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ACCEPTANCE

This dissertation, THE INFLUENCE OF A K-5 SCIENCE ENDORSEMENT ON THE PROFESSIONAL KNOWLEDGE BASES OF ELEMENTARY TEACHERS, by DONNA JOY BARRETT-WILLIAMS was prepared under the direction of the candidate's Dissertation Advisory Committee. It is accepted by the committee members in partial fulfillment of the requirements for the degree, Doctor of Philosophy, in the College of Education, Georgia State University.

The Dissertation Advisory Committee and the student's Department Chairperson, as representatives of the faculty, certify that this dissertation has met all standards of excellence and scholarship as determined by the faculty. The Dean of the College of Education concurs.

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Barrett, D.J., Puvirajah, A., Martin-Hansen, L.M. (2014). *The influence of a K-5 science endorsement on the self-efficacy and instructional practices of elementary science teachers*. International Association for Science Teacher Educator Conference, San Antonio, TX.

Barrett, D.J. (2012). *Differentiation in the Science.* National Science Teachers Association Regional Conference. Atlanta, GA

Dean, M.L., Polizzi, S.J., Barrett, D.J., Rushton, G. (2013) *Exploring the Impact of an Induction Program Centered on Teacher Leadership.* Southeastern Association for Science Teacher Education (SASTE), Statesboro, GA.

Barrett, D.J. (2012). *PCK Literature Review in Proposed Study.* Southeastern Association for Science Teacher Education (SASTE), Macon,GA.

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Barrett, D.J. (2012). *K5 Science Endorsement at Metro RESA*, Presentation at Georgia Science Teachers Association Conference, Atlanta, GA.

Barrett, D.J. (2009) *Incorporating Literacy, Inquiry and Differentiation into Professional Development*, Presentation at Southeastern Association for Science Teacher Educators (SASTE).

Barrett, D.J. (2009). *Planning Professional Development Using the 5E Inquiry Model,* Presentation at National Science Teachers Association (NSTA) Annual Conference.

Barrett, D.J. & Usselman, M. (2006). *Issues Surrounding the Evaluation of Teacher Internship Programs.* Proceedings of the 2006 American Society for Engineering Education Annual Conference & Exposition.

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Barrett, D.J. & Usselman, M. (2005). *Georgia High School Teachers in Academic Laboratories: Engineering's Important and Increasing Role*, Proceedings of the 2005 American Society for Engineering Education Southeast Section Conference.

Barrett, D.J. (2005). *Georgia Teachers in Academic Laboratories: Research Experiences in the Geosciences.* Presented at American Geophysical Union.

PROFESSIONAL ORGANIZATIONS

Association for Science Teacher Educators (ASTE)
Georgia Science Supervisors Association (GSSA)
Georgia Science Teachers Association (GSTA)
National Association for Research in Science Teaching (NARST)
National Science Teachers Association (NSTA)

ABSTRACT

THE INFLUENCE OF A K-5 SCIENCE ENDORSEMENT ON THE PROFESSIONAL KNOWLEDGE BASES OF ELEMENTARY TEACHERS
by
Donna Barrett-Williams

Elementary teachers face many constraints when teaching science including limited time, content knowledge, confidence, and experience with reform-oriented instructional practices (Lee & Houseal, 2003; Davis, Petish & Smithey, 2006; Appleton, 2007; Metz, 2009; Wilson & Kittleson, 2011). The scope of this study was to (a) explore the influence of a K-5 science endorsement on the dimensions of professional knowledge of elementary science teachers and (b) to explore how those knowledge bases inform a teacher's Pedagogical Content Knowledge (PCK). Within the consensus definition of PCK, PCK is defined as "knowledge of, reasoning behind, and planning for teaching a particular topic in a particular way for a particular purpose to particular students for enhanced student outcomes" (Gess-Newsome & Carlson, 2013).

Fifty four elementary teachers that had completed a K-5 science endorsement participated in the study. A mixed methods study was conducted to explore the influence of the endorsement on the dimensions of knowledge of elementary teacher. Content pre/post assessments on life, earth, and physical science content; and a retrospective pre/post self-efficacy and background survey were administered to all participants. A cross-case analysis of six participants was conducted to explore the professional knowledge bases of these participants following the endorsement. Observations, interviews, and document analysis were the qualitative data analyzed.

The teachers began the endorsement with a higher efficacy for pedagogical knowledge and a lower efficacy for reform-oriented instructional practices. Quantitative and qualitative data suggest a shift towards more reform-oriented practices following the endorsement. Pre/post content assessments and a retrospective pre/post self-efficacy survey showed statistically significant increases in content knowledge and self-efficacy following the endorsement. Observations and interviews provided support for emerging orientations towards the use of reform-based instructional strategies. Findings suggest the important role of an elementary teacher's beginning pedagogical knowledge in the shift toward a reform-orientation. Multiple regression analyses provide an exploratory model for understanding the interactions of an elementary teacher's professional knowledge bases following a reform-oriented professional development. This study provides insight to how elementary teachers navigate reform-oriented pedagogy in science.

THE INFLUENCE OF A K-5 SCIENCE ENDORSEMENT ON THE PROFESSIONAL KNOWLEDGE BASES OF ELEMENTARY TEACHERS

by

Donna J. Barrett-Williams

A Dissertation

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ABBREVIATIONS

AK	Assessment Knowledge
CK	Content Knowledge
KC	Curricular Knowledge
KIS	Knowledge of Instructional Strategies
KS	Knowledge of Students
ISTEBI	Inquiry Science Teaching Efficacy Belief Instrument
NAS	National Academy of Sciences
NCLB	No Child Left Behind
NOS	Nature of Science
NGSS	Next Generation Science Standards
NRC	National Research Council
NSES	National Science Education Standards
PACES	Professional Assessment and Comprehensive Evaluation System
PD	Professional Development
PCK	Pedagogical Content Knowledge
PK	Pedagogical Knowledge
PKB	Professional Knowledge Base
POGIL	Process Oriented Guided Inquiry Learning
PSTE	Personal Science Teaching Efficacy
RTOP	Reformed Teaching Observation Protocol
SE	Self-efficacy
STEBI	Science Teaching Efficacy Belief Instrument
STOE	Science Teaching Outcome Expectancy
TEBS	Teacher Efficacy Beliefs Survey

CHAPTER 1: INTRODUCTION

During the past fifteen years or so, teachers in the U.S. have experienced unprecedented changes in education with the focus on high stakes assessments authorized with the passage of the Elementary and Secondary Education Act (ESEA) in 2002. Commonly known as No Child Left Behind (NCLB), ESEA outlined a mandate for states to assess student performance in reading, mathematics and a third indicator such as graduation rate, and to provide public report cards disaggregating test data by economics, race and ethnicity, students with disabilities, and limited English fluency (NCLB, 2001). The focus on the disaggregation of test data was deemed a positive outcome, leading to an emphasis on closing the achievement gap between ethnic groups. With NCLB, states have the flexibility to determine accountability standards for their schools known as Adequate Yearly Progress (AYP). Failure to meet the standards often led to punitive consequences for the schools. Schools with over 40% of their students in poverty are eligible to receive federal Title I funding, and the schools receiving federal funds that do not meet Adequate Yearly Progress (AYP) receive sanctions. Title I funding comes from the federal government, and Title I funding is designed to assist the most economically disadvantaged students meet academic standards.

NCLB has had many implications for science education including decreased time for teaching science and increased time for test preparation, particularly at the elementary level (Font-Rivera, 2003; Anderson 2011). These implications complicate the implementation of new goals in science reform that call for practices that engage students in science and engineering (NRC, 2012; NRC, 2013). The focus of this study is the influence of a K-5 science endorsement on the dimensions of professional knowledge of elementary science teachers. The goals of the K-5 science endorsement include enhancing the content knowledge, knowledge of reform-oriented instructional strategies, and lesson planning practices of the participants. With increased knowledge of effective ways to teach science, the endorsement may help to reduce the constraints elementary teachers face as a result of NCLB. The purpose of this study is to determine how participation in the endorsement influences the professional knowledge bases of in-service elementary science teachers.

The Center on Education Policy reported 42% of school districts increased time spent in reading and mathematics since NCLB requirements were implemented. Forty-four percent of elementary schools reported reduced class time for subjects such as science and social studies (Center for Education Policy, 2007) and 53% of elementary teachers reported spending 90 minutes or less teaching science per week (Griffith and Sharmann, 2008). Teachers have reported increased pressure to improve test scores, often through direct instructional methods (Font-Rivera, 2003; Hamilton, Stecher, Marsh, McCombs, Robyn & Russell, 2007; Anderson, 2011).

The implications for NCLB on science education are concerning, but science education has also experienced a number of changes over the years. Achievement in science and mathematics has long been associated with America's ability to compete at a global level. As evidenced by the public outcry in the United States when the Soviet Union launched *Sputnik* in 1957 to the more recent concerns of globalization and innovation (Friedman, 2005), achievement in science and mathematics has been an ongoing concern of the American government and has fueled waves of public panic about the state of science education and its role in economic security and global competition.

Anderson (2011) notes “[S]cience education continues to iteratively move through reform efforts, from constructivism to direct instruction, and from local accountability to national standards” (Anderson, 2011, p. 105). These reform efforts are often driven by documents that both criticize the state of science education and those that offer suggestions to ways to address those criticisms.

The reform efforts of the 1980’s and 1990’s included a movement away from the use of teaching strategies that included rote memorization towards strategies that actively engage students including a focus on student misconceptions, inquiry based learning, conceptual learning, diversity and a focus on the nature of science (Southerland, et al., 2007). Reform documents such as *Science for All Americans* (AAAS,1990), the *Benchmarks for Scientific Literacy* (AAAS, 1993), and the *National Science Education Standards* (NRC, 1996) were developed with an emphasis that “science is for all students” (NRC, 1996, p. 19) and that students should be actively engaged in science. The vision of the *National Science Education Standards* included an emphasis on changes in teaching standards including: “focusing on student understanding and use of scientific knowledge, ideas, and inquiry process; guiding students in active and extended scientific inquiry; continuous assessment of student learning” (NRC, 1996, p. 56). *Inquiry and the National Standards* (2000) further elaborated on the five essential features of inquiry:

1. Learner engages in scientifically oriented questions.
2. Learner gives priority to evidence in responding to questions.
3. Learner formulates explanations from evidence.
4. Learner connects explanations to scientific knowledge.
5. Learner communicates and justifies explanations. (p. 29).

Though the ideas of teaching through reformed based orientations have been embedded throughout reform documents for almost twenty years, reform-based practices are not occurring in many classrooms. Elementary teachers often have difficulty implementing reform-based strategies in their classrooms. Their challenges with teaching science, not just inquiry science, have been well documented in the literature (Appleton, 2007; Davis, 2006; Park Rogers, 2006). Appleton (2007) reports some of the major issues surrounding the challenges of elementary teachers include the lack of science subject matter knowledge, pedagogical content knowledge (Shulman, 1986), and low self-confidence and self-efficacy for teaching science (Jarrett, 1999). The elementary years are a critical period for students to develop an interest in science, develop a foundation of science content, and gain an understanding of how to do science. It is an important time not only to prepare students for middle school science, but also to plant the seeds for science literacy (NRC, 1996; NRC, 2000; NRC 2012). Yet, in Banilower, Smith, Weiss, Malzahn, Campbell & Weiss' (2013) *2012 Report of the International Survey of Mathematics and Science Teachers,* only 36% of elementary teachers reported they met National Science Teachers Association (NSTA) educator preparation recommendations of courses in earth, life and physical science. Twenty percent had taken one of three courses while 38% had taken two science courses in their educator preparation program. While 77% of elementary teachers felt very well prepared to teach mathematics, only 39% felt very well prepared to teach science. Metz (2009) found that limited subject matter knowledge in elementary teachers hindered the implementation of reform-based curricula.

The stakes are high for elementary science teachers. They are often charged with the responsibility for teaching multiple subjects as well as the different domains of science (Davis & Smithey, 2009; Wilson & Kittleson, 2011), and they are expected to teach science in a reform-oriented manner. This includes emphasizing not only the content, but also the nature and processes of science. This expectation is now magnified with the recent release of reform documents, *Taking Science to School* (Duschl, Schweingruber, & Shouse, 2007) and *The Framework for K-12 Science Education* (NRC, 2012). These documents present a synthesis of the research on science education and propose a focus on a smaller number of core disciplinary ideas organized by learning progressions by grade bands; seven cross-cutting concepts such as patterns, form and function, and stability and change and eight science and engineering practices. The *Frameworks* include the five essential features of inquiry and the additional practices of developing and using models; using mathematics, information and computer technology and computational thinking; and engaging in argument from evidence.

Implementing the *Framework* include overcoming the “challenge to the long tradition of science teaching as telling that has been so pervasive in schools, characterized by the stereotypical view of the transmission of science as propositional knowledge” (Loughran, 2007, p. 1043). The *Framework* includes the goal of students being actively engaged in and applying their knowledge to the practices of science and engineering. “Teaching science as envisioned by the new frameworks requires that teachers have a strong understanding of the scientific ideas and practices they are expected to teach, including an appreciation of how scientists collaborate to develop new theories, models and explanations of natural phenomena" (NRC, 2012, p. 256). Professional development will be important in helping teachers meet the expectations of the *Frameworks*.

Professional development (PD) experiences for elementary science teachers occur at both various settings and under different contexts. For example, while some elementary teachers participate in PD voluntarily, on their own accord, others participate in PD as an employment requirement. In addition, the duration and frequency of PD sessions vary from few minutes of school-based training to weeks long training at the school or at an off-site location. The quality and relevancy of PD sessions also vary, yielding mixed results. Horizon Research's *2012 Report of the 2012 National Survey of Science and Mathematics Education* found that 65% percent of elementary teachers reported they spent less than six hours in the last three years on professional development in science (Banilower et al., 2013). Only 4% reported they spent more than 35 hours in science professional development. Of the teachers engaging in PD over the last 3 years, 48% reported that they had opportunities to engage in science investigations. When asked about the primary focus of the science PD experiences, 47% reported the PD included a focus on assessment, 47% on planning differentiated instruction, 45% on monitoring student understanding, 41% on prior knowledge, and 37% on deepening their content knowledge.

