in pedagogical content knowledge she learned from her students illustrating how messy it can get.

I wanted to observe a tree for the month of October, and I wanted to focus on the tree as a system that would need to like shut down in the winter and wake up in the spring. We were watching what was happening to the tree and the leaves were falling off. I felt like the kids needed to understand what was happening in the system of the tree to make the leaves fall off .I wanted them to understand capillary action and the stopping of it.

I thought they could get that the ground was going to freeze and the water could go up any more. I tried to keep it simplistic. I know it is much more complicated than that. I did this good old celery experiment that water you know travels up. You color the water so they can see. So we put the celery in and I ask them to make some predictions what do you think is going to happen when I put the celery in the water. We had talked about how the trees need water and where does the water come from.

I can’t remember what the predictions were but when we came back the next day and we were looking at our experiment. I had used red water, which was a really bad choice because the leaves on the tree were red in the fall we were observing. They made a direct connection that the water in the ground turned the leaves red. Because the water in our celery came up and turned the celery leaves red. And I was like oh no…. we needed to back track .The majority of the students were distracted by the color.

Oh yeah they are kindergarteners and that was it and I probably left my kids with the misconception. I tried to back track but the fact is I think seeing is believing and they saw it and now that's what they think. And we talked more about the other things too but in that moment I was like oh that's bad.

And then another little girl, I think this is really interesting because this is very kindergarten, too, I said to her [as] she is drawing the picture of what happened.

So Penny, what happened overnight?

She's like, 'Oh everything turned red.'

And why is the celery red?

She was just like. "I don't know"

I said, "so do you have any thinking about that?"

"Its magic."

So my backtracking for her was. "Science can feel like magic can't it? But I am going to tell you a secret about science. There is nothing in science that's magic. There is always a reason".

And so I said let's think more about it.

That experiment was a little disastrous in my opinion, and the way I covered it was to go back and try other lessons to re-fix what I had messed up.

Experiences like the one mentioned above influenced Ann to acquire knowledge of the intellectual and emotional needs of children. She perceives engaging students and making the learning accessible were important aspects of pedagogical content knowledge. Gwen and Kelly also had a variety of classroom experiences that influenced them to make STEM more accessible to their students. Kelly commented about how she integrated STEM across the curriculum. "I just like to switch things up and do things differently and try to the things that are best for the kids." Since Kelly was also responsible for the social studies content, she integrated it with science. As she incorporated her acquired content knowledge to her teaching, the integration provided more time for science and engineering. She tied United States geography, NASCAR racing, engineering, and physics together.

> I am doing a little USA tour. We are studying United States geography. One of the things I am really looking forward to having them do is build things. Like for example, when we study the southeast I know they have a racetrack [Daytona]. So maybe they could build a racecar and then they could build that and time how long it takes to go from the top of the ramp like see how long it can go. You know just to kind of incorporate the social studies with the science.

Classroom experiences that included curriculum integrated to facilitate learning provided a venue for these committed elementary teachers of STEM to increase their pedagogical content knowledge. However, Kelly was conscious of how and when to integrate curriculum. “This year with the waves I am trying to figure out where I am going to put that. I could do it in the Southeast with the hurricanes with the waves in the oceans. So it’s like I don’t want to stop in the middle of what I am doing and just throw it in.”

Ann perceived her role as a teacher was to help students learn holistically. “I think of science as science and then it is my job to take the big picture and make it translatable to five year olds. I believe education should be integrated. I believe it should be hands on. I think they need to be able to make connections for why we are doing this.” In one of her examples of integrating content, Ann applied her own knowledge of art to teaching her kindergarteners.

> We did Jackson Pollock. We were doing movement. So we did motion painting inspired by Jackson Pollock. They had sticks with all these different colored paints. And each stick had a different type of motion they had to use. So like yellow might be up and down. Green was a circle. They did that and we hung these in the hallway with a big sign: 'Can you find the motion in our paintings?'

Gwen provided inquiry experiences for her students and supported them in their efforts to learn, she firmly believed "stand and deliver" teaching was a waste of time. Gwen described what she would call a 'perfect' STEM learning experience. Her students collaboratively created a model based on an engineering design of their own while learning about gravity, acceleration and momentum.

> It was about marble rolling down. In the balance unit there are half piece of Styrofoam pipe like pipe covers. It was literally the last day of school and I was determined we would get a last experiment in. [I] turned them loose with this whole box of stuff and tape. And they taped it everywhere. And everyone was trying to see what would happen, where it would go and how far it would go. And so they did started putting the whole thing together and it was monstrous. But the coolest things is that they kept a couple of them that had such steep pitches that the marbles fell off. There was a group of seven and were trying to study it. They talked with different groups of students to see what they could do. "What if you put a lid on it?" And so they did. And they taped a lid on this tricky part to force it down so it would pop out the same way below. They finally got the hang of it. They had to cover it to a certain point. The entire class was watching and

everybody was talking. The principal happened to come in right then and they couldn't wait to show off.

Gwen described several hands on, physically active lessons in science, mathematics and engineering where she perceived her students' learning was influenced by her constructivist teaching. "Turtle moves" helped students understand procedural writing.

Kelly connected her own learning to her classroom and her commitment. She expressed it this way, "I teach science and I love learning what I am doing." When she was asked what would she do if she were told to stop teaching science and to teach more reading and writing she replied, "I would probably use that reading and writing time to read and write about science."

Among their experiences in the classroom each of these committed teachers used engineering practices, along with science practices, to have students question, design, build and test phenomena. Ann's students designed and build their "pom-pom people's" neighborhood. Gwen's students designed and built catapults (see below). Kelly explains how she has her students design and test circuits.

> O.K so I have been trying, slowly. I haven't really done much of a transition. But trying to get more hands-on stuff, more with building and creating. I do an electricity and magnetism unit, which I just finished. And they basically take magnets and they do explorations about what things stick to magnets. For the electricity part they build circuits. The first thing I did was I told them, "O.K. this is a "D" cell, and here is a wire and a light bulb and try to get it to light. These are your components and these are what you have to do." I walk around and they are

> working in groups and I try to get them to figure out how because a lot of kids will just take the "D" cell and the wire and go like this [stretched out arm representing the battery at one end of the wire and the light bulb at the other]. And I ask them questions to get them to see well you know "how is the electricity going to go from the light bulb back?" I try to ask them questions that get them thinking so "why don't you try this?" And you know, eventually, one person gets it and they all run to see how they did it and so then it is like an exploration type of thing.

Kelly's assessment of the activity required student understanding of electrical circuit mapping acquired during the activity.

STEM classroom interactions like the one Kelly described above and Ann's demonstration with red food coloring and celery provided experiences where identifying misconceptions and modifying lessons were necessary aspects of pedagogical content knowledge. These committed teachers differentiated the STEM activities so all their students could learn. They integrated literacy and science. Gwen spoke of a physical science lesson that required the students to write down observations.

> We are trying a new literacy unit that is about writing lab reports.
>
> You'd be so proud of their little lab reports. They are quite cute.
>
> There is a question. Then they have written their hypothesis. We have our procedure pages and our experiment pages; they are all sort of mishmash, but then at the end they have the results and conclusion. They have to mention their hypothesis they have to say, 'What made them think this?'

They are trying very hard to make sure that in each trial the conditions are the same, the best that a 6,7, or 8 year-old can do. They know when they had to write their own question. Each group had to design another question. But they could change only one variable.

But we wrote our first procedure together. We did the experiment all together at first so that was sort of their model to go from. We were doing ramps, 'Will it go farther on the carpet or the bare floor?' They tried to keep those the same and then they changed one variable. And they did a lot of interesting things.

And the next one was a catapult. They had a pile of materials. Some asked for something different, so we got it. Which would go further using their catapult, with a cotton ball or Ping-Pong ball? Some [catapults] were built up in the air to get them off the ground. Some were just a plastic spoon and rubber band. Some just took the spoon and rubber band, but they had the hardest time keeping their controls. And those were a little harder for them to write up in the sense that there were more things they had to think about. But they understood the procedure a little better so the lab reports were very interesting.

[Procedural writing] is very difficult. I think it is more difficult than even claim writing. Remembering all the pieces. That was the big learning for them. You have to remember things. But scientists have to write down their data immediately. As they collect [data] they write it down. And you make sure you write it down with units. I think my class was the only class that measured in centimeters.