The National Academy of Science (NRC) report, *Preparing Teachers: Building Evidence for Sound Policy* (2010) describes the following attributes of teachers needed to meet the goals of the ideas in the new reform including:

- grounding college-level study of the science disciplines suitable to the age groups and subjects they intend to teach, which develops understanding of the big conceptual ideas in science;
- understanding of multifaceted objectives for students' science learning;

- understanding the ways students develop science proficiency; and
- command of an array of instructional strategies designed to develop students' learn the content, intellectual conventions, and other attributes essential to science proficiency, also known as pedagogical content knowledge (NRC, 2010, p. 143).

Professional development for teachers will be important in realizing the goals of the *Frameworks.* Professional development may be targeted at all or some of the constructs within the aforementioned attributes. The attributes presented can provide a guide for professional developers. In reference to the above attributes, it is important to note the importance of content knowledge development that focuses on conceptual understanding of big ideas in science such as heredity or energy. It is also important to provide ideas about how students learn science as well as instructional strategies to develop content in a way that is developmentally appropriate for the students. Pedagogical content knowledge (PCK) describes a unique teacher knowledge base that includes the ability to transform science content into a form that students can understand (Shulman, 1987). Sometimes considered, the intersection of content and pedagogy, PCK includes selecting the best instructional strategies to convey a particular topic (Gess-Newsome & Carlson, 2013).

Looking to the literature about effective PD will also be important. Singer, Lotter, Fetter, and Gates (2011) synthesized the literature on effective professional development and outlined six core components of *'high quality'* professional development. Table 1 compares these six components of with the recommendations for professional development of K-8 science teachers suggested by Duschl, Schweingruber, and Shouse (2007).

Table 1

Parallels of Recent Recommendations for Professional Development

<table>
<tr><th>Six Core Components of ‘High Quality’ Professional Development</th><th>Recommendations for Professional Development of K-8 Science Teachers</th></tr>
<tr><td>1. Immersing participants (teachers) in inquiry, questioning, and experimentation;</td><td rowspan="3">Recommendation 7: University-based science courses for teacher candidates and teachers’ ongoing opportunities to learn science in service should mirror the opportunities they will need to provide for their students, that is, incorporating practices in all four strands giving sustained attention to the core ideas in the discipline. The topics of study should be aligned with central topics in the K-8 curriculum so that teachers come to appreciate the development of concepts and practices that appear across all grades.</td></tr>
<tr><td>2. Intensive and sustained support;</td></tr>
<tr><td>3. Engaging teachers in concrete teaching tasks that integrate teachers’ experiences’</td></tr>
<tr><td>4. Focusing on subject matter knowledge and deepening teacher content knowledge;</td><td rowspan="3">Recommendation 6: State and local school systems should ensure that all K-8 teachers experience sustained science-specific professional development in preparation and while in service. Professional development programs should be rooted in the science that teachers teach and should include opportunities to learn about science, about current research on how children learn science, and about how to teach science (Duschl, Schweingruber and Shouse, 2007. p. 350).</td></tr>
<tr><td>5. Providing explicit connections between professional development activities and student outcome goals; and</td></tr>
<tr><td>6. Providing connections to larger issues of education/school reforms (Singer, Lotter, Fetter & Gates, 2011, p. 205).</td></tr>
</table>

Both the six core components of quality professional development and the recommended professional development from *Taking Science to School* suggest teachers need to experience professional development that emulates reform-oriented pedagogy through different forms of inquiry. The word *sustained* is used in both documents and reflects the importance of spending a significant amount of time with teachers developing pedagogical skills, enhancing content knowledge, and making connections between the professional development and student learning. Opfer and Pedder (2011) used complexity theory to analyze the professional development research to look for relationships of why teacher learning may or may not occur. The general ideas synthesized from their literature review included the importance of sustained and intensive contact, the importance of time for teachers to have "time to develop, absorb, discuss and practice new knowledge, " connecting the professional development to the daily work of the teachers, and actively engaging teachers in the way students should be engaged.

The specific goals of a professional development could include multiple constructs such enhancing teacher professional knowledge bases such as content knowledge, pedagogical knowledge and knowledge of assessment. Sometimes the goals may include an affective component such as beliefs, confidence, or self-efficacy. The goals of a professional development may be the understanding of a reform-oriented construct such as the nature of science or inquiry based learning.

A type of professional development that may be used to support teachers in reaching the goals of science reform efforts is a teaching endorsement. While the language used in describing teacher endorsement may vary somewhat across different states, teaching fields (certification) generally describe areas in which teachers have demonstrated competency to teach, endorsements are typically added to an existing certificate as affirmation of additional formal training to teach in a particular subject or a group of students. The competencies are predetermined by a series of requirements which may include college courses, content or pedagogy assessments, and fieldwork experience. Endorsements have a specified list of requirements that teachers must successfully complete to add a field to their certificate.

The focus of this study is to examine the influence of a K-5 science endorsement on in-service elementary science teachers' pedagogical content knowledge (PCK), self-efficacy, content knowledge, and the interaction of those components. The goals of the K-5 science endorsement include enhancing in-service elementary teacher science content knowledge and providing opportunities for teachers to experience reform based science teaching practices with embedded opportunities for teachers to develop, teach, and reflect on reform based lessons. The K-5 science endorsement program in this study includes four courses: life, earth, and physical science and pedagogy. The content of the courses are delivered using reform-based strategies. The endorsement program includes a residency with requirements for developing, teaching and reflecting on lessons developed throughout the endorsement.

Research Questions

The overarching research question is: *How does participation in a K-5 science endorsement influence the professional knowledge bases of in-service elementary science teachers?* Several sub questions will be explored to provide more insight to the question:

1. How does participation in a K-5 science endorsement influence the content knowledge of science teachers?
2. How does participation in a K-5 science endorsement influence the self-efficacy of science teachers?
3. How does a K-5 science endorsement influence the interaction of the professional knowledge bases of elementary science teachers?

This study hopes to make contribution to the literature in several ways including an understanding of the role of an endorsement in influencing the professional knowledge bases and self-efficacy of elementary science teachers. This includes how those dimensions of professional knowledge may influence the enactment of PCK in lesson plans and classroom practice. The study looks at the professional knowledge bases that influence PCK (Gess-Newsome & Carlson, 2013a). In previous studies, PCK has been considered to be composed of five knowledge bases of teachers: orientations, knowledge of student conceptions, knowledge of assessment, and knowledge of curriculum (Magnusson, Krajcik and Borko, 1999). A newer model situates Teacher Professional Knowledge Bases such as Content Knowledge, Pedagogical Knowledge, and Curricular Knowledge and other dimensions such as Knowledge of Instructional Strategies as constructs that influence PCK. In this model, PCK is critical during the enactment of topic specific science lessons (Gess-Newsome & Carlson, 2013b). This study will add to previous studies about elementary teachers' enactment of reform-oriented instructional strategies by observing and interviewing teachers who have completed the endorsement. A literature review that follows will include information about the model.

Content knowledge is one of the professional knowledge bases associated with PCK. The limited content knowledge of elementary teachers has been linked to low levels of confidence, self-efficacy for teaching science, avoidance of teaching science, and difficulties implementing reform-based instructional strategies (Appleton, 2007; Davis, Petish & Smithey, 2006; Lee & Houseal, 2003; Metz, 2009; Wilson & Kittleson, 2011). This study addresses gaps in the literature as it relates to the content knowledge of elementary science teachers following a yearlong K-5 science endorsement.

Professional development and college courses have been shown to increase the subject matter knowledge of inservice (Kang, 2007; Kanter & Konstantopoulos, 2010; Goodnough & Nolan, 2008; Smith & Neale, 1987) and preservice elementary teachers (Nilsson & Van Driel, 2011). Smith and Neale (1989) found that a professional development experience had an impact on the content knowledge and PCK of teachers of elementary teachers participating in a summer program designed understand changes in the content knowledge of elementary science teachers. Nilsson and Van Driel (2011) conducted a study of 40 pre service elementary teachers enrolled in an eight week physics course and found that having the opportunity to discuss subject matter with experts, explaining concepts to others, and having opportunities to address their own misconceptions were impactful. Misconceptions became visible when student teachers' had to explain a concept to another teacher which made it easier for instructors to address the misconceptions of the student teachers. Akerson (2005) sought to find ways experienced and inexperienced elementary teachers compensated for incomplete content knowledge. This study adds to the knowledge base of the content knowledge of elementary teachers by observing and interviewing one year after completing the endorsement. Interviews will include questions about the endorsements' influence on content knowledge and confidence to teach science. Observations will include a focus on the enactment of content knowledge, pedagogy, and instructional strategies.

The PCK literature includes more studies about secondary science teachers than elementary science teachers. Many of the studies are about the role of professional development on content knowledge. There are a large number of studies with chemistry teachers (Dreschler & Van Driel, 2007; Park & Oliver, 2007; Van Driel, DeJong &

Verloop, 2002) and biology teachers (Friedrichsen, Abell, Pareja, Brown, Landford, Volkmann, 2009; Friedrichsen & Dana, 2005; Kapyla, Heikkinen, Asunta, 2009; Park & Chen, 2012; Park, Jang, Chen & Jung, 2011). A few studies on PCK have focused on a specific topics such as osmosis and diffusion (Lankford, 2010), density (Dawkins, Dickerson, McKinney & Butler, 2008) or cells (Cohen and Yarden, 2009). This study will add to the knowledge base of the influence of a professional development on the content knowledge of elementary teachers.

This study also addresses the self-efficacy of elementary science teachers as related to PCK. Few PCK studies have specifically addressed teacher self-efficacy. Park & Oliver (2008) considered self-efficacy to be an affective component of PCK. In the Professional Knowledge Bases including PCK model, efficacy is situated as one of many components may amplify or filter a teacher's enactment of their PCK (Carlton & Gess-Newsome, 2013). The other components include motivation, risk-taking, and dissatisfaction. Major findings in self-efficacy research include that increased content knowledge has shown to increase the self-efficacy of mathematics (Swackhamer, Koellner, Basile & Kimbrough, 2009) and science teachers (Granger, Bevis, Saka, Southerland, Sampson & Tate, 2012). Elementary teachers that participated in a constructivist oriented professional development showed gains in content knowledge, personal science teaching self-efficacy, and pedagogical content knowledge (Khourney-Bowers & Fenk, 2009). Science teachers with a higher self-efficacy are more likely to implement reform-based strategies than teachers with a lower self-efficacy (Czerniak & Schriver, 1994). Lakshmanan, Heath, Pelmutter & Elder (2010) found that teacher efficacy and use of reformed based teaching were positively impacted by professional development that focused on content knowledge and professional learning communities. Carleton, Fitch, and Krockover (2008) found "as a result of mastery experiences, teachers' confidence in their teaching ability improved significantly" (p. 60). Dellinger, Bobbett, Olivier & Ellett (2008) recommend more studies on teacher self-efficacy. This study will add to the literature on self-efficacy by linking self-efficacy to the professional knowledge bases that inform PCK and focusing on the influence of an endorsement program on self-efficacy.

This study is also unique in that it is coordinated by a state agency and offered within the school districts of participants. The agency developed the endorsement based upon certification rules which included an emphasis on reform-oriented teaching practices. The endorsement is an example of a job-embedded professional development experience and includes multiple opportunities for teachers to develop, teach, and reflect on lessons. Looking more closely at this type of professional development will contribute to the current knowledge base.

Theoretical Framework

The theoretical framework that guides this study is Social Cognitive Theory. Crotty (2005) describes a theoretical perspective as "the philosophical stance that lies behind our chosen methodology" (p. 7). Social cognitive theory (Bandura, 1997) provides a theoretical basis for this research because the focus of the study is how participation in an endorsement influences the teaching practices of elementary science teachers. Merriam, Caffarella and Baumgartner (2007) classified learning theories into five basic orientations: cognitive, social cognitive, constructivist, behaviorist and humanist. Social cognitive learning theory "combines elements of from both behavioral and cognitive orientations" (p. 287) and asserts people learn by observing others in a social environment. "By observing others, people acquire knowledge, rules, skills, strategies, beliefs and attitudes" (Merriam et al., 2007). The social cognitive theory suggests a "multifaceted causal structure that addresses both the development of competencies and the regulation of action (Bandura, 1997, p. 34 (from 1987).

Human agency is a central component of the social cognitive theory. Bandura identifies three types of agency: "personal agency exercised individually; proxy agency in which people secure desired outcomes by influencing others to act on their behalf; and collective agency in which people act in concert to shape their future (Bandura, 2002, p. 270). Bandura (1997) asserts "human agency operates within an interdependent causal structure involving triadic reciprocal causation" with "internal personal factors in the form of cognitive, affective, and biological events; behavior; and environmental events all operat[ing] as interacting determinants that influence one another bidirectionally" (p. 6). The yearlong endorsement class has opportunities to primarily influence the personal agency of participants. The study will inform the research on human agency and the reasons a professional development may or may not have an influence on participants.

Bandura (1997) identifies self-efficacy as a component within the social cognitive theory and asserts self-efficacy "operates in concert with other determinants in the theory to govern human thought, motivation and action" (p. 34). Bandura (1997) identified four types of experiences that play a role in the development of self-efficacy: "*enactive mastery experiences* that serve as indicators of capability; *vicarious experiences* that alter efficacy beliefs through transmission of competencies and comparison with the attainment of others; *verbal persuasion* and allied types of social influences that one possesses certain capabilities; and *physiological and affective states* from which people partly judge their capableness, strength and vulnerability to dysfunction" (p. 79). Mastery experiences are considered the most influential because of the authentic experience of demonstrating mastery. Positive experiences in these areas are associated with higher self-efficacy. Through the endorsement, participants developed, implemented and reflected on lessons developed for their particular students. This lesson planning cycle has the potential to influence self-efficacy through mastery experiences. Instructors modeled reform-oriented instructional practices and provided a system of support for participants during the endorsement. Instructors may have influenced through vicarious experiences and verbal persuasion.

During the K-5 science endorsement, teachers experience science content that is delivered using the 5E model and in turn develop lessons using the 5E model. The 5E model is based on the Learning Cycle first developed by Karplus and Thier (1967) and includes opportunities for *Engagement, Exploration, Explanation, Elaboration,* and *Evaluation* (Bybee, 1997). The 5E model is a well researched model that was designed to facilitate conceptual change (Bybee et al., 2006). Lesson and unit plans are developed during each course and teachers are required to teach and reflect on the lessons taught. Research indicates that lesson planning practices become more reform-based when teachers are exposed to reform-based instruction (Beyer & Davis, 2012). The 5E learning cycle model is an effective tool for planning lessons that focus on conceptual change (Appleton, 2002, 2003; Hanuscin & Lee, 2008; Hume, 2012) and inquiry (Huziak-Clark, Van Hook, Nurnberger-Haag and Ballone-Duran, 2007; Moseley & Ramsey, 2008). Huziak-Clark, Van Hook, Nurnberger-Haag and Ballone-Duran (2007) found that a professional development in which teachers participated in modeling, developing and implementing 5E inquiry lessons, increased teacher understanding of and use of inquiry.