In Gwen's second-grade class there were students who read and wrote above and below grade level because of their developmental stage and age. She differentiated the writing exercise to emphasize the scientific knowledge. "It's a very hard writing for some of them so I put the closed procedure page on one of them. 'When the ball went ____ it was _____.' "

Each of these committed teachers expressed their personal expectations to meet the needs of their students learning in all areas including STEM.

Professional learning and collaborating experiences. Kelly, Ann, and Gwen demonstrated their commitment to STEM teaching and learning during their teaching careers. Until they became teachers they did not become intellectually engaged with STEM content and pedagogy, but during this study Kelly, Ann, and Gwen revealed a lifelong love of learning, and called upon previous professional experiences to guide their search for STEM professional development. Along with other members of the Collaborative Conversations in STEM, these committed teachers believed that high-quality professional development in STEM had positively influenced their pedagogical content knowledge, while engaging their intellects**.** Kelly, Ann, and Gwen described a variety of professional development experiences that occurred in programs provided by universities.

To support her own learning and strengthen her commitment to her students learning, Gwen took a year leave of absence from teaching to broaden her pedagogical content knowledge in several subjects including science. Her graduate course in science and mathematics teaching and learning with Eleanor Duckworth made a great impression on her values, and influenced her pedagogy.

> The part that has changed is that I am better at making sure they [students] are talking about it [science] and saying what they are thinking. The questioning piece. From Duckworth. That definitely came from her, and spending all these half-hours with those four little kids week after week. I really knew those four little kids really well, at least what they thought about science. I am less willing to not do science.

Recent summer time professional development in science has made a strong impression on Kelly, Ann, and Gwen.

Kelly attended a weeklong "STEM camp" at a remote math and science magnet school where the courses were taught by university professors and K-12 science teachers. From her comments, the experience engaged her intellectually and emotionally. It made an impression on her personally. Kelly enjoyed investigating in a content area that previously stumped her.

> I went to [Saltrock] last summer and I took a physics class. I was afraid of physics in high school, but I took it [here] for motion and stuff. I don't teach motion in fourth grade, balance and motion, but I really enjoyed it. We did a lot of experiments with it and stuff. I seriously think that this summer STEM camp really got me interested in physical science even though I was afraid of physics in high school.

Kelly described the camp.

> It's five days, Sunday to Friday and you live on campus. Three classes a day. Its like one hundred bucks and includes everything, room and board. It's like being at school again. Go to breakfast. Go to two classes. Go to lunch. Go to another class.

> You have evening activities, then dinner, and then more evening activities. And then you go to bed. And do it again the next day. It's like being a student again. It's fun. Again why I wanted to be a teacher is because I loved being in school. It's fun.

That same summer, Ann and Gwen also participated in a weeklong summer professional development experience at a state university. The week was to prepare them to support other teachers' STEM professional development during the school year. The university they attended had previously trained Ann as a STEM resource-person during a series of workshops in the school year. She had facilitated a group of colleagues in the activities. After that school-year session, Gwen joined Ann as a resource partner, and they attended the summer session together. It involved one week in which they did activities aimed at their students' age group, followed by a professor sharing the science or engineering behind the activity's phenomenon, discussing it with the participants. Both teachers described the experience as influential to their acquisition of STEM content knowledge and pedagogical content knowledge, while connecting with their emotions. Gwen spoke at length.

> [It was] a week where we could go and have professional development ourselves. Literally had various college instructors. Working with us poor teachers who didn't really know very much, and had lots of misconceptions. But it was great.

Gwen's curiosity prompted her to observe and analyze other teachers' efficacy and reflected on her own.

> It was interesting watching some people who felt very confident and some people like me who were less confident. I was in the middle range. Ann and I were in the

> middle range except for math when Ann would say. "I know nothing." But I didn't have that feeling even though I didn't have much more than she did but I didn't feel that way.

. Gwen described those instructors who could communicate and engage the teachers.

> The engineering guy was amazing. He just knew how to talk to us and some of the things he said were so insightful. But his way of introducing projects that we did and helping us through a discussion and give us enough information so we actually understood some of what we were observing.
>
> He didn't make you feel stupid and that it was obtainable, but more importantly you could work with kids and other adults and help them. Not that we would have the information that he had, but we could help them have the experience.

Participating in professional development that influences STEM teaching and learning can be overshadowed by early experiences, and can determine engagement in later experiences. When asked about taking a university physics class after the summer experience Gwen said, "A full class in it, no. I would love to be able to take one but that's like a trig problem." (Gwen was referring to her struggle to learn trigonometry and physics in high school that was discussed previously.)

In contrast to the summer professional development she shared with Ann, Gwen told of a different summer experience that was very informative and engaging, but, since it did not relate to the kinds of things she could do her classroom, it did not affect her STEM teaching in the long run. She missed the opportunity to share the experience with someone else, and to share it with colleagues on her return.

> No actually it was an out of body experience for me, too. It happened so close to the end of the school and it was sitting by itself. And I feel the knowledge seeping away. It was fabulous out of body experience, intensity, but without other supports.

Kelly, Ann, and Gwen frequently spoke of the need for professional development experiences in STEM. According to these teachers, until they came together to initiate STEM PD at the school after regular working hours there had been no on-site science and engineering professional development within the last decade. The literacy push after NCLB had employed all the school's professional development resources. Grants and stipends from other sources had provided some professional development in the sciences. Gwen found an opportunity on coastal sciences that was aimed at middle- and high-school teachers, but the organization was willing to include her because of her interest. The Talk Science and HOT Science resource partnership program that Ann and Gwen brought to the district was completely funded by an outside organization.

Collaborative experiences fueled Kelly, Ann, and Gwen's commitments to teach STEM. The social aspect of scientific development, the discussion of ideas, the sharing of opportunities, the mutual interest and support brought them together with the Collaborative Conversations in STEM. The invitation for the conversations was sent to all elementary teachers in the district. These three teachers and one other colleague responded and stayed active over the course of several years. Other elementary, middle- and high-school teachers have participated in the conversations, but these three have consistently engaged in the discussions, and used it as a spring board for other discussions of science in their buildings. As Ann stated, "Two factors that were hugely important for me to push to do the work: one was the collaboration with other teachers. That it wasn't just about me being curious. So that it was collaborative was huge; and [the other factor was] that one of our administrators sort of gave the green light for this kind of off board work."

As elementary teachers committed to actively teaching science and engineering, Kelly, Ann, and Gwen were supported by their collaboration to experience leadership roles. A member of the Collaborative Conversations in STEM, stated, " It is good to get together and hear what other people think, what they are doing especially in science." The collaboration influenced these teachers to lead PD activities and curriculum policy within the district that in turn supported their pedagogical content knowledge. Gwen related what was happening,

> But what's so cool about what is going on right now for us is it's all coming from the teachers. The principals are not saying no. They are saying ok. No one is required to do it [after school professional development] and not everyone is doing it. The vast majority of people are involved in it. Twenty-nine people are signed up right now. Not all of them are teachers, some are ed techs. And [the math coach] is signed up, and the principal is signed up. So probably 24 teachers. So two-thirds [of the faculty] are voluntarily doing it, and this is their second round. They had to take the Talk Science before they could do HOT Science.

Kelly, Ann, and Gwen, with support from the PLC, requested funds and attended an NGSS workshop together. They began a discussion group around the document, *Ready, Set, Science.* They applied for and received grants to create new STEM activities for their students, and they were awarded grants to form another grade-specific professional learning community that developed and coordinated curriculum.

Kelly, Ann, and Gwen repeatedly noted their need for content and pedagogical content knowledge particularly in science, engineering and technology. According to Kelly, “I would like to have more PD. I like having the freedom and not having a specific curriculum because I like making up a tour and it’s fun to build and do my own thing. But at the same time it would be nice to have some PD around the concepts and know what are some things I could do to make my teaching better.”

As lifelong learners, Kelly, Ann, and Gwen perceived that high quality intellectually stimulating experiences strengthened their commitments to teaching STEM. Such experiences in the classroom and in professional development were perceived by these teachers as important, engaging, informative, not constricting or overwhelming learning experiences.

Summary

These committed elementary teachers , Kelly, Ann, and Gwen, shared their knowledge and beliefs as visionaries, investigators, problem solvers, creative modelers, critical analysts and collaborative communicators. Their collective commitment was most evident in their dedication to their students’ future, and their need to collaborate with other teachers who were actively teaching science and engineering.

A lifetime of STEM experiences influenced their knowledge and beliefs. Early formal and informal experiences included enjoying nature and the outdoors, as well as hands-on inquiry learning they encountered as students in elementary school or high school. Interactions with teachers, and a variety of teaching methods, were recalled.

Professional STEM learning experiences were perceived as influential to their commitments to STEM teaching. Kelly, Ann, and Gwen's influential STEM experiences were unique to each of them, and occurred in no particular pattern or time in their careers. Their perceptions of those experiences characterize how they approach STEM teaching and learning personally and professionally, and influence their commitments to actively teaching science and engineering. Their accounts of in-service experiences included collaborations on many levels, with students, colleagues and within professional development opportunities. These teachers perceived that the activities within the Collaborative Conversations in STEM led to their collaboration with other colleagues. Kelly, Ann, and Gwen perceived a change in their colleagues and the administration, and attributed that to their initiation of professional development opportunities within the school..

Chapter Five: Discussion, Implications, Future Research and Final Remarks

Elementary teachers committed to STEM learning are critical players in the development of a 21st century workforce. These elementary teachers, Kelly, Ann, and Gwen, teach science and engineering despite an environment that minimizes the importance of the subjects. This qualitative study investigated the epistemologies, knowledge and experiences of these committed elementary teachers of science and engineering to answer the research questions: What are the beliefs and knowledge of elementary teachers committed to actively teaching science and engineering? What experiences do elementary teachers describe as important to their knowledge, beliefs and their commitments to actively teaching science and engineering?

Kelly, Ann, and Gwen shared their perspectives and perceptions in a series of interviews that were framed to explore their backgrounds, knowledge, experiences, epistemologies, and collegial interactions related to STEM teaching and learning. This chapter will discuss the findings to understand the essence of their commitment to teaching science and engineering. Kelly, Ann, and Gwen's beliefs and knowledge as elementary teachers committed to actively teaching science and engineering are presented in light of the professional interactions with students and teachers that reflect their personal epistemology and understanding of science and scientists. Analysis reveals how their formal and informal STEM experiences, particularly their in-service teacher experiences, influence their individual and collective commitment as it is demonstrated in their values, teaching stances, lifelong learning, and emotional engagement with science, engineering and mathematics. The beginnings of their transformative leadership science-education reform are discussed. Finally, the policy implications of the results of this study, and suggestions for further research, are presented.

Teacher Knowledge and Beliefs

Kelly, Ann, and Gwen are committed elementary teachers of STEM. This section of the chapter will focus on revealing the underlying structure of their beliefs, teaching knowledge and knowledge of science that their perceptions revealed. The evidence of how they approach, prepare for, implement, evaluate and refine their teaching of STEM illustrates their deep connection to STEM teaching and learning, which further strengthens their commitment to teaching STEM.

Kelly, Ann, and Gwen approach teaching and learning as a scientist would approach doing science. These committed teachers have become visionaries, investigators, problem solvers, modelers, analysts, and interpreters. Like scientists, they have found intellectual engagement and emotional support when they collaborate with other educators. They communicate their content, pedagogical content knowledge, and commitment to their colleagues and students.

The characteristics of scientists were presented in Table 1 in Chapter 2, and served, along with Table 3 in Chapter 3, as a framework for the characterization of committed elementary teachers in Chapter 4. Because engineering practices are closely related, only the more consistently evident scientific thinking and practices will be discussed in the analysis. These findings illustrate the extent to which the epistemologies and practices of teachers and scientists are parallel. A comparison of the characteristics of scientists

Table 5. Characteristics of Scientists' and Teachers' Thinking and Practices

	Scientist	Teacher
Visionary	Scientists look to the future. Asking the right questions propels scientists into investigating the unknown (Moore, 1993).	Teachers look to the future, aware of their students' future needs, and those of society. Teach children to be inquisitive, curious and creative. Teachers strive to increase their students' interest in science and engineering.
Dedicated investigator and problem solver	Scientific questions are distinguished from other types of questions in that the answers lie in explanations supported by empirical evidence, including evidence gathered by others or through investigation. (Lead States, 2013, p4)	Teachers ask questions of themselves and their students. Teachers are inquisitive, and look for evidence regarding what they should know, what they should teach, how they should teach, and how effective their teaching is. Teachers are problem solvers by making time for science in their classrooms and in the school ,and overcome obstacles that might stop them from learning and teaching STEM.
Creative modeler	Modeling is a process of representing phenomena in a logical way. Scientists strive to make sense of observations of phenomena by constructing explanations for them that use, or are consistent with, currently accepted scientific principles" (AAAS, 1993)	Teachers create models to help their students visualize and understand STEM. Teachers perceive learning as creating knowledge, and they design activities that foster conceptual change in ways that are meaningful for their students.
Critical analyst and imaginative interpreter	Scientists, who create meaningful models of phenomena review, retest and rethink previous models. (AAAS, 1993).	Teachers are reflective. Teachers investigate the ideas of other educators, analyze those theories, and interpret them in the light of their own experiences.
Collaborative communicator	Science is a social practice. Scientists obtain information and communicate ideas to evaluate the merit and validity of claims, methods and designs. (AAAS, 1993).	Teachers interact with one another and their colleagues to share and evaluate their teaching and learning experiences. The opportunity to collaborate was key to the increase of STEM teaching and learning in their classrooms.

with the characteristics of these elementary teachers committed to actively teaching science and engineering is given in Table 5. The practices of professional scientists are so persistent and pervasive in Kelly, Ann, and Gwen's teaching and learning that it is appropriate to refer to them as *scientist-teachers*.

Scientist-teacher as visionary

Science moves forward because of imaginative thinking and the keen appreciation individuals have for the natural world. Scientists look to the future, and seek to increase knowledge of the world. They dig deeply into phenomena, and reach out to find new phenomena. Kelly, Ann, and Gwen have had myriad experiences that influence their commitment to STEM teaching and learning. The experiences developed their appreciation for the world as it is, and as it could be. These elementary teachers committed to actively teaching science and engineering also look to the future, aware of their students' future needs and those of society. Because they recognize the skills their young charges will need in the future, Kelly, Ann, and Gwen strive to increase their students' interest in science and engineering as an impetus to be inquisitive, curious and creative. They teach their young students the skills they need now, with an eye to the abilities they will need in high school, college, and as happy, productive adults. As Gwen put it, "Because they have to understand the world and be curious about it. You can't be a lifelong learner if you're not curious. And the world is all around us, involves science and math everywhere, and if they don't understand that, they are going to be fairly boring people, and not going to think life is as interesting as it is."

Teaching can be isolating. Meeting the immediate needs of young students with very brief interactions with adults can narrow a teacher's perspective of what is and isn't important. Kelly, Ann, and Gwen do not isolate themselves in their classrooms, but keep abreast of local, national and international developments. Ann reads extensively about international education reform particularly in Finland. Both Ann and Kelly achieved National Board Certification. Each of these teachers is aware of the reform movements in the United States. While NCLB makes an impact on their teaching each day, they are well versed in the Common Core State Standards for English Language Arts and Mathematics, and have delved into the intricacy of the Next Generation Science Standards. These elementary teachers' visions have led the way for STEM reform in their own school by providing STEM professional development and advocating for STEM resources. Encouraging other teachers to look beyond the classroom door may influence their colleagues' and their own commitments to STEM.

Scientist-teacher as investigator and problem solver

Scientists are inquisitive. They ask questions about phenomena and devise a way to answer those questions. They share problem-solving skills with engineers. New knowledge, new inventions arise from their curiosity.

Committed elementary teachers are curious. They ask questions of themselves and their students. Their lifelong learning experiences reinforce their resolve to learn the content and pedagogy of science, technology, engineering and mathematics. Their dedication empowers them to solve problems, and overcome obstacles that might stop them from learning and teaching STEM.