The study will be viewed through the lens of the epistemology of pragmatism and conducted through a mixed methods approach. Creswell (200) lists four major elements associated with pragmatism: consequences of actions, problem centered, pluralistic and real-world practice oriented. Throughout the course of the yearlong endorsement, teachers experience 200 contact hours situated in content and pedagogy classes that model reformed based practices including the use of a learning cycle to develop content knowledge. Participants implement endorsement requirements with their classrooms.

Creswell (2009) summarizes the research on pragmatism and combines these ideas with his own to provide a philosophical basis for research which includes that researchers are "free to choose the methods, techniques, and procedures of research that best meet their needs and purposes" (p. 11). Johnson and Onwuegbuzie (2004) provide insight to the general characteristics of pragmatism. A few points include:

- Places high regard for the reality of and influence of the inner world of human experience in action.
- Knowledge is viewed as being both constructed *and* based on the reality of the world we experience and live in.
- Views current truth, meaning, and knowledge as changing over time. What we obtain on a daily basis in research should be viewed as provisional truths.
- Endorses practical theory (theory that informs effective practice; praxis)
- Places high regard for the reality of an influence of the inner world of human experience in action (p. 18).

Morgan (2007) advocates for a pragmatic approach to mixed methods research and argues for the need to "concentrate on methodology as an area that connects issues at the abstract level of epistemology and the mechanical level of actual methods" (p. 68).

In his view of a pragmatic approach, he puts the methodology at the center between epistemology and methods with methodology informing both the epistemology and methods of the study. This study will employ the use of quantitative and qualitative methods in order gain an understanding of the influence of the K-5 science endorsement on content knowledge, self-efficacy and professional knowledge bases of elementary teacher.

Limitations of the Study

It should be noted that the lead author is the coordinator of the K-5 science endorsement and the study that follows is my dissertation. The development of the endorsement was a collaborative effort of science specialists from local school districts and was developed for elementary science teachers in their respective districts. My current role includes the responsibilities of training endorsement instructors, coordinating cohorts within in districts, managing the day to day operations of the endorsement including providing support and resources for instructors and participants. It is my responsibility to ensure all participants of the endorsement meet the criteria to be awarded the endorsement. I made the decision to study participants after they had been awarded the endorsement to reduce the possibility of a conflict of interest.

My role with the endorsement could be considered both a strength and weakness of the study. My committee has approved the data collection process and agreed that my intimate knowledge of the goals and structure of the endorsement is more a strength than a limitation. Teddlie and Tashakkori (2009) purport "a golden rule of making inferences in human research is *know thy participants!* Having a solid understanding of the cultures of the participants and the research context is a valuable asset in the process of making inferences" (p. 289). During the implementation of the endorsement, I have observed endorsement instructors teaching courses to these participants and engaged in discussions with participants primarily about the endorsement requirements. My role in developing the endorsement makes me very aware of the intended goals. Because of this, my intimate knowledge of the endorsement is considered a strength. In order to prevent a potential bias and conflict of interest, peer debriefers were engaged throughout the data analysis components of the study.

The literature review that follows will include an overview of the research base of pedagogical content knowledge and the professional knowledge bases that influence it.

CHAPTER 2: LITERATURE REVIEW

Recently published reform documents from the National Research Council (NRC) provide a research base for a new movement in science reform with the goal of producing students who are proficient at science (Duschl, Schweingruber, & Shouse, 2007; Michaels, Shouse & Schweingruber, 2008; NRC, 2012). These documents outline the research base used to propose new learning progressions for science content and link science content with crosscutting concepts and science and engineering practices. The purpose of this literature review is to provide an overview of the most recent science reform documents and to discuss the role of teacher Pedagogical Content Knowledge (PCK) as a framework for realizing the goals of the new science reform. PCK was introduced by Shulman and has been defined as the unique knowledge and skills that teachers need in order to be effective in the subjects they teach (Shulman, 1986). PCK has been described as "what a teacher knows, what a teacher does, and the reasons for the teacher's actions" (Baxter & Lederman, 1999, p. 158). This unique knowledge base of science teachers is what differentiates them from scientists. PCK is important to consider when preparing teachers for reform-based practices. Thus PCK research can also provide a lens through which to examine professional development efforts.

This literature review of PCK will be organized by the four components of science education identified in the Frameworks for science education as important in preparing teachers to implement the goals of the Frameworks (NRC, 2012). The components include: curriculum and instructional materials, learning and instruction, teacher development, and assessment. The current base of PCK literature will be linked to the Frameworks with the goal of providing insight into the alignment among PCK, the

Framework, and teacher professional development. The literature review will also compare the widely used PCK model developed by Magnusson, Krajcik & Borko (1999) with a recently developed Professional Knowledge Bases including PCK model synthesized by Gess-Newsome and Carlson (2013a). The literature review will conclude with a summary of the strengths and weakness of using PCK as a conceptual framework and discuss the gaps in the research literature associated with PCK of elementary science teachers.

A Brief History of Science Reform Efforts

The reform efforts of the 1980’s and 1990’s included a movement away from the use of teaching strategies that included rote memorization towards strategies that actively engaged students; including a focus on student misconceptions, inquiry based learning, conceptual learning, diversity, and a focus on the nature of science (Southerland, et al., 2007). Reform documents such as *Science for All Americans* (AAAS, 1990), the *Benchmarks for Scientific Literacy* (AAAS, 1993), and the *National Science Education Standards* (NRC, 1996) were developed with an emphasis that “science is for all students” (NRC, 1996, p. 19) and that *all* students should be actively engaged in science. The vision of the *National Science Education Standards* included an emphasis on changes in teaching standards including: “focusing on student understanding and use of scientific knowledge, ideas, and inquiry process; guiding students in active and extended scientific inquiry; continuous assessment of student learning (NRC, 1996, p. 56).” This was a move away from more traditional methods of learning that included the acquisition of knowledge primarily through lecture. *Inquiry and the National Standards* (2000) further elaborated on the five essential features of inquiry:

1. Learner engages in scientifically oriented questions.
2. Learner gives priority to evidence in responding to questions.
3. Learner formulates explanations from evidence.
4. Learner connects explanations to scientific knowledge.
5. Learner communicated and justifies explanations. (p. 29).

Though the ideas of teaching through reformed based orientations have been embedded throughout reform documents for almost twenty years, reform-based practices are not occurring in many classrooms. Elementary teachers' challenges with teaching science, not just inquiry science, have been well documented in the literature (Appleton, 2007; Davis, 2006; Park Rogers, 2006). Appleton (2007) reports some of the major issues surrounding the challenges of elementary teachers include the lack of or low science subject matter knowledge, pedagogical content knowledge (Shulman, 1986), self-confidence and self-efficacy for teaching science. Preservice teachers often express doubts about their ability to teach science while experienced teachers express concerns about being qualified to teach science (Abell & Roth, 1995) often as a result of having poor experiences as science students (Watters & Ginn, 1995). Gallagher (2000) reported from classroom observations that the majority of science class time was utilized to help students gain a knowledge base in science in contrast to being spent to help students gain scientific understanding.

A New Wave of Reform

In recently released reform documents, the National Research Council (NRC) builds on previous reform to outline four fundamental strands of proficiency (Duschl, Schweingruber, & Shouse, 2007; Michaels, Shouse & Schweingruber, 2008) and three dimensions (NRC, 2012) of science learning that students need in order to become proficient at science. These documents incorporate the ideals in the *National Science*

Education Standards and focus on integrating the ideas of science content, process, and the nature of science instead of learning science content in isolation of science process. In *Taking Science to School*, students who are able to integrate, organize, and apply what they know about science are considered to be proficient in science (Duschl, Schweingruber, & Shouse, 2007). The strands of proficiency are listed in Table 2 with additional information summarized from the reports (Duschl, Schweingruber, & Shouse, 2007; NRC, 2012). The strands demonstrate the need for students not only to conceptually understand science content, but to be able to apply content to science processes including explanations, modeling, and constructing arguments. Students should demonstrate a deeper understanding of how science works including using evidence to make claims and construct viable arguments.

Table 2

Strands of Scientific Proficiency

Strands of Proficiency	Elaboration
1. Know, use, and interpret scientific explanations of the natural world;	Includes "conceptually central ideas and facts integrated in well-structured knowledge systems; includes the "big ideas" of science; there is a focus on applying these ideas to explanations, arguments and models.
2. Generate and evaluate scientific evidence and explanations;	Includes designing and analyzing investigations, generating and using evidence to support arguments and build models.
3. Understand the nature and development of scientific knowledge; and	Through their participation in the practices of science, students gain an understanding of how science is a way of knowing confirmed by evidence and revised as new information becomes available
4. Participate productively in scientific practices and discourse (Duschl et al., p.36).	Focuses on students gaining an understanding of the norms of participating in science; engaging in debates, taking a stand and asking questions.

The *Framework for K-12 Science Education* (NRC, 2012) followed the development of *Taking Science to School* (NRC, 2007) and was organized into three dimensions: Science and Engineering Practices, Cross-Cutting Ideas, and Core Disciplinary Ideas. The dimensions inform the Next Generation Science Standards released in 2013 (NRC, 2013). These reform documents call for a focus on a smaller number of core disciplinary ideas organized by learning progressions by grad band. Also included are eight science and engineering practices in which students are actively engaged in the learning strands; and seven cross-cutting concepts such as patterns, form and function, and stability and change. The cross-cutting concepts are considered to span all disciplines and encompass the unifying concepts and processes included in the *National Science Education Standards*. The eight science and engineering practices are:

1. Asking questions (for science) and defining problems (for engineering)
2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematics, information and computer technology, and computational thinking
6. Constructing explanations (for science) and designing solutions (for engineering)
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information (NRC, 2012, p. 254)

The Frameworks include the five essentials features of inquiry (NRC, 2000) but include the additional practices of (2) developing and using models and (5) using mathematics, information and computer technology, and computational thinking. Learners given priority to evidence has been further elaborated to include (7) engaging in argument from evidence.

Pedagogical Content Knowledge

Teaching is a complex and unique profession and one in which teachers transform their subject matter knowledge into a form that students can understand and use. Pedagogical Content Knowledge (PCK) is a multifaceted framework that incorporates teachers' knowledge base of content, instructional strategies, assessments, curriculum, and beliefs about the goals and purposes of teaching. PCK can be a useful framework for realizing the goals of the Frameworks. It can provide insights into the complexities of teaching and teachers. The nature of the development of PCK is of a constructivist epistemology with a teacher's PCK evolving throughout his or her teaching career and being influenced by many factors. The acquisition of PCK is a complicated process that is formalized during pre-service experiences for traditionally certified teachers (Adams & Krockover, 1997), during the first year of teaching for alternatively certified teachers (Baldwin, 2003; Friedrichsen, Abell, Pareja, Brown, Lankford & Volkmann, 2009), and further developed during professional development for teachers at all levels of experience (Van Driel, Verloop, & de Vos, 1998) including the National Board Certification process (Park & Oliver, 2008).

According to Shulman, PCK lies at the intersection of content and pedagogy. Shulman (1987) and Grossman (1990) organized PCK as a domain of knowledge that influences and is influenced by three other domains of knowledge: subject matter content (SMK), pedagogical knowledge (PK) and knowledge of context (K of C) which includes knowledge of students, schools, and school environments. PCK is considered to be subject, topic, and likely, grade band specific (Abell, 2007), and the PCK of science teachers would be different from the PCK of other subject teachers. Science teachers need to develop PCK for teaching science as well developing PCK for the specific domains of science they teach. Beyer and Davis (2012) describe their "view of PCK entails examining not what teachers know but rather how they are able to use what they know in practice" (p. 132). They further elaborate that "knowing" would describe a static orientation while "using" is a more dynamic orientation with teachers flexibly applying what they know in different situations.

PCK has been "translated, explicated, revised and extended by a number of science educators" (Abell, 2007, p. 1108) and the definition for and understanding of PCK is still evolving. "It [PCK] represents the synthesis of teachers' knowledge of both subject matter and pedagogy, distinguishing the teacher from the content specialist" (Hanuscin, Lee, & Akerson, 2010, p. 148). A science teacher would have different set of knowledge bases from a scientist. According to Magnusson, Krajcik & Borko (1999), PCK is composed of five components:

1. *Knowledge of students' understanding of science* includes how students learn science, the misconceptions they may hold, and learning difficulties they may experience
2. *Knowledge of instructional strategies* includes the toolbox of teacher strategies such as inquiry learning, teaching for conceptual understanding, using models, analogies and multiple representations, as well as subject and topic specific strategies
3. *Knowledge of curriculum* includes knowledge of standards and curricular programs, vertical and horizontal alignment of the curriculum, knowledge of curriculum reform and standards
4. *Knowledge of assessment* includes knowledge of current assessment methods such as formative and summative assessment
5. *Orientations to teaching science* includes the goals and purposes for teaching and were organized into nine orientations that include both teacher centered and student centered orientations; orientations are considered to play a key role in PCK decision making

National Science Education Standards (NRC, 1996) does not utilize the PCK framework but does emphasize that teachers should have strong content knowledge, understand the nature of scientific inquiry, and be able to make "conceptual connections" across science disciplines and other subjects. These ideas are addressed in the PCK framework as it includes knowing how to use the most effective tools of teaching science including the use of analogies and inquiry, knowledge of misconceptions, how students learn, and the importance of connecting to prior knowledge (Gess-Newsome, 1999; Grossman, 1990; Park & Oliver, 2007).