Kelly, Ann, and Gwen are inquisitive, and look for evidence of best practice to know what they should teach, how they should teach, and how to determine the effectiveness of their teaching. They are ingenious problem solvers who make time for science in their classrooms and in the school, even when there appears to be no time. These teachers make every effort to feed their students' curiosity, along with their own. They are not bored by teaching or learning because they discover ways to make it interesting.

Kelly, Ann, and Gwen independently and collaboratively delve into the Framework for K-12 Science Education and The Next Generation Science Standards to determine the content they should teach. They investigate sources of professional development, curricula, and materials that support STEM teaching and learning in their classrooms and school. They ask questions of one another to learn what STEM-content and pedagogical-content knowledge is most useful in a particular learning situation.

While teaching, Kelly, Ann, and Gwen promote their students' understanding by asking questions, and listening to the students' thinking. They teach their students how to investigate and, simultaneously, they investigate what their students do and do not know, can and cannot do. They do so with science and engineering content, but also with art, social studies, and technology. Kelly told how she helped her students investigate why an electric circuit would or wouldn't light up, without explicitly telling them the reason. The students constructed the knowledge as they constructed the circuits foreshadowing a time when they may construct their own invention.

Scientist-teacher as creative modeler

Scientists strive to make sense of phenomena by constructing explanations for them using currently accepted scientific principles. Modeling is a process of representing phenomena in a logical way (AAAS, 1993). Committed elementary teachers create models to help their students visualize and understand STEM content.

Kelly, Ann, and Gwen perceive learning as creating knowledge, and they design activities that foster conceptual change in a way that is meaningful for their students. They are skillful teachers. The questions they ask their students lead the students to logically construct their own knowledge of phenomena and ideas based on evidence. They present multiple novel opportunities to students encouraging investigation, the gathering of evidence, and the development of the students' own models. They help their students visualize the phenomena from different perspectives, and lead their students to develop accurate models. They explicitly present mathematical models, as well as visual models. Ann's autumnal tree observations and experiment is one example of modeling a complex system.

Kelly, Ann, and Gwen balance the models of phenomena they present to their students with the inquiry process they model as they teach. These elementary teachers committed to actively teaching science and engineering wonder aloud. They ask questions of themselves. They propose explanations. These teachers create an environment that encourages observation and analysis based on evidence. Gwen's looking out the window at the sky to observe changes due to steam is one example. Using ordinary examples to illustrate STEM concepts makes knowledge accessible to a learner. Kelly, Ann, and Gwen are creative modelers, making the abstract understandable to the youngest of learners.

Modeling teaching is one of the most effective ways to teach others how to teach. Professional development sessions presented were designed so that the participants were the students doing the activity. and Ann and Gwen initiated inquiry discussions. Ann and

Gwen reported that the other teachers enthusiastically participated in the PD, and carried their new knowledge with them into their own classrooms.

The findings show that only Kelly indicated her science and mathematics educational methods course in college involved understanding and using models effectively. When college instructors model best practices, the experience influences good teaching in elementary classrooms. Modeling of STEM pedagogical content knowledge in education courses would have a significant impact on STEM learning. Making STEM knowledge accessible will influence more individuals to choose STEM-related careers.

Scientist-teacher as critical analyst

Scientists, review, retest and rethink their own theories, as well as those of other scientists. That ensures that science progresses in a logical, valid and orderly manner (AAAS, 1993). Committed elementary teachers investigate the ideas of other educators, analyze those theories, and interpret them in the light of their own experiences.

As Kelly, Ann, and Gwen model inquiry and ask questions they reflect on their students' work, and their own teaching, and evaluate the content and quality of those products and processes. It became very clear in this study that the STEM experiences these committed teachers have had over a lifetime became a part of them. By reflecting on the individual and summative experiences from their earliest recollections these committed elementary scientist-teachers uncovered the dedication and the pedagogical content knowledge to teach STEM. The questioning, the examination of evidence, the reflection and interpretation of their experiences, and those of other professionals, were essential to Kelly, Ann, and Gwen's commitment to STEM teaching within an environment that dismisses STEM teaching and learning.

Reflecting alone and collectively supports adult learning, particularly transformative learning. These teachers perceive that the professional development opportunities that encouraged reflection are the most influential experiences for acquiring pedagogical content knowledge. As scientist-teachers, Kelly, Ann, and Gwen are poised to become more committed to actively teaching science and engineering and more knowledgeable STEM teachers.

Scientist-teacher as collaborator and communicator

Science is a social practice. Scientists discuss their findings and theories with other scientists, and acquire multiple perspectives that help them further refine their ideas. Committed elementary teachers interact with one another and their colleagues to share and evaluate their teaching and learning experiences. The findings from this study indicate that the opportunity to collaborate is key to the increase of STEM teaching and learning in elementary classrooms.

Kelly, Ann, and Gwen perceive that the Collaborative Conversations in STEM is important to their commitment to teaching STEM. As Ann said, "Creating this collaboration was hugely a factor for me to do this STEM work." These teachers were committed to actively teaching STEM in their individual classrooms, but the collegiality of the group strengthened the commitment. They are all in it together. They share a vision. The mutual support empowers them.

Initially, the teachers used the professional learning community to express their frustration with no formal STEM program at the elementary school; however, those individuals who were truly committed to STEM teaching and learning quickly dismissed that attitude, and used their collaboration to investigate ways to grow what little STEM teaching and learning there was. Unconsciously modeling scientists as they began a research study, these teachers analyzed the state of affairs currently in their schools, investigated sources of information to deepen their own knowledge of STEM teaching and learning, participated in opportunities to learn about NGSS and STEM pedagogical-content knowledge, and came together to share their perspectives.

This sharing of perspectives and reflecting on their recent experiences reiterated the purpose of the Collaborative Conversation in STEM. As Gwen noted earlier, a rich learning opportunity in marine ecology faded in significance because she had no one with whom she could share her knowledge. She was learning in isolation and it wasn't fruitful for her students. Formally joining forces in the Collaborative Conversations in STEM provided a venue and a community for these committed elementary scientist-teachers to share knowledge and ask questions.

Scientists and scientist-teachers find that dialogue with others sharpens their perspectives, verifies evidence, forms models, and illuminates theories by bringing many talents to the table.

Kelly, Ann, and Gwen succeed in teaching the content of science, particularly the nature of science, to their students because their teaching embodies the essence of that content. These committed elementary teachers are scientist-teachers because they both teach and learn as scientists do. Their beliefs and constructivist epistemology, embodied in inquiry-based experiences, are passed on to their apprentices, their students, implicitly as well as explicitly. Furthermore, these committed teachers model the beliefs and knowledge for their colleagues in the hope that they too will be apprenticed as scientist-teachers.

Teacher Experiences

Kelly, Ann, and Gwen became scientist-teachers because of their life experiences. The second research question, “What experiences do elementary teachers committed to actively teaching science and engineering describe as important to their beliefs, knowledge and their commitment to teaching science and engineering?” considers Kelly, Ann, and Gwen’s early, K-16 formal and informal STEM learning experiences as well as their professional experiences in the STEM classroom, in STEM professional development, and in STEM collaboration.

The life experiences of teachers are complex. Kelly, Ann, and Gwen’s experiences with STEM demonstrate complex and sometime conflicting perceptions. Each of these elementary teachers committed to actively teaching science and engineering found positive, negative and neutral learning experiences in their lives.

Early informal experiences and formal K-16 experiences influencing the scientist-teachers.

Kelly, Ann, and Gwen related fun and engaging interactions with science and engineering in informal settings when they were young. Playing outdoors and enjoying nature as a backdrop to their growing up were positive STEM experiences, along with building, collecting and examining enterprises. Those kinds of experiences continued throughout their lives.

Formal STEM learning experiences were problematic. Kelly, Ann, and Gwen shared their perceptions that classroom-based STEM learning experiences were few and far between in their K-16 education. Opportunities to learn science and engineering may have been available more often than they reported, but those experiences did not make positive or negative impact. Those influential situations occurred when the perceived experience was tied to a teacher, teaching epistemology, or the content taught. Teachers that engaged them in hands-on investigations made the most positive impression. Highly controlling teachers, teaching a topic through a textbook, or when the topic seemed disconnected from their other life experiences, produced a negative reaction.

Kelly, Ann, and Gwen had vivid memories of formal STEM. Kelly remembered her high-school biology teacher fondly, and her sixth-grade teacher with distain. Her science and mathematics methods courses in college resonated positively, as they provided knowledge applicable to her career goals. Ann had no recollection of science in elementary school, except for reading about clouds in a book. Only one middle-school teacher made a positive impression on her science learning. Gwen perceived her formal science-education experiences as extremes. Interactions with her teachers strongly influenced her perception of her STEM experiences. Teachers who engaged with her learning. and provided inquiry experiences that connected with her interests fostered a positive attitude towards STEM. Elementary, secondary and university professors who were unable to explain concepts clearly, or who brushed off her attempts to understand, created a strong negative perception.

Kelly, Ann, and Gwen’s positive perceptions of hands-on, inquiry learning experiences strongly indicate the effect their experiences had on their developing constructivist epistemologies. As other researchers have reported elsewhere, the early

STEM experiences of Kelly, Ann, and Gwen were remembered decades later (COSMOS, 1998).

In-service experiences influencing the scientist-teachers.

Kelly, Ann, and Gwen's professional experiences shaped their commitments, and influenced their development as scientist-teachers. Their in-service experiences include their experiences with students, learning experiences in professional development, and collaborative experiences with colleagues.

In-service experiences with students influencing scientist-teachers.

Day-to-day interactions with young learners presented many opportunities for all three to develop the pedagogical content knowledge they perceive as necessary to teach students. In Kelly's electric-circuit-making challenges, Ann's deciduous-tree systems investigations, and in Gwen's engineering and physics experiments, each teacher related situations in which she engaged in "an active and dynamic process" (Park and Oliver, 2008, p. 8) to make learning a difficult science or engineering concept accessible to their students (Shulman, 1986; 1987). Their constructivist-teaching stance enabled them to persist in learning along with their students. Kelly learned how to ask questions that enable her students to discover that electricity requires a circular path. Ann reflected upon previous classroom experiences, and provides multiple inquiry activities so her kindergarten students see that "magic" can be explained with scientific evidence. Gwen permitted students to design and build structures that present problems to be solved, and she became adept at asking her students to explain why the ball jumps the track and how a new structure will prevent it. How students react to a learning situation provided evidence that Kelly, Ann, and Gwen reflected upon, and encouraged them to develop new teaching models. They became reflective analysts, creative modelers, scientist-teachers.

These teachers are committed to bringing science and engineering into their classrooms. Their experience with students reinforces that commitment. They integrate content to help students develop twenty-first century skills. Ann believes "the world 's integrated so STEM to me is just a way to approach the world." Integrating content can provide evidence of the depth of a student's knowledge. Gwen's "little lab reports" are an opportunity for her to measure how the "claim, evidence and reason" of her literacy units integrates with the investigating, modeling and analysis of student experiments. Kelly bring engineering design and construction, along with wave behavior, into her teaching of geography, which demonstrates her commitment to ensuring science and engineering are accessible and relevant to her students. STEM learning, inquiry learning, and constructivist teaching are applicable to content outside of science, technology, engineering and mathematics. Ann and Gwen found that when integrated and interdisciplinary connections are made explicit to their colleagues, other elementary teachers were more amenable to learning and teaching science and engineering.

Professional learning and collaborating experiences influencing scientist-teachers.

Kelly, Ann, and Gwen related professional experiences that influence their knowledge and beliefs about teaching and learning science and engineering. The professional development experiences these scientist-teachers perceived as most influential to their pedagogical content knowledge and commitment to actively teaching science and engineering were similar to those positive K-16 formal STEM learning experiences. The inclusion of hands-on inquiry activities, and the relevance of the learning to their own classroom teaching in various summer learning opportunities, multiple-day workshops, intensive week-long workshops and graduate programs were applauded based on the ability of an instructor to engage Kelly, Ann, or Gwen. For these scientist-teachers the positive perception of their experiences intensified their epistemological teaching stance, and expanded their content knowledge and pedagogical content knowledge of STEM, thereby reinforcing their commitment to actively teaching science and engineering.

Scientist-teachers collaborate with one another. Kelly, Ann, and Gwen repeatedly indicated that their experiences working with one another and other colleagues supported their acquisition of pedagogical content knowledge, and shaped their constructivist teaching epistemology. As Ann said, “It wasn’t just about me.” Together in the Collaborative Conversations in STEM these teachers related experiences that they perceived as supportive of their active teaching of science and engineering. Sharing professional development opportunities and reflecting together, writing grants to support the development of science and engineering curricula, and lobbying for school policy changes regarding resources for teaching science and engineering are a few of the collaborations that stood out in the findings. The professional learning community, Collaborative Conversations in STEM did provided an initial venue for the collaborations. But Kelly, Ann, and Gwen spoke of pairs of teachers, small groups and large groups of teachers visualizing, investigating, modeling, analyzing, and reflecting together on science and engineering teaching and learning. When these scientists-teachers shared their epistemologies, knowledge and commitment with their colleagues, the experience strengthened their commitments to actively teaching science and technology, and provided a model that other teachers could emulate in their own classrooms.

Scientist-Teachers Demonstrating Commitment Through Experiences

For Kelly, Ann, and Gwen, developing a commitment to teach science and engineering was non-linear, and not spontaneous. Multiple experiences at various times influenced their teaching values, teaching epistemology, lifelong learning attitude and emotional engagement, the hallmarks of commitment. Table 6 presents the theoretical evidence for teacher commitment mentioned in the literature review, and the empirical evidence of the teachers' commitment in their science teaching (Day, Elliott and Kington. 2005). This section of the chapter will expand upon Kelly, Ann, and Gwen's commitment to teaching STEM to their students by relating the teachers' life experiences to their expression of commitment.

Table 6: Elementary STEM Teacher Demonstration of Commitment

Evidence of commitment.	Expression of commitment
Values	Student welfare and future Holistic learning Societal responsibility
Teaching Epistemology	Constructivist Inquiry based Persistent
Lifelong Learning	Self-directed acquisition of professional development Persistent
Emotional Engagement	Love of nature Care for student welfare Collaboration with colleagues

Values

Kelly, Ann, and Gwen are committed to providing a holistic education for their students, because they believe that is good for their students and good for society. These elementary teachers' decision to teach STEM demonstrates their commitment. Coughlan (1969) identifies valuing education and STEM learning as professional values. These teachers are willing to teach science and engineering despite their institutions' devaluing of STEM in favor of literacy.

Kelly, Ann, and Gwen are experienced generalist teachers, who accept responsibility for educating the whole person, making skills useful, and integrating knowledge so it is meaningful (and not boring). Their experiences in the classroom with students helps them perceive the deep and long term damage that monolithic implementation of policy such as NCLB can have has on their students' lives. While they value literacy as a mode of human expression, they feel that literacy is a foundational tool for learning. Science, mathematics, engineering and technology are among the subject matters that are equally valuable to their students' futures. Ann and the research literature agree, "I think students form their opinions about subjects quite early. I think that our priority right now is increased student interest in science."

Kelly, Ann, and Gwen's early experiences with nature influenced their values. Those informal experiences are reflected in their desires to awaken their students' curiosity so they are aware of their world, and are skilled in ways that can solve future problems that might arise in that world. Wondering about nature, people, and society is on equal footing with acquiring knowledge about nature, people and society. These teachers are committed to providing a balanced education, even if there are pressures to downplay one content area for another. Speaking of individuals like these committed elementary teachers Emans noted “Persons of divergent values cannot with equal feeling of approval implement the same curriculum”(1969, p 461). As Gwen stated, they will “not not teach science.”

Teaching Epistemology

Kelly, Ann, and Gwen are committed to the constructivist epistemology. Their perceptions of their classroom teaching experience demonstrate their strong affinities for hands-on, inquiry experiences. These generalist elementary school teachers include many experiences for students to construct knowledge, particularly science and engineering knowledge, in their teaching.