Methods in PCK Research

There has been a great deal of research on the nature of PCK and how it manifests itself in the classroom. Most of the research has been qualitative and includes case studies and grounded theory methodologies in an attempt to develop substantive theories about the development of PCK through in-depth studies of teaching practices and instructional decision making (Baldwin, 2003; Friedrichsen & Dana, 2005; Park & Oliver, 2007; Park & Oliver 2008). The methods include extensive teacher observations, interviews, and surveys such as the Views on Science-Technology-Society (VOSTS) to assess the knowledge of the nature of science (Abd-El-Khalick & BouJaoude, 1997), Teachers' Pedagogical Philosophy Interview (TPPI) (Adams & Krockover, 1997), Lesson Plan Preparation Model (Friedrichsen et. al 2009), lesson planning (Beyer & Davis, 2012), story-lines (Dreschler & Van Driel, 2007), and teacher developed assessments (Cohen & Yarden, 2009).

Instruments such as Content Representations CoRe's and Pedagogical and Professional-experiences Repertoires) or PaP-eRs have been developed to capture PCK (Loughran, Mulhall, & Berry, 2004; Bertram & Loughran, 2011. CoRe's provide a common language and encompass a teacher's articulation of why the big ideas of science are important and include the influence of limitations of students experience when learning about the topic. PaP-eRs were developed to gain an understanding of the influence of how knowledge of content and pedagogy informs classroom practice (Loughran, Mulhall, & Berry, 2004; Bertram & Loughran, 2011). These two instruments are used together to create Resource Folios and attempt to capture multiple components of a teacher's PCK. Another instrument, the PCK-ERT, an Evidence Reporting Table was developed to record the frequency of elements of PCK during a classroom observation (Park & Oliver, 2007). Park, Jang, Chen and Jung (2011) developed a PCK rubric to study two components of PCK: Knowledge of Student Understanding and Knowledge of Student Instructional Representations and used the rubric to review videotapes of 33 lessons of 7 teachers teaching units on heredity and photosynthesis. They analyzed the videos using the RTOP and the PCK rubric and found a statistically significant correlation of .831 between the RTOP and PCK rubric. They concluded "this result indicates that a teacher's PCK level is positively related to the extent to the teacher's instruction is reformed oriented" (Park, Jang, Chen and Jung, 2011, p. 252).

Early research on PCK focused on identifying the components of PCK and developing instruments to identify and gain an understanding of the development of PCK. Major findings included the following: PCK guides how teachers approach subject matter (Van Driel, DeJong & Verloop, 2002); PCK is socially constructed through work with other teachers (Loughran, Mulhall, & Berry, 2004); teacher misconceptions (Smith & Neale, 1989; Abd-El-Khalick & BouJaoude, 1997) and student misconceptions (Park & Oliver, 2008) impact PCK; teacher efficacy is considered an affective component of PCK (Park & Oliver, 2007). The recent focus of PCK research has shifted from identifying PCK to how teachers apply and integrate PCK components (Beyer & Davis, 2012; Park & Chen, 2012). There has also been a focus on specific aspects of PCK such as inquiry (Avraamidou & Zembal-Saul, 2010), using models (Dreschsler & Van Driel, 2007; Henze, Van Driel & Verloop, 2008), the nature of science (Hanuscin, Lee & Akerson, 2010), and formative assessment (Falk, 2011). PCK research provides a lens into the complexity of teaching. These studies highlight how a focus on the development of PCK can help enhance the knowledge bases of teachers with the capabilities needed to help students become proficient at science as outlined by the Frameworks.

Schneider and Plasman (2011) synthesized twenty years of PCK research of science teachers in order to propose learning progressions for the five components of PCK. “Learning progressions are descriptions of successively more sophisticated ways of thinking about a topic that can follow one another as children learn about and investigate a topic over a broad span of time” (Duschl et al., 2007). Specific learning progressions for students are presented in the newer reform document and include science content and practices of science and engineering (Duschl, et al., 2007; NRC, 2010). In order to establish a learning progression of PCK for teachers, Schneider and Plasman (2011) first organized science teachers into five categories of experience levels based upon the existing PCK knowledge base: preservice teachers with no classroom experience, new teachers with 0 – 3 years of experience, teachers with “some” experience (4 – 10 years), teachers with “much” experience (11+ years), and teacher leaders with experience as mentors or peer leaders. Their findings included a continuum of teacher development over time described in learning progressions. Trends demonstrated a progression from teacher-centered to student-centered orientations. Characteristics of teachers at the two ends of the experience continuum: preservice and teachers with "much" experience had similar characteristics of other members in their respective groups. They found the most variation of teachers with "some" experience. Schneider and Plasman (2011) found "…indications that PCK as defined by researchers might actually decline over time as teachers advance in their careers, highlighting the importance of advanced or extended professional development guided by the idea that teacher learning should progress across a profession" (Schneider & Plasman, p. 556). This suggests the importance of professional development across all experience levels. They also suggested science teacher leaders had the most sophisticated ideas and recommended this area needed more research.

Teacher Professional Knowledge Bases Including PCK

In order to bring together internationally represented PCK experts, a PCK Summit was held in the fall of 2012 (Gess-Newsome & Carlson, 2013a, 2013b). A consensus definition for personal PCK was one of the outcomes of the summit. In the newly proposed model, PCK is explained to be influenced by other knowledge bases of teaching including content and pedagogical knowledge. PCK includes both knowledge and enactment and is suggested to be topic specific with a focus on student outcomes. The consensus definition of PCK includes two statements:

> Knowledge of, reasoning behind, and planning for teaching a particular topic in a particular way for a particular purpose to particular students for enhanced student outcomes (Reflection *on* Action, Explicit). The act of teaching a particular topic in a particular way for a particular purpose to particular

students for enhanced student outcomes (Reflection *in* Action, tacit or explicit) (Gess-Newsome & Carlson, 2013a, 2013b).

Figure 1 shows the Teacher Professional Knowledge Bases Including PCK. This model reorganizes the previous ideas of PCK into two types of teacher knowledge bases: Teacher Professional Knowledge Bases (TPKB) and Topic Specific Professional Knowledge Bases (TSPKB) that influence PCK. The TPKB are Assessment Knowledge (AK), Pedagogical Knowledge (PK), Content Knowledge (CK), Knowledge of Students (KS), and Knowledge of Curriculum (KC). The TPKB inform and are informed by Topic Specific Professional Knowledge Bases (TSPKB) which include knowledge of specific topics taught at specific grade levels. This includes a Knowledge of Instructional Strategies (KIS) such as content representations, student understandings, science practices, habits of the mind. Included in the model are several amplifiers and filters that influence the development of teacher knowledge including beliefs, efficacy, orientations, misconceptions, motivation, dissatisfaction, risk taking, etc. All of these knowledge bases influence PCK which is a result of personal knowledge and skill and is composed of planning and enactment. PCK is impacted by the classroom context including curriculum, time, standards, etc. All of these knowledge bases influence student achievement. With this model, PCK has moved from a broad overarching knowledge base (Magnusson et al., 1999) to one that is more narrowly focused with an emphasis on enactment and practice.

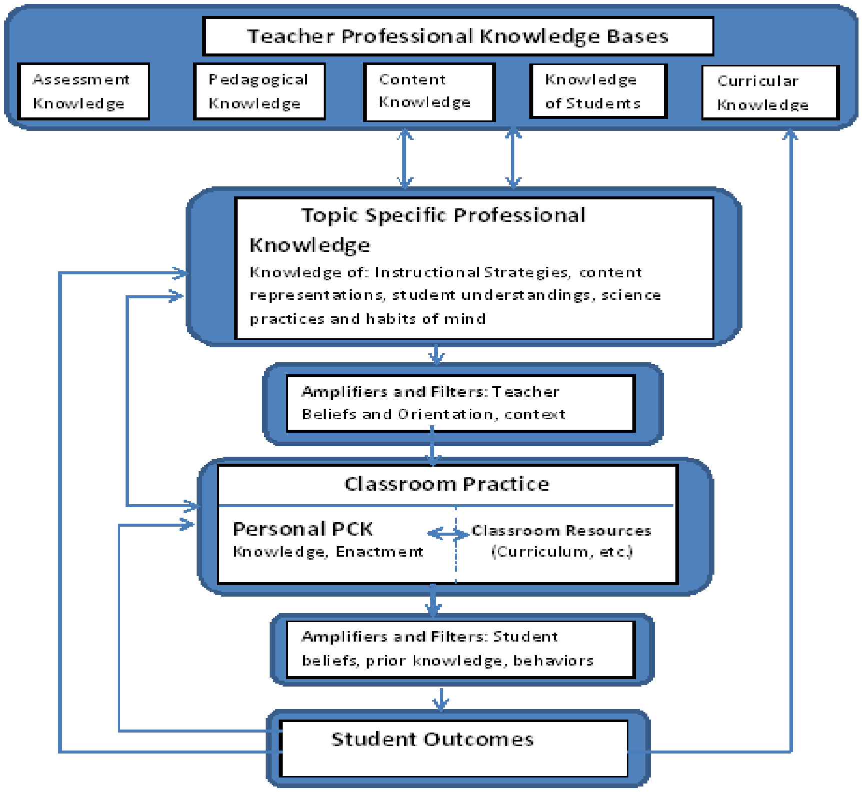

Figure 1. Teacher Professional Knowledge Bases Including PCK. Reprinted with permission from Gess-Newsome, J. & Carlson, J. (2013, January). An international perspective of pedagogical content knowledge. Presented at the Association for Science Teacher Knowledge (ASTE). Charleston, SC.

Researchers have been disseminating information from the summit at various conferences and have posted extend papers and conference presentations at the website, http://pcksummit.bscs.org/. The summit has opened up discussions among researchers and set out a research agenda that includes common item development, ways to measure PCK, studying the growth of PCK and testing the PCK model (Rollnick & Mavhunga, 2013).

PCK and the Frameworks Efforts

PCK involves teachers making the best instructional decisions for a "on a particular topic for a particular group of students." The National Academy of Science (NRC) report, *Preparing Teachers: Building Evidence for Sound Policy* (2010) describes the following attributes of teachers that are needed to help students become proficient at science:

- grounding college-level study of the science disciplines suitable to the age groups and subjects they intend to teach, which develops understanding of the big conceptual ideas in science;
- understanding of multifaceted objectives for students' science learning;
- understanding the ways students develop science proficiency; and
- command of an array of instructional strategies designed to develop students' learn the content, intellectual conventions, and other attributes essential to science proficiency, also known as pedagogical content knowledge (NRC, 2010, p. 143).

These attributes are embedded in the key components of the science education system: *teacher development, curriculum, instruction and assessment* as identified in the Frameworks (NRC, 2012). Work with these components will be essential in realizing the vision of the Frameworks (NRC, 2012). The research on PCK can provide a knowledge base for working with teachers on the key components of the Frameworks. When PCK was used as a framework for student teaching experiences, teachers went beyond collecting activities and focused on teaching and learning (Loughran, Berry & Mulholl, 2008). The explicit focus of PCK provided student teachers insight into the complex nature of teaching and "pushed student teachers beyond the mindset of an immediate need to gather up tips and tricks" (Loughran, Berry & Mulholl, 2008, p.1302).

The developers of the Frameworks acknowledge the complex system of stakeholders including teachers, schools and districts; universities; state and national organizations that will be needed to prepare teachers for implementation. The developers focus on four major components which they consider to be key areas in which work is needed to ensure the vision of the Frameworks: Teacher Development, Learning and Instruction, Curriculum and Assessment. These components will be the organizing framework of the next section of this literature review. *Teacher Development* will include PCK studies that primarily deal with teaching orientation, knowledge of subject matter or content knowledge, and self-efficacy. Orientations include goals and purposes for teaching (Magnusson et al., 1999; Schneider & Plasman, 2011) as well as degree of student centeredness (Friedrichsen, Van Driel & Abell, 2011. This section will also include PCK studies on implementing the nature of science (NOS) associated with orientations (Schneider & Plasman, 2011). *Learning and Instruction* will include knowledge of instructional strategies and knowledge of student conceptions of science. Strategies will include PCK studies involving inquiry, models, and representations in science. This section will include studies of difficulties enacting reform strategies. *Assessment* will include studies that discuss the PCK of assessment strategies. Finally, the Curriculum section will include knowledge of science curriculum and the implementation of new curricula. Table 3 organizes the professional knowledge bases that influence PCK with the key system components of the Frameworks.

Table 3

Identified Key Components of Science Education & PCK Knowledge Bases

Key Component of Science Education	Teacher Knowledge Bases
Teacher Development	Content Knowledge Orientations Towards Teaching Science Beliefs Self-efficacy
Learning & Instruction	Knowledge of Instructional Strategies Knowledge of Students' Understanding of Science
Assessment	Knowledge of Assessment
Curriculum	Knowledge of Science Curricula

Teacher Development

One of the challenges for implementing the Frameworks is the "challenge to the long tradition of science teaching as telling that has been so pervasive in schools, characterized by the stereotypical view of the transmission of science as propositional knowledge" (Loughran, 2007, p. 1043). Within the Framework is the goal of students being actively engaged in and applying their knowledge to the practices of science and engineering. "Teaching science as envisioned by the new frameworks requires that teachers have a strong understanding of the scientific ideas and practices they are expected to teach, including an appreciation of how scientists collaborate to develop new theories, models, and explanations of natural phenomena" (NRC, 2012, p. 256). A focus on subject matter knowledge and teaching orientations will be an important focus for teacher development. For many teachers, the focus on science and engineering practices may require a shift in teaching orientation towards one that is more student centered and reform oriented. A teacher's self-efficacy for teaching science will also be important in the implementation of the disciplinary core ideas, practices and cross-cutting concepts.

Content Knowledge

Content knowledge was defined by Shulman (1986) as "the amount and organization of knowledge per se in the mind of the teacher" and recommends "going beyond knowledge of facts or concepts of a domain" (p. 9). Shulman includes both knowledge and structures of the subject matter in his definition. Numerous PCK studies have addressed secondary teachers' content knowledge and provide a look at how PCK guides the way teachers approach subject matter (Van Driel, DeJong & Verloop, 2002). There are a large number of studies with chemistry teachers (Avargil, Herscovitz & Dori, 2012; Dreschler & Van Driel, 2007; Khourey-Bowers & Fenk, 2009; Park & Oliver, 2007; Park & Oliver, 2008; Van Driel, DeJong & Verloop, 2002;) and biology teachers (Friedrichsen, Abell, Pareja, Brown, Landford, Volkmann, 2009; Park & Chen, 2012; Park, Jang, Chen & Jung, 2011). One study looked at middle school teachers teaching density (Dawkins, Dickerson, McKinney & Butler, 2008). Student misconceptions (Park & Oliver, 2008) impact PCK as seen during observations of chemistry teachers implementing new instructional strategies during the NBCT process. Many of these studies will be discussed in more depth in other sections.

Teacher misconceptions about science content interfere with PCK development (Abd-El-Khalick & BouJaoude, 1997; Smith & Neale, 1989) and are the focus of several PCK studies involving elementary teachers. Nilsson and Van Driel (2011) conducted a study of 40 elementary student teachers enrolled in an eight week physics course and found that having the opportunity to discuss subject matter with experts, explaining concepts to others, and having opportunities to address their own misconceptions were impactful. Misconceptions became visible when student teachers had to explain a concept to another teacher which made it easier for instructors to address the misconceptions of the teachers. Smith and Neal (1989) found elementary teachers had misconceptions about light and shadows that were similar to their students. A professional development experience was instrumental in helping them overcome those misconceptions.

One of the concerns related to the content of elementary science teachers is related to the number of science courses taken during their educator preparation program. Banilower et al, 2012 report only 36% of elementary teachers reported they met National Science Teachers Association (NSTA) requirement of courses in earth, life and physical science. Twenty percent had taken one of three courses, while 38% had taken two science courses in their educator preparation program. While 77% of elementary teachers felt very well prepared to teach mathematics, only 39% felt very well prepared to teach science. They also reported they felt better prepared to teach life and earth science than physical science. Nowicki, Sullivan-Watts, Shim, Young, and Pockalny (2013) found teachers performed better on life science content assessments than other content areas. They performed the lowest on assessments about electricity and magnetism.

Nowick et al. (2013) videotaped 81 lessons of 27 preservice teachers and their cooperating teachers. They analyzed the lessons for content accuracy and "found 74% of experienced teachers and 50% of student teachers presented lessons with greater than 90% accuracy" (p. 1135). They used a multiple regression model to compare how ten factors might play a role in predicting the content accuracy of the lesson. They found that the use of kit based curriculum had significant influence on the content accuracy of the lessons. The science content of upper elementary teachers (grades 4 & 5) was higher than that of lower elementary teachers (grades 1 – 3). The grade level taught and whether or not they had a preference for teaching science were the other two most significant factors. Their results suggest that traditional content assessments were not an accurate measure of the content knowledge portrayed in lessons.

Orientations to Teaching Science

Magnusson et al. (1999) describe the PCK component of orientations towards teaching science as the "…teachers' knowledge and beliefs about the purposes and goals for teaching science at a particular grade level" and further elaborate "…these knowledge and beliefs serve as a 'conceptual map' that guides instructional decisions" (p. 97). Friedrichsen and Dana (2005) found that teaching orientations were complex, varied by the course taught by teacher, and impacted by factors such as time constraints, professional development, and nonteaching work experiences. Friedrichsen, Van Driel & Abell (2011) synthesized the science teacher orientation research and organized the nine orientations identified by Magnusson et al. (1999) which are didactic, academic rigor, process, discovery, activity, inquiry, guided inquiry, problem based, and conceptual understanding into two categories: teacher centered and student centered/reformed oriented. Teacher centered orientations included didactic (lecture driven) and academic rigor (verifying challenging problems). Marek and Cavallo (1997) claim teachers overuse expository teaching methods through telling students what they need to know and requiring rote memorization. Approaches that are associated with traditional teacher centered methods include rote memorization and reliance on a textbook.

Friedrichsen, Van Driel & Abell (2011) proposed reform orientations were classified as student centered and divided into two categories 1) reforms of the 60's: process, activity and discovery oriented; and 2) current reforms: inquiry, guided inquiry, problem based learning and conceptual understanding. They emphasized that teachers are likely to have multiple orientations at one time and cautioned the use of labeling teachers as having one orientation. Reform-based strategies include opportunities for students to construct their own knowledge. With constructivist or reform-based strategies, truth or meaning comes into existence within the realities of our world. Meaning is constructed by humans as they engage with the world. "Within a constructivist framework learning is defined as the construction of knowledge by individuals as sensory data are given meanings in terms of prior knowledge" (Tobin, Briscoe, & Holman, 1990, p. 411). Students are provided opportunities to construct their own knowledge.

Anderson (2002) outlines a traditional to reformed based pedagogy curriculum continuum that ranges from the traditional teacher being the "dispenser of knowledge" to a "coach and facilitator" in a reform orientation. In this continuum, the roles of the teacher vary from a traditional orientation which might include directing student actions and the directed use of textbooks compared to a reform-orientation which might include facilitating student thinking, modeling the learning process, and flexibly using materials.

Research on PCK often includes reform oriented aspects of science teaching such as inquiry (Avarramidou & Zembal-Saul, 2010), nature of science (Hanuscin, Lee & Akerson, 2010; Faikhamta, 2013), and reform oriented lesson planning (Beyer & Davis, 2012; Otto & Everett, 2013). Park, Jang, Chen & Jung (2011) found links between PCK and reform-based orientations during observation of biology teachers. PCK embodies the ideals of reform-based practices including inquiry (NRC, 1996; Martin-Hansen, 2002, 2009).

Akerson & Hanuscin (2007) noted that elementary teachers participating in a three year professional development on teaching NOS and scientific inquiry begin with an activity orientation and ended with an inquiry orientation. Inquiry based instruction is a reform orientation of teaching that has demonstrated positive effects on student achievement and interest in science (Geier, Blumenfield, Marx, Krajcik, Fishman & Soloway, 2008; Johnson, 2011; Lynch, Kuipers, Pyke, & Szesze, 2005). While the Frameworks do not emphasize the term inquiry as with previous reform documents, the do emphasis inquiry in the practices of science. Bybee (2011) explains "scientific inquiry is one form of scientific practice" and "the framework is not replacing inquiry; rather, it is expanding and enriching the teaching and learning of science" (p. 14). Using models, engaging in argumentation, and engineering practices have been added to the practices. This will be discussed in more depth in the learning and instruction section.

Friedrichsen et al. (2011) had four concerns in PCK studies that have used the teaching orientations originally synthesized by Magnusson et al. (1999). Their concerns include the different ways in which orientations have been defined in various studies; the lack of studies with connections among the orientations and other PCK components; assigning teachers to one orientation and not acknowledging teachers may hold more than one orientation at a time; and studies that do not connect the orientations to the four other components originally proposed: knowledge and beliefs about curriculum, students' understanding of science, instructional strategies, and assessment of scientific literacy.

Teacher Beliefs

Teacher beliefs have been associated with teaching orientations. Crawford (2006) conducted a study of preservice teachers implementing inquiry and found "evidence from this study strongly suggests the most critical factor influencing a prospective teacher's intentions and abilities to teach science as inquiry, is the prospective teachers' complex set of personal beliefs about teaching and views of science" (Crawford, 2007, p. 636). Beliefs are subjective, have an emotional component, include attitudes and are derived from significant episodes that one experiences (Gess-Newsome, 1999). Luft and Roehrig (2007) assert "beliefs are critical when it comes to understanding a teacher's practice" (p. 40).

In a study that included both quantitative and qualitative methods, Roehrig & Kruse (2005) found that teachers with a traditional teaching orientation showed little change towards reformed based orientation following their implementation of a reform-based chemistry curriculum. The belief systems of the teachers seemed to be a constraint when implementing the curriculum. They reported that limitations of the study included the small sample of teachers in the study and implementation of only one unit of study.

Luft and Roehrig (2007) have spent years developing the Teacher Beliefs Inventory (TBI) by interviewing over 100 teachers including preservice and experienced teachers. One of the goals of their research is to gain an understanding of what is involved when teachers change their beliefs so they "... could design programs for teachers that would support their development towards constructivist or reform-based ideologies" (Luft & Roering, 2007, p. 39). Using emerging categories from TBI results, they identified five categories that represent either teacher centered beliefs which include *traditional* with a "Focus on information, transmission, structure or sources" and *instructive* with a "Focus on providing experiences, teacher-focus, or teacher decision" or *student centered* beliefs which include responsive with a "Focus on collaboration, feedback, or knowledge development" and *reform-based* with a "Focus on mediating student knowledge or interactions" (p. 54). Friedrichson & Dana (2003) adapted a card sort task originally developed to research science teaching orientations for use with preservice students. In their research, they found that it wasn't how teachers sorted the cards but what they said while sorting the cards that provided insight into their orientations to teaching science (Friedrichson & Dana, 2003). The card sort task was useful in helping teachers clarify their beliefs about teaching and learning.

Learning & Instruction

"Instruction refers to methods of teaching and the learning activities used to help students master the content and objects specified by a curriculum" (NRC, 2010, p. 250) while learning is "not just the accumulation of facts but also the developing capacity to integrate knowledge, and skills for use in solving problems and responding to new situations and information (p.132)." The Frameworks assert a variety of instructional strategies will be required to implement the goals of the new frameworks (Duschl, et al., 2007; NRC, 2010). Treagust (2007) organizes instructional methods based on the amount of control teachers have in their implementation. He organized his review of science teacher instructional strategies from most to least teacher centered including teacher demonstrations, classroom explanations, questioning, forms of representation (models, analogies and levels of representation), group and cooperative learning, and deductive-inductive approaches such as learning cycle. NRC (2007) elaborates "instruction needs to build incrementally toward more sophisticated understanding and practices. To advance students' conceptual understanding, prior knowledge and questions should be evoked and linked to experiences with experiments, data and phenomena." NRC, 2007, (p. 251)

PCK includes selecting the best analogies, illustrations, and demonstrations to enhance student conceptual understanding (Shulman, 1986) and is a way of transforming subject matter into a form that students understand (Abd-El-Khalick, 2006). Knowledge of instructional strategies is a component of PCK and research on instructional strategies can provide insight to working with teachers on the diverse teaching toolbox needed. Teachers with a wider variety of instructional strategies are better able to help student understanding (Van Driel, DeJong & Verloop, 2002). The National Board Certification process influenced the PCK development of three veteran chemistry teachers (Park & Oliver, 2008). During the certification process, the teachers began to use more "why" questions of students; implemented new teaching strategies; and became more reflective about their teaching. Kind (2009) found a link between subject matter knowledge and the selection of instructional strategies. It will be important to ensure teachers have strong subject matter knowledge if they are to implement the reform strategies within the Frameworks.

Further support for reform-based instructional strategies can be found in a recent meta-analysis of empirical research in science education in the United States. The researchers sought research based evidence of the effect of teaching strategies on student achievement. Schroeder, Scott, Tolson, Huang and Lee (2007) included 61 of 390 possible studies published between 1980 and 2004 that compared eight "reformed oriented" teaching methods to traditional teaching strategies as the control group. They found that Enhanced Context Strategies had the largest effect size of 1.48 when comparing science teaching strategies on student achievement. These strategies included using context to engage students and included using real world and problem-based learning. Collaborative learning strategies, using a flexible arrangement to group students was second with an effect size of 0.96. Utilizing questioning strategies was ranked third with an effect size of 0.74. Inquiry strategies had an effect size of 0.65 and were the fourth most effective method was using manipulatives an effective size of 0.57. Assessment strategies, instructional technology strategies, and the use of enhanced material strategies had effect sizes of 0.51, 0.48 and 0.29, respectively. It will be important to look to the research on working with teachers on the implementation of these strategies in the literature on PCK and instructional practices.

Inquiry Based Instructional Strategies

Inquiry based instruction is a reform orientation that includes instructional strategies that have demonstrated positive effects on student achievement and interest in science (Fishman & Soloway, 2008; Geier, Blumenfield, Marx, Krajcik, Johnson, 2011; Lynch, Kuipers, Pyke, & Szesze, 2005). Inquiry teaching and learning has been a focus of national reform efforts in science and includes opportunities for students to actively engage in asking questions, controlling variables, and analyzing results of experiments. Inquiry is often described as a continuum from structured to open inquiry with varying degrees of scaffolds for students (Martin-Hansen, 2009; NRC, 1996; NRC, 2000). Anderson (2002) notes that there is not an operational definition for inquiry and different researchers may define inquiry differently. This lack of definition makes inquiry difficult for teachers and researchers to generalize (Barrow, 2006; Martin-Hansen, 2009).

There is a growing body of evidence that supports inquiry based instruction over traditional instruction especially for disadvantaged students (Blanchard, Southerland, Osborne, Sampson, Annetta, Granger, 2010; Geier, Blumenfield, Marx, Krajcik, Fishman, Soloway, & Clay-Chambers, 2008; Hmelo-Silver, Duncan & Chinn, 2007; Johnson, 2011; Lynch , Kuipers, Pyke, Szesze, 2005). The achievement gap between middle school minority girls and boys decreased upon the completion of two cycles of inquiry and standards based units (Geier, et al, 2008). Lynch, et al. (2005) report positive effects on the disaggregated achievement data of a diverse student population from a standards-based curriculum taught through a "guided inquiry" approach to students at five urban middle schools. When compared with comparison group from the same school district that did not participate in the curriculum, students that participated in the inquiry curriculum unit showed moderately significant positive effects on an assessment that was aligned to the curriculum and focused on conceptual change. Middle school students in high poverty schools that experienced guided inquiry instruction demonstrated higher gains on pre/post assessments than students in low poverty schools experiencing guided inquiry instruction (Blanchard, et al., 2010). When incorporated as a part of a transformative professional development (TPD) that focuses on culturally relevant pedagogy, inquiry based learning and differentiated strategies motivated Hispanic students (Johnson, 2011).

Lee, Buxton, Lewis, and LeRoy (2006) report substantial pre to post test gains in the understanding and use of scientific inquiry in a diverse group of students in grades 3 – 5. Pretest scores showed little understanding of controlling variables, designing experiments, or using data to support their ideas. Following the use of scaffolding inquiry, students from all demographic subgroups demonstrated substantial gains during the posttests.

Modeling and Representation

PCK research also includes instructional strategies such as modeling and multiple representations. Developing and using models are included as a practice of science and engineering and are described as mental or conceptual models (NRC, 2012). Mental models are described as functional with “the purpose of being a tool for thinking with, making predictions, and making sense of experience” (p. 3-8) while conceptual models are “in contrast, explicit representations that are in some way analogous to the phenomena they represent” (p. 3-8). Treagust (2007) describes three levels of representations that science teachers should be familiar with: symbolic which includes pictures, computer and algebraic relationships; submicroscopic which includes the particle level (atoms, molecules, subatomic particles); and macroscopic which includes links to everyday, visible experiences (Treagust, 2007). PCK research has included micro/macro representations in chemistry.