Kelly, Ann, and Gwen’s constructivist teaching is due in a large part to the hands-on investigations that were the infrequent highlights of their STEM learning as students. Exceptional science teachers like Mrs. Brookes, Gwen’s second-grade teacher, stood out for their inquiry-teaching and ability to adapt lessons to the students’ interests. However, Kelly, Ann, and Gwen’s experiences with many of their teachers’ empiricist epistemologies did not engage them intellectually or emotionally, and provided a negative model of teaching. They were not engaged if a positivist, information-delivery pedagogy was employed. Learning science from texts, and memorizing facts, are perceived as negative influences at the elementary, high school and college levels, although at different times for each of them. Unfortunately, these teachers’ K–16 experiences are all too common. Science learning is not made accessible to all students. In an effort to instill rigor into high school programs, the teaching emphasis has been on rigid mathematical analytic skills, particularly in the physical sciences. Such rigor can be paired with lackluster science instruction.

Without a foundation of conceptual understanding, rigorous mathematics-based science falls on deaf and disappointed ears. Fortunately, individuals like Kelly, Ann, and Gwen take it upon themselves to assimilate STEM knowledge and the nature of scientific and engineering practices. They use inquiry teaching to provide the strong base of conceptual understanding that can progressively grow into more sophisticated STEM knowledge. Kelly, Ann, and Gwen feel students respond well to that teaching stance, and it is compatible with STEM learning. As Ann said, "I think of science as science and then it is my job to take the big picture and make it translatable to five year olds. I believe education should be integrated. I believe it should be hands on. I think they need to be able to make connections for why we are doing this." Their STEM commitments manifest their desires for students to acquire knowledge, and 21st century skills.

Lifelong Learning

Lifelong learning is a critical part of Kelly, Ann, and Gwen's commitment to teaching science and engineering. Recognizing the teacher as a learner resonates with Dewey's work, "The most important attitude that can be formed is that of desire to go on learning" (Dewey, 1938, p. 20). These committed elementary teachers continue to learn each and every day, formally and informally. Through their academic and professional experiences, Kelly, Ann, and Gwen have found teaching and learning stimulating phenomena to analyze. Moreover, STEM teaching and learning has a particularly strong critical thinking component that they find challenging.

For these committed elementary teachers, science content knowledge and pedagogical content knowledge are perceived to be personal and critical needs. Kelly, Ann, and Gwen believe that they are not well prepared to teach all STEM content because their previous science instruction experiences did not give them an expansive science or engineering background. Fortunately for their students, they also believe that their K-16 education was not the end of their STEM education. They are true lifelong learners.

Kelly, Ann, and Gwen have been very concerned that their school district did not provide or encourage professional development in STEM in past years because NCLB and annual yearly-progress testing prompted the school district to limit professional development almost exclusively to literacy. Consequently, these committed elementary teachers sought to increase their own STEM content knowledge by participating in professional development experiences outside of the school system whenever possible, again giving evidence to their commitment to science and engineering teaching and learning. They take responsibility for their own learning. In a national study, Banilower found that 70 percent of elementary teachers who had professional development in science believed that their science content knowledge was influenced by those opportunities. Unfortunately, he also found that only 12 percent of elementary teachers had had more than 15 of professional development, and 41 percent had had none in the three years prior to his study (2013).

Lifelong learning occurs in many venues. These teachers perceive that classroom experiences have influenced their commitment to teaching science and engineering because interacting with students informs the teachers' beliefs about what students need.

Kelly, Ann, and Gwen have always taught some science or engineering content to their students. Over the years the experiences have increased their pedagogical-content knowledge because different groups of students offer different experiences for these teachers who choose to increase their STEM knowledge in reaction to the classroom experiences. For example, Kelly was afraid take physics in high school, but chose to learn physics in a professional development opportunity. Magnetism and electrical circuits were among the topics she was teaching. The high quality of the physical science professional development activities Kelly experienced in the STEM summer camp transformed her motivation from a need to learn to a joy to learn.

For Kelly, Ann, and Gwen, STEM learning did not arise from the courses they took in their early formal education. Instead, their lifelong learning experiences accumulated STEM knowledge. In the course of this study it was apparent that these teachers were enthusiastic about their recent experiences in learning how to teach science and engineering content and practices that align with the Next Generation Science Standards. That strongly suggests that the commitment to teach STEM is not directly related to the number of hours of formal K-16 science, engineering, or mathematics instruction experienced by these elementary teachers. It also presents an opportunity for expanding the ranks of elementary teachers actively committed to teaching science and engineering through well-structured and available professional development experiences.

Emotional Engagement

Kelly, Ann, and Gwen’s commitment to helping students construct their knowledge of science is a reflection of their emotional engagement with their students and teaching. These teachers’ perception of their informal and formal STEM education experiences is intertwined with positive and negative emotions. Kelly, Ann, and Gwen's emotional engagement in education and in STEM education was evident in their recollections of early STEM learning experiences that include "hating rocks," "loving school," "loving exploring," "hating Mrs. Soanso," and "loving my seventh-grade biology teacher." Kelly loved school and learning, and wanted to be a teacher for as long as she could remember. Ann and Gwen's love of exploring and "figuring out" led them to art and psychology, but their joy at sharing learning experiences led them to teaching. Playing outdoors as children set the stage for a deeper appreciation of the world in which they live. Reflecting on those experiences, as well as experiences with students in the classroom, highlights the need for science and engineering inquiry-teaching and learning in elementary school. Kelly, Ann, and Gwen are fully engaged in creating positive STEM experiences for their students. Gwen provided a motion activity that engaged the students' interest and their pride. "The entire class was watching and everybody was talking. The principal happened to come in right then and they couldn't wait to show off." Girod spoke of transformational learning as a transaction between the world and the individual "beyond just the mind of the learner and is extended to include emotions, actions, and perceptions." Developing into a committed elementary teacher is not limited to knowing the science, mathematics, engineering or technology. That is, knowledge of mind only. It must include more "of heart, eye, and body. Education should leave us different; understanding more, seeing differently, and willing to act in accordance with these differences (2010, p 804).

Wondering about nature, finding things out, are natural attitudes for children and Kelly, Ann, and Gwen are committed to seeking "wondering experiences" to share with their students. They are compelled to acquire the science- and engineering-content knowledge and pedagogical-content knowledge and to offer hands-on, inquiry-learning experiences for their students. Furthermore, Kelly, Ann, and Gwen's emotional connections to the natural world are a driving force in their desire to help their students be prepared to take on STEM-related issues later in life.

Their exhilarating experiences sharing the wonder of nature, as well as their emotional engagement with students, prompted Kelly, Ann, and Gwen to share the knowledge and dedication to STEM learning with their peers. Their sense of responsibility to educate their students extends to all the students in the school. Until the formation of the Collaborative Conversation in STEM, Kelly, Ann, and Gwen reported that their school district had no science or engineering professional development on-site for ten years. Consequently, only the committed teachers of science and engineering have been accumulating knowledge and experience in the STEM content areas.

While experiences throughout their lifetime influence them, Kelly, Ann, and Gwen's experiences influential to their commitments to teaching science and engineering became most evident when the teachers began to talk about their classroom experiences, professional development experiences, and collaborative experiences. The findings suggest that their commitment to teaching science and engineering is largely constructed and refined while they are professional teachers. For these teachers the commitment process is continuous and multifaceted.

Kelly, Ann, and Gwen's perceptions of their own experiences are an excellent source of ideas that would improve STEM teaching and learning at all levels of education. While they still believe they have much to learn about STEM content and

STEM pedagogical content knowledge, their expressions of their collective commitment suggest that: STEM teaching commitment arises from values, emotional engagement, and lifelong learning influenced by STEM life experiences and not from accumulated STEM content or pedagogical content knowledge acquired in their formal K-16 education; commitment supporting teaching epistemologies and pedagogical content knowledge can be gained from experience in the classroom or in professional development experiences.

Committed Teachers as Leaders in Transformative Learning

This study has focused on the personal commitment of three teachers to teaching science and engineering through their experiences, beliefs, and knowledge. During the study it became apparent that these individuals were leaders and STEM-education advocates. Within the evidence collected it can be suggested that, as a result of Kelly, Ann, and Gwen's commitments, other individuals in the school began a transformation. This study's methodology did not support expanding the interviews to other teachers or administrators in the school, and the evidence is filtered through the eyes of the participants, but it seems there was a quiet revolution in the school. Aspects of Kelly, Ann, and Gwen's transformations gives light to what the other teachers may be experiencing.