Van Driel, DeJong & Verloop (2002) conducted a study aimed at veteran teachers’ PCK of understanding of the relationship between macro – micro concepts of chemistry. Participants observed a color change in a chemical reaction to understanding what is happening at the atomic level. Following professional development teachers reported they gained an awareness of their “jumping” between macro and micro in a manner that was confusing for students and realized they should be cautious with their language. Van Driel, DeJong & Verloop (2002) concluded that the development of PCK is an integrative process strongly impacted by classroom practice. They further elaborated

PCK guides how teachers approach subject matter and teachers with a wider variety of instructional strategies are better able to help student understanding. For example, in biology, micro/macro representations are used with meiosis (micro) and Mendelian genetics (macro) and in physics teachers need to understand the connections between "the macro (visible moving bodies), the invisible forces (e.g., forces, reactions, electrons), and the symbolic (mathematics, formulas)" (Treagust, 2007, p. 383). Khourney-Bowers and Fenk (2009) found elementary teachers used primarily macroscopic models when they presented chemistry concepts to students. Many of the teachers had difficulty explaining abstract ideas to students. Professional development was found to enhance their content knowledge and efficacy for teaching chemistry concepts.

Cohen and Yarden (2009) reviewed and analyzed the data using the five components established by Magnusson et al. (1999) in the specific context of teaching about cells. Specifically, they looked at teachers' orientation to teaching the cell, knowledge of the curriculum as related to the cell, knowledge of student understanding of the cell, knowledge of assessment of the cell, and instructional strategies for the teaching the cell. They viewed the PCK components as intertwined and as a whole. They found several contradictions among the components such as "despite the importance the teachers placed on teaching and learning about the cell topic in junior high school, their concerns about their students' comprehension difficulties reduced the time they devoted to teaching the topic in class" (p. 150). They also found teachers had difficulty with their understanding of the duality of micro-macro concepts. Teachers tended to present information about the cells at only the microscopic level and did not include examples of cellular respiration at the macroscopic level. Previous work by Van Driel, DeJong &

Verloop (2002) looked at teacher understanding of micro-macro concepts while teaching chemistry. They also found teachers had difficulty moving between micro and macro concepts.

Henze, Van Driel, & Verloop (2008) studied nine veteran science teachers teaching a new course that included topic of 'Models of the Solar System and the Universe' and the nature of science. The study was a three year longitudinal study and included interviews each year. The goals included describing the development of the PCK of each participant and to look for patterns of PCK among the group of teachers. They focused on the instructional strategy of modeling which they described as the "constructivist view on knowing and learning, models can be used as tools to promote students to think deeply, instead of the teacher supplying all the answers" (p. 1324). Two types of PCK emerged: Type A which was oriented toward science as 'a body of established knowledge' (p. 1337) and Type B, oriented toward model production and thinking about the nature of models. This information could be helpful in planning professional development for teachers on how models are used in science. Understanding the different epistemologies that teachers may hold about models can be useful for those developing experiences for them.

Dreschsler and Van Driel (2007) conducted a study on the PCK of nine veteran chemistry teachers. The goal of the study was to investigate the PCK of teacher knowledge of student difficulties and knowledge of teaching strategies related to acids and bases two years after participating in a course on using acid-base models. They selected teachers who were aware of the Brønsted-Lowry model since their previous work found not all chemistry teachers had knowledge of the various models of acids and bases. They found two orientations toward teaching acid-base models. Teachers who were considered student centered and model oriented tended to focus on student difficulties and thought about ways they could make concepts clearer. Those that were considered teacher centered and micro/macro oriented tended to reflect on their teaching with a goal of developing stimulating lessons. Even though teachers had experienced a course on using models in chemistry, few chose to utilize the two common models of acids and bases with their chemistry students.

Constraints of Implementing Reform-Based Instructional Strategies

New teachers may experience challenges enacting reform-based instructional strategies (Davis, Petish & Smithey, 2006). Preservice elementary teachers who struggled as science learners because of the traditional nature of instruction dealt with their discomfort of science in one of two ways: 1) taking a passive approach of student learning through providing "fun activities" but having them memorize facts; or 2) using that struggle as an educative experience to learn ways to facilitate student understanding of science (Wilson & Kittleson, 2011). Wilson and Kittleson (2011) assert "the ways in which students dealt with their own learning struggles mirrored the way in which they dealt with struggles to become teachers of reform-based science instruction" (p. 19). Eick and Reed (2002) found beginning secondary science teachers implemented hands on activities with students for them to “see” science but did not integrate these activities into an inquiry format. Elementary teachers may use inquiry oriented science because of their desire to promote student interest in science not necessarily in order to engage students in authentic science (Davis, 2006).

Martin-Hansen (2009) found nine roadblocks to inquiry as perceived by preservice teachers that can be useful in considering ways to work with teachers on implementing science and engineering practices:

1. Inquiry is difficult to understand and is still confusing.
2. Classroom management is difficult.
3. Inquiry uses a lot of time at the expense of not covering as many concepts.
4. Inquiry is mainly process and very little content. Therefore, inquiry is better for younger students as opposed to high school students because they deal less with content.
5. There are limitations of materials in expense or in the ability to locate appropriate items.
6. A lot of effort on the teacher's part is involved in creating an inquiry lessons.
7. Inquiry is not rigorous or challenging.
8. Some concepts cannot be taught using an inquiry approach.
9. Assessment of inquiry lessons is difficult (p. 94).

Crawford (2007) saw enthusiasm for teaching inquiry wane during preservice teacher's field experiences which seemed to lead to skepticism about the feasibility of implementing inquiry. Contributing factors included the various ability levels of the students, students' resistance to inquiry methods, the concern with covering standards, and the openness of the mentoring teacher. In addition, concerns about classroom management problems may lead to a teacher engaging in low risk activities and less reform-based strategies (Davis, Petish & Smithey, 2006).

Martin-Hansen (2009) describes 4 developmental stages of inquiry teaching for preservice teachers. In the first two stages, *Intellectualization* and *Operationalization*, teachers gain a working definition of inquiry and the ability to create an inquiry lesson. In the *Actualization* stage they create and implement an inquiry lesson. If they are successful in their implementation, they internalize the practice of using inquiry thus leading to *Internalization*. If the implementation is not successful, they may try again or give up inquiry teaching. Martin-Hansen (2009) found preservice teachers' understandings of inquiry pedagogy increased over time during several science methods courses. She also found that preservice teachers were in the developmental stages of actualization of implementing inquiry during their student teaching but inquiry was not part of their teaching repertoire.

Duschl et al. (2007) recommend teachers experiences in professional development “mirror” the four fundamental strands of learning that need to occur for students to become proficient in science. Teachers with inquiry experience are more likely to implement inquiry strategies with students and those having no experience with inquiry are less likely to implement inquiry (Windshitl, 2003). Professional development for the new frameworks should include engaging teachers in experiences with all eight of the science and engineering practices. The studies on the challenges associated with the implementation of reform oriented curriculum could help professional developers anticipate roadblocks that teachers may face with the new frameworks.

Integrated Nature of PCK

The components of PCK are often described as integrated. Park and Chen (2012) explored the integrated nature of the PCK of five high school biology teachers through a qualitative study that included classroom observations, semi-structured interviews, lesson plans, instructional material, and student work samples. They videotaped teachers during two instructional units: five class periods on photosynthesis and eight class periods on heredity for each teacher. They interviewed teachers throughout the implementation of the lessons and conducted three interviews including a background interview prior to observations, pre-observation and post-observation interviews. They identified teaching segments from the videos that demonstrated explicit PCK and conducted an in-depth analysis of that "PCK Episode". They completed an analysis that included a) what the teacher and students did, b) what components of PCK were integrated in the PCK Episode, and c) evidence of the presence of identified components. They found the most connections between knowledge of instructional strategies and knowledge of students. They also found that having a didactic orientation inhibited knowledge of instructional strategies and connections to the other PCK components. The most limited connections were between knowledge of curriculum and the other PCK components.

The pentagon model of PCK developed from previous research (Park & Oliver, 2007) was used as the conceptual framework of their research. The pentagon model moves away from what they describe as the linear depiction of the previous [Magnusson] PCK model to one in which the five PCK components are integrated and equally weighted with respect to one another. Park and Chen (2012) created PCK maps to represent the interactions among PCK components by drawing lines between PCK components connected during “PCK episodes” of observed teachers and counting the number of connections. They applied a constant comparative method to identify patterns from the data including information from interviews. Their findings included that a didactic orientation to teaching inhibited the interactions among other components and the integration of components was idiosyncratic. They found the most connections between knowledge of student understanding and knowledge of instructional strategies. The most limited connections were among knowledge of curriculum and knowledge of assessment.

In another study, Hanuscin, Lee and Akerson (2010) used the concept of “PCK in action” to describe how elementary teachers took a nature of science (NOS) concept and their knowledge of instructional strategies and transformed them into a form that was understandable to students. Examples included using kid friendly language to explain NOS, using children's books to teach NOS concepts, and debriefing sessions to discuss NOS. They found that teachers drew primarily upon their SMK for NOS, and general pedagogical knowledge (PK) as well as their knowledge of instructional strategies for teaching science (PCK).

Assessment

The Frameworks (NRC, 2012) call for coordinated efforts of designing different types of assessments: formative (for the purposes of ongoing feedback), summative (end of unit), program (such as high stakes assessment) and teacher effectiveness. The report discourages a “one-size-fits-all” approach to standardized assessments. It is important that assessments, including high stakes assessments align with the research on diverse learners (Johnson, 2011; NRC, 2012). The literature on culturally relevant pedagogy can also provide insights to developing assessments for diverse learners and includes the goal of setting high expectations for all learners to experience academic success (Ladson-Billings, 1996; Johnson, 2011.)

PCK Knowledge of Assessment Strategies

There were a limited number of PCK-related articles on assessment strategies. Schneider and Plasman (2011) organized a learning progression for teacher PCK of assessment using the continuum from traditional end of unit assessments to using a variety of assessment strategies. They also included the ideas that the criteria for the assessments “should be matched with specific science ideas” (p. 554). Park and Oliver

(2008) looked at the role of analyzing student work samples in the National Board Certification process of veteran chemistry teachers.

Falk (2011) sought to investigate the relationship between the formative assessment practices and PCK of elementary teachers in the context of a collaborative assessment of student work samples during a science professional development for 4th grade science teachers. He found teachers' most frequently used knowledge of curriculum and instructional strategies during their collaborative work sessions to plan formative assessments. Teachers used their knowledge of instructional strategies to propose changes in instruction, to consider the role of prior instruction and to assess the alignment of the task and activities. They used their knowledge of student understanding to discuss misconceptions identified in the student work. There was evidence of the reciprocal relationship between formative assessment and PCK as teachers both used and built their PCK during their collaborative work on formative assessment. The study included a focus was on a collective group of teachers as opposed to individual use and enactment of formative assessment.

Beyer and Davis (2012) found preservice teachers struggled to develop assessments and modify lessons to accommodate different learners in a recent study that highlighted the use of lesson plan analysis with 24 preservice elementary teachers during a methods class. The focus of the study was the PCK of teachers while critiquing lessons using a reformed based lens. The researchers wanted to know how the teachers applied their PCK, specifically to the five components of PCK such as their knowledge of curriculum and knowledge of instructional planning to lesson plans.

Curriculum

Changes in curriculum are not always embraced by teachers. The Frameworks and Next Generation Science Standards will incorporate new ideas about curriculum and how to deliver it to students. Knowledge of curriculum is a key component of science education (NRC, 2012) and a PCK component (Magnusson et al., 1999). NRC (2012) calls for the development of curriculum that integrates the practices of science, core disciplinary ideas, crosscutting concepts, and learning progressions. Recommendations include the inclusion of "…historical, social, cultural, and ethical aspects of science and its applications, as well as of engineering and the technologies it develops…" (p. 248). It is also recommended that students have repeated experiences engaged with the science and engineering practices and "not rote procedures" (NRC, 2012).

The organization of the new curriculum will be a paradigm shift for many teachers. Research has shown that teachers tend to teach the way they were taught (Jarrett, 1999). Cohen and Yarden (2009) investigated the PCK of junior high teachers' ten years after a curriculum change of teaching the cell in life science. In the revised national curriculum in Israel, cells are taught "longitudinally" or throughout the year as a foundation for other concepts since all living things contain cells. Although student difficulties with the topic of cells are well documented in the literature (Dreyfus & Jungwirth, 1988, 1989; Flores, et al. 2003), Cohen and Yarden (2009) found teachers' made only minor changes in the way they taught the cell and did not make any deep changes to their curriculum despite their participation in professional development. Teachers claim they implement curricula the way they do because of constraints placed upon them by state and district policies (Tobin et al, 1990). It will be important to consider teacher constraints in the implementation of the Frameworks as teachers will need support systems and resources in place to help them overcome constraints.

Cohen and Yarden (2009) identified internal and external factors that may play a role in establishing teacher's PCK. Internal factors included such as subject matter knowledge, experience, teaching habits, and "other internal factors can be the teachers' practical experience, their habits of teaching the topic, their lack of awareness of the curriculum, and their fear of their students' inability to comprehend the topic" (Cohen & Yarden, 2009, p. 150). External factors included the national evaluation system and curriculum.

Reform-Oriented Professional Development

Defining teacher professional knowledge bases is a complex task. As suggested by many who research the field of PCK, there is considerable overlap among these knowledge bases (Abell, 2007; Magnusson, et al., 1999; Otto & Everett, 2013; Shulman, 1987). These knowledge bases are influenced by many factors including content knowledge, teacher efficacy, and orientations. While defining the knowledge bases is challenging, the literature overwhelmingly suggests that reform-oriented professional development has been shown to influence the self-efficacy, content knowledge and practices of elementary teachers. PCK studies provide support for the role of professional development and college courses in increasing the subject matter knowledge of inservice (Goodnough & Nolan, 2008; Kang, 2007; Kanter & Konstantopoulos, 2010; Smith & Neale, 1989) and preservice elementary teachers (Nilsson & Van Driel, 2011). Elementary teachers who participated in a constructivist oriented professional development showed gains in content knowledge, personal science teaching self-efficacy, and pedagogical content knowledge (Khourney-Bowers & Fenk, 2009). The term *advanced PCK* was used to describe “gains in scientific representational thinking and implementation of conceptual change strategies and model development in their classrooms” (p. 450). The introduction of this dissertation includes an overview of studies involving professional development.

Teacher Efficacy

Studies have linked professional development to increases in teacher efficacy. Lakshmanan, Heath, Pelmutter and Elder (2010) found that teacher efficacy and use of reformed based teaching were positively impacted by professional development that focused on content knowledge and professional learning communities. Professional development that included peer interactions along with opportunities for experimentation and discussion were attributed to increases in elementary teachers’ efficacy for teaching chemistry concepts (Khourney-Bowers & Fenk, 2009).

Efficacy has been included as an amplifier or filter that influences the enactment of specific topics for a particular group of students. Self-efficacy has been defined as “beliefs in one’s capabilities to organize and execute courses of action required to produce given attainments” (Bandura, 1997, p. 3). Dellinger et al. (2008) provide a history of the use of the terms *teacher efficacy* and *teacher self-efficacy* in the literature and purport that the two terms have been used synonymously, but represent different things. “*Teacher efficacy* is defined as teachers’ beliefs in their abilities to affect student performance” (Dellinger, et al. 2008, p. 753). In contrast, *teachers’ self-efficacy* beliefs are defined as “teachers’ individual beliefs about their own abilities to successfully perform specific teaching and learning tasks within the context of their own classrooms” (p. 751). They purport that *self-efficacy* is “task and situation specific” (p. 754). They developed a new self-efficacy instrument, the Teachers' Efficacy Beliefs System – Self Form (TEBS-Self) to measure self-efficacy based upon their definition which is aligned with Bandura's definition of self-efficacy (1987).

Dellinger et al. (2008) synthesized the results of three studies using the TEBS-Self with K-6 elementary teachers that looked at various factors including organizational factors of schools with professional learning communities, self-efficacy and school effectiveness, and sources of efficacy and the relationship to perceptions of self, work groups, and collective faculty efficacy (Dellinger et al., 2008). Each of the studies organized the self-efficacy items into component categories such as motivation of students and higher order thinking skills. Findings (Dellinger et al., 2008) included a positive relationship between teachers' self-efficacy of classroom management and schools' organizational effectiveness and a positive relationship between a teachers' self-efficacy of classroom management and climate with school effectiveness. They also found that self-efficacy was "positively correlated with professional learning experiences that included enactive mastery or occurrences of successful teaching experiences, whereas teachers' faculty collective efficacy beliefs were more strongly correlated with vicarious learning experiences such as those offered through peer demonstrations and observations of other teachers" (Dellinger et al. 2008, p. 761).

The STEBI-A was designed to measure the efficacy of in-service teachers and contains two subscales: personal science teaching efficacy (PSTE) and science teaching outcome expectancy (STOE) (Enoch & Riggs, 1990). The science teaching efficacy scale attempts to measure a teachers' confidence to teach science and perceived influence on student achievement while the outcome expectancy scale attempts to measure teachers' beliefs about how outside factors (socioeconomic status) impact their ability to impact achievement. Czerniak and Shriver (1994) found that successful preservice teachers were more likely to use open-ended inquiry and student centered activities while less successful teachers used more teacher-centered instruction. Shriver and Czerniak (1999) used the STEBI-A with middle grades science teachers. They found that middle school science teachers had higher outcome expectancy than junior high school teachers indicating the middle school teachers held beliefs they could overcome factors such as the low socioeconomic status of students. “Teachers with greater outcome expectancy would be inclined to work with students who are vulnerable to at-risk behaviors and losing interest in science” (Shriver & Czerniak, 1999, p. 35).

There are many studies on the efficacy of elementary science teachers. Avery and Meyer (2012) modified the Inquiry Science teaching Efficacy Belief Instrument (ISTEBI) originally developed by MaKinster (2000) to measure self-efficacy for inquiry-based teaching and learning of elementary preservice teachers enrolled in an environmental biology class. They used the two subscales of outcome expectancy and self-efficacy and added five subscales including inquiry, comfort with student control, and comfort with messy science. Avery and Meyer (2012) established the reliability of the instrument by correlating ISTEBI responses with those from interviews and class post survey. They reported ambiguous results with some students experiencing increases and others experiencing decreases in self-efficacy following participation.

Carleton, Fitch, and Krockover (2008) worked with teachers of grades 4 to 9 during a Standards-Based Integrated Science Instruction (SISI) program. The program goals were to increase teacher self-efficacy by “introducing teachers to the constructivist model of learning; improving content knowledge; modeling inquiry methods" (p. 47). They measured teachers' self-efficacy, beliefs, and attitudes at various phases during professional development and implementation of tasks with students during the school year that followed. They found that teachers struggled initially when learning new methods during the summer which was followed by a decrease in confidence upon returning to their schools. After experiencing success with the methods and through implementation with students, the "result of mastery experiences, teachers' confidence in their teaching ability improved significantly" (p. 60).

The STEBI-B was modified from the STEBI-A and developed for preservice teachers (Enoch & Riggs, 1990). Bleicher (2004) found males had a higher Personal Science Teaching Efficacy (PSTE) than females prior to a science methods course in a study that includes a revalidation of the STEBI-B. The study also found that students who had taken four or more science courses had a higher PSTE than those that had taken three or fewer courses. Cantrell (2003) found significant differences in the pre/post measures of PSTE, but not Science Teaching Outcome Efficacy (STOE) when using the STEBI-A with preservice teachers. When using a retrospective pre/post design, however significant differences were found in both PSTE and STOE.

Hechter (2011) administered the STEBI-B three times to elementary preservice teachers enrolled in a science methods course to find out if number of science methods classes and prior school science experiences had an impact on self-efficacy. The STEBI-B was given as a pretest and post test with a retrospective pretest to look for response shift bias. Hechter (2011) found a significant difference between the pre and retrospective pretest with candidates reporting lower level of self-efficacy on the personal self-efficacy and outcome expectancy subscales on the retrospective pretest. When comparing the retrospective pretest and posttest on the number of science content courses taken, Hecther (2011) found significant differences in personal science teaching efficacy but not of outcome expectancy. The lack of difference in outcome expectancy was attributed to the limited teaching experience of the preservice teachers.

Conclusion

There are many strengths of using PCK research as a lens for implementation of the Frameworks. Abell (2008) describes "four important characteristics of PCK: PCK includes discrete categories of knowledge that are applied synergistically to problems of practice; PCK is dynamic, not static; content (science subject matter) is central to PCK; and PCK involves the transformation of other types of knowledge" (p. 1407). These characteristics include the importance of how the knowledge bases interact in the enactment of teaching and the key role that content knowledge plays in PCK.

The Frameworks are highly integrated, and the highly integrated nature of PCK provides a research base on how the various professional knowledge bases are integrated with each other. One of the strengths of PCK is that it encompasses a breadth of teacher knowledge and can provide a lens to understand enactment of topic-specific teaching strategies. Recent PCK studies have looked at the integrated nature of PCK (Park, et al. 2008; Park & Chen, 2011; Beyer & Davis, 2012; Avraamidou & Zembal-Saul, 2010). Park, et al. (2011) recommends more studies that look at the integrated nature of the construct. The recent focus of PCK research includes the integration of PCK components (Beyer & Davis, 2012; Park & Chen, 2012) focusing on specific aspects of PCK such as inquiry (Avraamidou & Zembal-Saul, 2010), using models (Dreschsler & Van Driel, 2008; Henze, Van Driel & Verloop, 2008), nature of science (Hanuscin, Lee & Akerson, 2010), and formative assessment (Falk, 2011). Otto & Everett (2012) used a PCK Venn diagram with K-8 preservice teachers to guide the development of lesson plans in a Science Capstone Project. Their diagram includes three overlapping circles consisting on pedagogy, content and context which provided an opportunity to consider how these components are integrated. For example, the overlap between pedagogy and content includes the "alignment of the appropriate teaching strategy with the content (p. 396).

The research in PCK focuses on how PCK can be enhanced. By working with colleagues, responding to students and reflecting on practice, teachers continually refine their PCK. Goodnough & Nolan (2008) recommended "the PCK model can serve as a valuable tool for individuals and collaborative inquiry groups to critically analyze and reflect upon their own experiences and evolving understandings, and to use these new insights to inform future action and classroom practice" (p. 211).

PCK ties together many aspects of teaching that have influence upon each other such as knowledge of curriculum and how that might impact instructional decisions. As teachers begin to implement the ideas of the Frameworks, it will be critical for teachers to understand the integrated nature of teaching and learning, assessment, and curriculum.

The goals of PCK research include understanding how PCK is developed in order to provide courses and professional development training to accelerate PCK development in teachers. This goal of PCK can help to aid in meeting the goal of teacher development in the Frameworks.

PCK can be a useful construct for studying changes in teachers over time as it can be used to "pinpoint" where teachers are at different points of their careers and determine potential career pathways or opportunities to enhance PCK. Schneider and Plasman's (2011) learning progressions for teachers which could be useful in providing a trajectory for science teachers experiencing professional development related to the reform. There are also calls for more longitudinal studies that look at changes in teachers over time in capacities such as professional development over years of teaching (Abell, 2008; Avraamidou & Zembal-Saul, 2010; Schneider & Plasman, 2011). Avraamidou & Zembal-Saul (2010) assert "We therefore point to the need for further large scale and longitudinal studies that will provide detailed descriptions of the pathways by which teachers come to know and identify experiences that prove to be critical to their development" (p. 681). Other recommendations include studies that compare the PCK of elementary, middle and high school teachers (Abell, 2008).

Some of the weaknesses of PCK as a research construct include that it is a bulky construct that is an amalgam of what teachers do and the reasons for their actions (Shulman, 1986; Baxter & Lederman, 1999). Settlage (2013) outlines shortcomings of PCK research which include the missing element of student learning and that it "has not generated solid research to inform our teacher education practices (p. 10). The outcomes of the PCK summit include a focus on how a teacher's PCK impacts student knowledge (Gess-Newsome & Carlson, 2013).

Another weakness of PCK is that it lacks the coherence of research on subject matter knowledge (Abell, 2007). There are many scholars that have heard the concerns and are working to add to the literature through research on PCK. There have been recommendations from scholars that multiple methods are needed to study PCK (Baxter & Lederman, 1999; Abell, 2008). Many scholars call for more studies that show the relationship among the components of PCK (Abell, 2008; Friedrichsen, Van Driel & Abell, 2011; Park & Chen, 2012).

Twenty five years after Shulman introduced the idea of PCK, we have learned a great deal about the interaction of the unique forms of knowledge that teachers' possess. Research of the PCK development of science teachers has provided insights to the complex nature of teaching. By having a better understanding of how PCK develops in individual teachers over time, we can begin to look for ways to accelerate the growth of this knowledge in teachers. This is particularly important in providing support for teachers with upcoming curricular reform and implementation as outlined in the Frameworks.

CHAPTER 3: THE RESEARCH PROCESS

Conceptual Framework

Pedagogical Content Knowledge (PCK) describes how teachers use instructional strategies to transform content knowledge into a form that students can understand and use (Shulman, 1986, 1987). PCK has also been described as the intersection of pedagogy and content knowledge (Shulman, 1986) and "what a teacher knows, what a teacher does, and the reasons for the teacher's actions" (Baxter & Lederman, 1999, p. 158). The focus of the study is a K-5 science endorsement program that emphasizes reform-based teaching strategies and content delivery using a 5E learning cycle approach (Abraham & Renner, 1986; Bybee, 2006). The conceptual framework of the study is organized around the professional knowledge bases and dimensions that influence the PCK of elementary science teachers.

Teacher professional knowledge bases are characterized as "knowledge for practice defined by experts and used by teachers" (Gess-Newsome & Carlson, 2013b). Following a summit that gathered international PCK scholars, Gess-Newsome and Carlson (2013a) proposed a consensus model and consensus definitions of PCK. The model is composed of Teacher Professional Knowledge Bases (TPKB), Topic Specific Professional Knowledge Bases (TSPKB), and other factors that may amplify or filter PCK.

Reorganizing the Ideas of PCK

"It [PCK] represents the synthesis of teachers' knowledge of both subject matter and pedagogy, distinguishing the teacher from the content specialist" (Hanuscin, Lee, & Akerson, 2010, p. 148). The field of PCK research has broadened and diverged over the years. According to Abell (2007), PCK has been "translated, explicated, revised and extended by number a science educators" (p. 1108). Following the summit, a consensus model of professional knowledge bases including PCK and a definition of PCK was proposed. PCK was defined as teacher knowledge and enactment and is suggested to be topic specific with a focus on student outcomes. The consensus definition includes two statements:

> *Knowledge* of, *reasoning* behind, and *planning* for teaching a particular *topic* in a particular *way* for a particular *purpose* to particular *students* for *enhanced student outcomes* (Reflection *on* Action, Explicit)
>
> The *act of teaching* a particular *topic* in a particular *way* for a particular *purpose* to particular *students* for *enhanced student outcomes* (Reflection *in* Action, tacit or explicit) (Gess-Newsome & Carlson, 2013a, 2013b).

This model reorganizes the previous ideas of PCK into two categories of teacher knowledge bases: Teacher Professional Knowledge Bases (TPKB) and Topic Specific Professional Knowledge Bases (TSPKB). The TPKB are Assessment Knowledge (AK), Pedagogical Knowledge (PK), Content Knowledge (CK), Knowledge of Students (KS), and Curricular Knowledge (KC). The TPKB inform and are informed by Topic Specific Professional Knowledge Bases (TSPKB) which include knowledge of specific topics taught at specific grade levels. This includes a Knowledge of Instructional Strategies (KIS) such as content representations, student understandings, science practices, and habits of the mind. There are several amplifiers and filters that influence the development of TPKB and TSPKB including beliefs, efficacy, orientations, misconceptions, motivation, dissatisfaction, risk taking, etc. These amplifiers or filters may positively or negatively influence PCK which is composed of planning and enactment of specific topics for a particular group of students. PCK is impacted by the classroom context including curriculum, time, standards, etc. Student beliefs, prior knowledge, and behavior as considered amplifiers and filters that influence student achievement. In this study, these knowledge bases, amplifiers and filters will be collectively known as the dimensions of teacher knowledge that influence the enactment of PCK.

The professional knowledge bases influencing PCK were chosen as the conceptual framework to study the influence of the endorsement for several reasons. Figure 2 depicts the conceptual framework for the study. Six of the dimensions of professional knowledge are in the three boxes in the framework. Three primary constructs emphasized by the endorsement are woven throughout the dimensions with the goal of influencing PCK enacted in classroom practice.