Ann experienced a change of perspectives when she no long thought science as "enrichment stuff to learn." Science education became "necessary" and "important." For many elementary teachers "science is scary." Kelly didn't think that her childhood experiences were "sciency" until she spoke with members of the Collaborative Conversations in STEM. Kelly and Ann avoided doing more than the minimum science in college. Gwen's studies didn't permit any more than the minimum.

Kelly recognizes that her recent change of epistemology is still in process. “O.K so I have been trying, slowly. I haven’t really done much of a transition. But trying to get more hands on stuff, more with building and creating.” Her commitment to inquiry teaching is solid. Transformation for her means evolving, learning and growing more confident to teach STEM. Gwen associates her transformation into a committed science and engineering teacher with her learning to teach science from Eleanor Duckworth. The questioning, probing, observing, and analyzing Gwen did in that experience committed her to “not not teaching science.

Mezirow describes transformative adult learning as accessing new information in unique experiences (1997). Kelly’s experience at STEM Camp in Saltrock, and Ann and Gwen’s experience at the summer university STEM professional development provided new experiences with new information. They were experiencing “cognitive mastery” as described by Palmer (2011).

Kelly, Ann, and Gwen are becoming STEM-education reformers and leaders in their school community. They are emergent leaders who are encouraged and supported by their professional learning community because they share a goal - to increase science and engineering learning in their school. Ann and Gwen’s efforts to provide professional development in STEM have met with great success. “What’s so cool about what is going on right now for us is it’s all coming from the teachers.” Teachers and administrators in their school are experiencing transformative learning. They are becoming intellectually and emotionally engaged in science and engineering teaching and learning. More constructivist-inquiry thinking is entering their classrooms. It’s becoming less scary. Those educators are experiencing an education that is leaving them different, "understanding more, seeing differently, and willing to act in accordance with these differences" (Girod, 2010,p 804).

Early evidence of a transformation within the school include: (1) The findings indicate there were a significant number of teachers who participated in the professional development that Ann and Gwen offered. (2) There was reference to a change in the school budget to include some STEM curriculum materials where there had been none for years before the existence of the professional learning community. (3) As this study was concluding, a new math curriculum was in the works, and a science curriculum was being discussed. Concurrently, though not directly a result of the efforts of these three committed elementary teachers, the literacy program was changing to reflect a new emphasis on informational reading and argumentative writing.

Gwen and Ann's modeling of STEM teaching supports a possible change in the collective efficacy of the teachers in the school. As Gwen said, "they are starting to see." Kelly, Ann, and Gwen have demonstrated a constructivist epistemology in their teaching of science and engineering. The professional development programs that Ann and Gwen offer the community also demonstrates a constructivist epistemology. Research quoted in Chapter 2 suggests that elementary teachers might employ constructivist pedagogy in most content areas, including literacy and mathematics, but they do not approach teaching science and engineering content in that way. Within the context of this study it cannot be concluded that other teachers changed their pedagogy to match the pedagogical-content knowledge offered through professional development. However, during the interview process, and observations made during the meetings of the Collaborative Conversations in STEM, it was apparent that members of the faculty were enthusiastic at the prospects of teaching STEM, and the tools provided in the professional development were employed in constructivist pedagogy. There is suggestion of a change in the collective efficacy and epistemology in the school

Implications

Committed teachers like Kelly, Ann, and Gwen are needed to implement STEM teaching and learning policy within an elementary school. Reforms to increase STEM knowledge and practices in the general population must take on many forms. Opportunities to experience transformative adult learning must be available and accessible, so more teachers and administrators in other schools will commit to STEM teaching and learning.

The findings from this study suggest further that a commitment to teaching science and engineering is largely constructed and refined during a teaching career. The findings indicate that the opportunity to collaborate is key to the increase of STEM teaching and learning in elementary classrooms. For these three elementary teachers the commitment process is continuous and multifaceted. These findings present an opportunity for expanding the ranks of elementary teachers actively committed to teaching science and engineering through well-structured, available professional development experiences, professional learning communities, and supportive school communities committed to the teaching and learning of STEM.

Kelly, Ann, and Gwen's perceptions of their experiences present a number of challenges for educators, scientists and policymakers.

1. In-service Teacher Education - In-service teacher education programs must be comprehensive and collaborative. A scientist-teacher's learning is not complete when she receives a diploma and a teaching license. Professional development opportunities in various content and pedagogical content areas are needed. For teachers who are neither confident nor committed to teaching science or engineering, professional development would do well to include inquiry activities that model good pedagogical-content knowledge, along with increasing content knowledge in STEM. The university partnership that Kelly, Ann, and Gwen felt the university partnership professional development they brought to their schools provided just that kind of professional development. did just that. A graduate- teacher academy that provides classroom- based professional development would be useful.

2. In-service Teacher Experiences -Professional learning communities directed by teachers should be encouraged and supported by the school communities. Collaborative Conversations in STEM was a powerful model for a professional learning community. The teacher-led and teacher-directed with support from the administration was respectful of the participants' professionalism. In this study, the professional learning community was thematic, but not restrictive, in its membership and mission.

3. STEM Education Support Structure: Educators and policymakers must collaborate to address the connection early education has to the 21st century, global economy. Kelly, Ann, and Gwen's school district perceived the need to address the larger issues of STEM education at the elementary school level. Administrators and policymakers must be visionary, and committed to a balanced education for the students' and society's future. They must support a strong and diverse curriculum conceptually and practically. They should be lifelong learners themselves. Policymakers must be inquisitive and take risks. They must be willing to access and apply new knowledge, and willing to support teachers who access and apply new knowledge. They must be reflective and realize that routine administration and direction is not education. Good administration requires self-analysis. Effective policymakers direct and support teachers conceptually and practically as they reflect on their teaching practices. Educators and policymakers must be collaborative among themselves and with teachers: learning together; sharing ideas; receiving constructive advice; and working together to improve teaching and learning.

Further research

Addressing STEM teaching and learning at all levels is a necessary direction for research if the human capital needs of the twenty-first century economy are to be met. Committed STEM teachers are a particularly important group to study because of their ability to move reform forward when provided with support. This qualitative study cannot generalize the characteristics of Kelly, Ann, and Gwen as the norm among committed elementary teachers of STEM. Quantitative methodologies would provide another perspective to this qualitative study of elementary STEM teachers actively committed to teaching science and engineering. Determining the accessibility and characteristics of professional learning communities like Collaborative Conversations in STEM to K-12 teachers would provide insight into opportunities for STEM education reform. Qualitative and quantitative methodologies are complementary for this research.

Understanding the influence of professional development programs on elementary STEM teaching and learning merits study to inform best practices and potential program development.

Closing Remarks

Kelly, Ann, and Gwen are admirable. As committed scientist-teachers they are providing the best education they can for their students. They are increasing the human capital necessary for economic success in the twenty-first century. They are leaders in their school community, influencing educational policy related to STEM teaching and learning.

Kelly, Ann, and Gwen should be emulated. They provide opportunities for other teachers to become committed to STEM teaching and learning, indirectly providing the best education for all students in their school. They model the values, teaching stances, lifelong learning and emotional engagement needed to enact real educational reform where it counts the most, the classroom. With their colleagues in the professional learning community, Collaborative Conversations in STEM, they are changing the face of elementary STEM education in their school district. Indeed, they are influencing STEM education at all levels. Middle-school and high-school teachers in the district now have a model of STEM teaching and learning that would be successful at all grade levels, and could increase the number of individuals preparing for STEM careers. University science-educators and teacher-educators now have insights into the effect of post-secondary teaching stances have on the knowledge and beliefs of those students who will ultimately be the university STEM students of the future.

Most of all, Kelly, Ann, and Gwen have shown that commitment to teaching STEM can be acquired, and can exist before the confidence to teaching STEM evolves. Their internalizations of inquiry and scientific practices in their teaching provides a model of transformative learning that will inform elementary teachers, and generate a larger number of committed elementary teachers of STEM.

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Appendix A: Interview Questions

Life history and early science experiences.

Today, I would like to hear about your previous out-of -school and in-school experiences so I may understand your experiences with science (technology and engineering).

Background and early experiences.

Please tell me about yourself. Where did you grow up?

How would you describe your family growing up?

Is there anything about your family that would help me understand your teaching and learning?

Describe for me your earliest memory of “science.” (How would you define science?)

Did you have a pet, a rock collection, a chemistry set, a hobby?

Would you tell me about your first experience with engineering?

About how old were you when you first went to a zoo, a nature park or a science museum? What stands out about that visit?

Elementary School Experiences

Thinking about your elementary school years. Please tell me about your most memorable experience with science, technology, engineering or math?

Would you describe an elementary teacher who may have influenced you with regards to STEM?

High School Experiences

Where did you go to high school? What science classes did you take in high school?

What was science like in high school? Does anything stand out in your memory?

Which high school science teacher influenced you the most – good or bad? Tell me about him/her and why you remember him/her particularly.

College Experiences.

What college or university did you attend?

What was your major in college? Why did you choose that discipline?

When did you decide to be an elementary teacher? Why?

What preparation did you have for becoming a teacher?

What courses did you take that you feel are particularly beneficial to you as a teacher today?

Describe for me your experiences with STEM in college. What courses did you take?

Have you returned to school to take any other courses? Which ones and why?

Tell me about any other experience; person, place or thing that you feel is important to you and your view of science or STEM today.

Teaching, Learning and Professional Learning Community

The last time we met you shared your early STEM experiences. Is there anything else you would like to mention that we did not discuss?

Today we are going to look at your experiences as a learner and a teacher and as a member of the Collaborative Conversations.

Learning history and beliefs

What is your philosophy of teaching and learning?

How do you learn?

Describe for me an instance in or out of school when you felt confident as a learner.

Why does that moment stand out?

Describe an instance in or out of school when you did not feel like a confident learner.

Describe and explain how children learn and why some children learn better than others.

How is learning science the same or different from learning any other subject?

Teaching history, confidence and perceptions

How long have you been teaching elementary school K-5?

What grades or age groups do you teach now?

What other grades have you taught?

Teaching card sort

What subjects do you teach?

Which subject matter do you feel most confident teaching?

Why do you teach those topics? Are there others that you think you would like to teach? Why?

Describe for me a particular activity you engage in with your students that demonstrates inquiry teaching and learning.

Perception of experiences' affect on teaching.

Explain how your informal or formal science experiences affect your teaching of science.

Explain how your commitment to teach science has remained the same or changed with experience.

Explain how your confidence level to teach science has remained the same or changed with experience.

Collaborative Conversations in STEM

Describe for me your most memorable professional development(it does not need to be STEM related). Why was it so memorable?

How did that experience affect your teaching or your students' learning?

What professional learning community or study group have you participated in prior to Collaborative Conversations?

Describe your experience in that group.

How did that experience affect your teaching or your students' learning?

Describe for me your most memorable STEM professional development.

How did that experience affect your inquiry teaching or your students learning?

Explain your motivations to respond to the invitation to join Collaborative Conversations and be at the first meeting.

What did you anticipate would happen?

What memorable moment or feeling did you have in that first June meeting?

How would you describe the motivations of the people at that meeting?

Explain why you returned for a second and third meeting in August and September.

What do you recall from those meetings?

What motivated you to continue to participate?

Describe any other STEM activities that you have become involved in as a result of participating in the group.

Describe the ways in which participating in the group affected your inquiry teaching, your learning, Describe how participating in the group affected your confidence to learn and to teach?

Explain how you perceive your role in the group changed over the year.

Describe and explain how your role in the school changed as the result of participating in the group.

Perceptions of teaching inquiry in STEM

If I observed an inquiry STEM lesson in your class, what would I see?

Explain your perspective on the initiation and progress the CC group has made.

How would you measure its impact on STEM in your classroom?

What has been key to its success?

What have been its shortcomings?

Describe an example of how participating in Collaborative Conversations has impacted you commitment to teaching STEM inquiry.

Describe an example of how participating in Collaborative Conversations has impacted you confidence to teach STEM inquiry.

Describe an example of how participating in Collaborative Conversations has impacted you ability to teach STEM inquiry.

Appendix B: Group Participant Information Letter and Consent Form

The following information is being provided for you to determine if you wish to participate in this study. In addition, you are free to decide not to participate in this research or to withdraw at anytime without affecting your relationship with the researchers.

The purpose of this phenomenological study is to describe the composition and dynamics of a group of elementary teachers who seek to influence STEM learning in their schools.

If you decide to participate you will be asked to participate in Collaborative Conversations. These meetings will be audio recorded to ensure the accuracy of the collected information and all meetings will be transcribed into a written record. You will be able to ask the researcher to turn off the audio recording equipment at anytime during the meeting.

Ensuring the confidentiality of data is the norm in research. Only the researcher, Julianne Opperman, and her dissertation advisory, Catherine Fallona, will read the transcripts for analysis. A professional transcriber will be used for the initial verbatim transcription but he or she will not be able to identify the participants.

Written transcripts will be stored in a locked filing cabinet in the office of the researcher for one to three years following the completion of the study.

The audio transcripts will be destroyed once the transcription process has been completed and a written record is produced and you are confident that the written transcript accurately reflects your comments during the meeting. There are no other known risks/discomforts associated with participating in this study.

There are several expected benefits from participating in this study. They are: 1) information on the experiences of elementary teachers who have become confident STEM teachers; 2) a better understanding of the impact of collaborative groups on the confidence of elementary STEM teachers, and 3) the ability for the researcher to participate in a qualitative study.

If you have any questions about the study at any time please do not hesitate to contact Julianne R. Opperman (julianne.opperman@maine.edu). Professor Catherine Fallona (catherine.fallona@maine.edu), the researcher's dissertation advisor, will also answer questions. The Institutional Review Board of the University of Southern Maine is also available at any time during the study.

A signed copy of this consent form will be given to you for your records.

____ ____________

Participant Date

Consent obtained by: ____________________________________ ____________

Interviewer/Researcher Date

Biography of the Author

Julianne Radkowski Opperman was born in Boston, Massachusetts and graduated from John W. North High School in Riverside, California. She earned her bachelor of arts in molecular biology in 1976 at Wellesley College, Wellesley, Massachusetts. In 1980, she received a master of science degree in nutritional biochemistry and metabolism from the Massachusetts Institute of Technology, Cambridge, Massachusetts.

Since 1980, Ms. Opperman has taught science at Greely High School in Cumberland, Maine. Concurrently, she taught at the Maine College of Art from 1985 to 1987, and at Westbrook College, Portland, Maine, from 1984 to 1986.

She has participated in professional research experiences at Radkowski Associates, Management Systems and Technology, Riverside. California from 1971 to1994; the Naval Blood Research Laboratory, Boston University Hospital, Inc., Boston, Massachusetts from 1977 to 1978; and at the Channing Laboratory, Harvard Medical School, Boston City Hospital, Boston, Massachusetts in 1975.

Ms. Opperman's publications include: Scientific writing and technological change: Teaching the new story of scientific inquiry, with M. Poe, in Herrington, A., Hodgson, K. S. & Moran, C. (Eds.); *Teaching the new writing: Technology, change, and assessment in the 21st century classroom*. Teachers College Press. New York, NY. 2009; *Those Who Can't Do, Teach.* Network of Educators in Science and Technology, MIT, Cambridge, MA. 2009; and *An Assault on Science.* Network of Educators in Science and Technology, MIT, Cambridge, MA, 2006 She has created curricular materials that integrate science education, writing instruction, art and chemistry, science fair projects and professional project management.

Julianne Opperman has presented and participated at international science and science education conferences in the United States, Europe, and China.. Several of the presentations focused on visualization of scientific concepts, as well as scientific and technical writing instructions.

Ms. Opperman is a member of the American Education Research Association, the National Science Teachers Association, the Maine Teachers Association, and the Network of Educators of Science and Technology. Her chemistry teaching was recognized by the New England Institute of Chemists in 2008. She was a visiting scholar at MIT from 2006 to 2009.

She has been involved in public service, public policy, and educational leadership at the local and state level since 1980. She chaired the Portland City Manager's Policy Advisory Committee; was a member of the board of trustees of the Children's Museum of Maine; the secretary of the board of trustees for Catherine McAuley High School; a member of the University of Southern Maine Institutional Animal Care and Use Committee; and a member of several state and school district curriculum, assessment, standards and teacher-evaluation communities. She is a candidate for the doctorate of philosophy in public policy with a concentration in educational policy and leadership at the University of Southern Maine, and will receive the degree in August 2015.