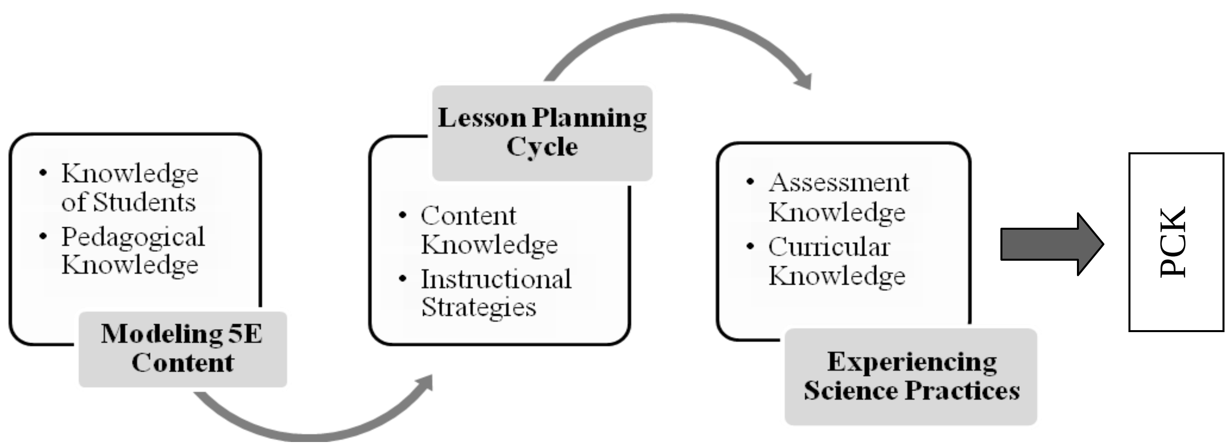

Figure 2. Conceptual Framework of the Study.

First, the endorsement is a yearlong program with a large number of professional development goals including enhancing the content knowledge, self-efficacy, and knowledge of reform-based instructional practices of participants. Embedded throughout the endorsement are opportunities for teachers to experience inquiry practices, 5E learning cycle lessons, formative assessment, vertical alignment, and integrating science with technology and other subjects. Instructors model standards based instruction of science content developed using the National Science Education Standards (NSES) at the K-4 and 5-8 levels and are delivered through 5E learning cycle lessons. The goals of the endorsement program align with the professional knowledge bases that influence PCK. While the definition of PCK has evolved (Abell, 2007) and diverged (Carlson & Gess-Newsome, 2013b) over the years, much of the PCK literature defines PCK as being composed of five components: knowledge of science instructional strategies, knowledge of science curriculum, knowledge of student conceptions of science, knowledge of assessment for teaching science, and teaching orientations (Magnusson et al., 1999).

Second, the endorsement includes the requirements of a residency and portfolio to document the impact of the endorsement on students. The residency runs throughout the courses and is designed for participants to design 5E inquiry lessons, implement with students, and reflect on the lessons developed during the endorsement courses. These various endorsement experiences are designed to provide teachers with opportunities to work toward mastery of their science teaching practices while being supported by instructors who model reform-oriented practices. It is hypothesized that as teachers work toward mastery in the endorsement program, their science teacher self-efficacy would shift (Bandura, 1997).

Third, *bulky* is a term often used to describe the K-5 science endorsement due to the nature of the application of endorsement goals during the courses and residency. Participants are required to observe other science teachers, analyze student data, and student work samples. PCK has been called a *bulky* construct that is an amalgam of what teachers do and the reasons for their actions (Shulman, 1986; Baxter & Lederman, 1999). The bulky nature of PCK aligns well with the endorsement requirements and allows for the endorsements' influence to be viewed through the lens of the professional knowledge bases.

Defining the Dimensions of Teacher Knowledge that Influence PCK

The PCK consensus model was built upon many years of research on PCK. The previous research will be used to construct an understanding of the dimensions that influence PCK used in this conceptual framework. Magnusson, Krajcik and Borko (1999) organized PCK into five components of PCK: Orientations, Knowledge of Instructional Strategies, Knowledge of Curriculum, Knowledge of Conceptions, and Assessment Knowledge. These categories have been widely used in PCK research. Their model will be referred to as the Magnusson model in this study. Their categories have been revised, renamed, and reorganized by other scholars. Their model and three other primary sources will be used to inform the definitions of the dimensions of teacher knowledge used in this in this study: the pentagon model of PCK (Park & Chen, 2012; Park & Oliver, 2007), PCK learning progressions (Schneider & Plasman, 2011), and teacher orientations (Friedrichsen, Van Driel, & Abell, 2011). Teacher orientations will be discussed following an overview of the consensus model.

Park & Oliver (2007) proposed the PCK pentagon model to clarify relationships among the five PCK components identified in the Magnusson model. In the pentagon model, the five components are considered to be integrated and equally weighted with respect to one another. Park and Chen (2012) used this model to create PCK maps to represent the interactions among PCK components of high school biology teachers by drawing lines between PCK components connected during "PCK episodes" of observed teachers. PCK episodes were identified as the integration of two or more PCK components. This study will focus on the interactions of the professional knowledge bases of elementary teachers.

Schneider and Plasman (2011) synthesized twenty years of PCK research on science teachers in order to propose learning progressions for each of the five components of the Magnusson model. They organized the learning progressions into bands of teaching experience based upon the existing PCK research base: preservice teachers with no classroom experience, new teachers with 0 – 3 years of experience, teachers with "some" experience (4 – 10 years), teachers with "much" experience (11+ years) and teacher leaders with experience as mentors or peer leaders. Their findings included a continuum of teacher development over time described in learning progressions. Trends demonstrated a progression from teacher-centered to student-centered orientations. Learning progressions were initially described as related to student learning and defined as "descriptions of successively more sophisticated ways of thinking about an idea that follow one another as students learn: they lay out in words and examples what it means to move toward more expert understanding (Wilson & Bertentahl, 2005, p. 5).

With the consensus model, PCK has moved from a broad overarching knowledge base (Magnusson et al., 1999) to one that is more narrowly focused with an emphasis on enactment and practice.

Table 4 compares the organization of the components within the Magnusson et al. (1999) PCK model and the PCK consensus model.

Table 4

A Comparison of Two PCK Models

	Magnusson et al., 1999 Model	**PCK Consensus Model**
Orientations	PCK Component	Amplifier or Filter
Knowledge of Instructional Strategies	PCK Component	Topic Specific PKB
Knowledge of Student Conceptions	PCK Component	TPKB
Knowledge of Curriculum	PCK Component	TPKB
Assessment Knowledge	PCK Component	TPKB
Pedagogical Knowledge	Separate Knowledge Base	TPKB
Content Knowledge	Separate Knowledge Base	TPKB
Self-efficacy	Not included	Amplifier or Filter

In order to provide definitions of the terms associated with my conceptual framework, I will briefly discuss below the TPKB, TSPBK and amplifiers and filters that are the focus of my study.

Knowledge of students' understanding of science includes students' ideas about science such as prior knowledge and alternative conceptions. Research supports the idea that students hold a variety of preconceptions about how the world works (Bransford, Brown & Cocking, 2000). It is important that teachers solicit students' prior knowledge. Being aware of student conceptions and utilizing strategies that tap into prior knowledge are an important component of a teacher's pedagogical content knowledge. Schneider and Plasman (2011) identified five categories for *student thinking about science.* These are prior knowledge, how science ideas develop, how students express *ideas*, "*challenging* ideas for students, and appropriate *level* of science understanding" (p. 538).

Knowledge of curriculum includes knowledge of mandated standards and curricular programs and materials (Magnusson et al., 1999). Vertical alignment includes ideas across grade bands and is currently thought of as learning progressions. Horizontal alignment of the curriculum includes integrating science with other curricular areas. Schneider and Plasman (2011) identified four categories of curriculum knowledge. These are scope, sequence, curricular resources, and using standards. Park and Chen (2012) mapped "PCK episodes" of biology teachers and found the most limited connections to be between knowledge of curriculum and other PCK components. Knowledge of curriculum reform and standards are an important aspect of teachers' knowledge of curriculum.

Assessment Knowledge includes knowledge of the goals and purposes of assessment as well as what to assess (Magnusson et al., 1999). This knowledge includes current assessment methods such as formative and summative assessments. Schneider and Plasman (2011) identified two categories; "*strategies* for assessing student thinking in science and how or when to *use* science assessments" (p. 537). Park and Chen (2012) found that knowledge of assessment was most often connected with knowledge of student understanding and knowledge of instructional strategies

Pedagogical Knowledge is generally thought of as the aspects involved in managing a classroom. Abell describes pedagogical knowledge (PK) as "the general, not subject-specific, aspect of teacher knowledge about teaching, such as learning theory, instructional principals, and classroom discipline (p. 1108). General pedagogical ideas that apply across multiple subject areas include conceptual understanding (Driver, Asoko, Leach, Scott & Mortimer, 1994) teacher versus learner centered instruction (Treagust, 2007), and 5E learning cycle lessons (Bybee et al., 1997; 2006). Otto & Everett (2013) used a PCK Venn diagram to help elementary preservice science teachers understand the nature of the integration of PCK components when planning lessons. They used "main teaching strategy" (p. 393) as the description and pedagogy and "5E lesson format, hands-on activities, demonstrations, videos, visual aids, models" as examples. With Venn diagrams, they focused on the overlap of the PCK components. As an example of the overlap between pedagogy and content, they used "alignment of teaching strategy with appropriate content."

Content knowledge is "the amount and organization of knowledge per se in the mind of the teacher" and recommends "going beyond know of facts or concepts of a domain (Shulman, 1986, p. 9). It requires understanding the structures of the subject matter. He references Schwab (1978) who identified two types of content knowledge: syntactic and substantive. Examples of syntactic content knowledge include the nature of the discipline and examples of substantive types of knowledge include the concepts and principles. Nowicki et al. (2013) draw attention to the long-standing debate about whether or not elementary teachers have the necessary content knowledge to teach reform-oriented science. They suggest previous studies of elementary science teacher content knowledge primarily included content test, lesson reflections, number of college courses, etc. (Nowicki et al., 2013). They used a multiple regression model to determine which of ten variables predicted the accuracy of science content. Access to kit based resources, grade level, and a preference for teaching science were the factors demonstrating the most significance. Teachers teaching at the upper grade bands (4 and 5) demonstrated a higher degree of content accuracy compared to teachers teaching at the lower grade bands. They did not find a correlation between content accuracy of observed lessons and number of college science courses or traditional science assessments.

Topic Specific Professional Knowledge Base

Knowledge of instructional strategies is considered to be a Topic Specific Knowledge base. Instructional Strategies may be organized into categories based upon the amount of control teachers have in their implementation (Treagust, 2007). Student-centered strategies include inquiry learning, teaching for conceptual understanding, using models, analogies, and multiple representations; while teacher centered strategies include teacher demonstrations and classroom explanations. Park and Chen (2012) found the integration of knowledge of instructional strategies and student understanding of science were central in the enacted PCK maps. Schneider and Plasman (2011) identified four categories of instructional strategies. These are inquiry, science phenomena, discourse, and student-centered strategies. In their recent literature review of PCK research, Schneider and Plasman (2011) found that over the course of their careers, teachers revise their methods and instructional strategies influencing their overall PCK. Much of the PCK research includes teachers enacting various instructional strategies.

Amplifiers and Filters

Orientations are considered an amplifier or filter in the PCK Consensus Model. Nine orientations were identified in the Magnusson model (Magnusson et al., 1999). These are didactic, process, academic rigor, activity, discovery, problem solving, inquiry, guided inquiry, and conceptual understanding. Orientations are considered to play a key role in PCK decision-making. Friedrichsen et al. (2011) arranged the nine orientations identified by Magnusson et al. (1999) into two categories: teacher centered and student centered/reformed oriented. Teacher centered orientations included didactic (lecture driven) and academic rigor (verifying challenging problems). The reform orientations were classified as student centered and divided into 1) reforms of the 60's and included process, activity and discovery oriented; and 2) current reforms which included inquiry, guided inquiry, problem based learning, and conceptual understanding. Friedrichsen et al. (2011) emphasize that teachers are likely to have multiple orientations at one time and cautioned the use of labeling teachers as having one orientation. Schneider and Plasman (2011) identified three categories for teaching orientations and they include teachers' thoughts about the "purposes and goals for teaching science, the nature of science, and the nature of teaching and learning science for students" (p. 538). A few findings related to orientations related to PCK include the importance of "examining not what teachers know but rather how they are able to use what they know in practice" with knowing representing a static orientation and using a more dynamic orientation with teachers flexibly applying what they know in different situations (Beyer & Davis, 2012, p. 132).

Park and Chen (2012) found that having a didactic orientation inhibited knowledge of instructional strategies and connections to the other PCK components.

Efficacy has been included as an amplifier or filter that influences the enactment of specific topics for a particular group of students. Self-efficacy has been defined “beliefs in one’s capabilities to organize and execute courses of action required to produce given attainments” (Bandura, 1997, p. 3). “Self-efficacy beliefs regulate human functioning through cognitive, motivational, affective, and decisional processes. They affect whether individuals think in self-enhancing or self-debilitating ways; how well they motivate themselves and persevere in the face of difficulties; the quality of their emotional life, and the choices they make at important decisional points which set the course of life paths” (Bandura, 2002, p. 270). Self-efficacy has been studied to understand how confident teachers are performing certain classroom tasks and how content knowledge, professional development may influence teachers efficacy.

After observing a chemistry teacher anticipate and respond to student misconceptions during a laboratory experience, Park & Oliver (2007) suggested “teacher efficacy emerged as an affective affiliate of PCK” (p. 270). They observed a teacher who thoughtfully and confidently responded to student questions and misconceptions about a situation that arose during a laboratory experiment. In an interview that followed the observation, the teacher expressed an even stronger sense of confidence following the episode in which she had responded to the student misconceptions. Granger, Bevis, Saka, Southerland, Sampson & Tate (2012) found teachers with a low self-efficacy prior to the beginning of a reform-oriented professional development demonstrated an increase in both self-efficacy and content knowledge following the implementation of a reform-oriented curriculum. Teachers with a higher self-efficacy are more likely to try new instructional strategies and create mastery learning environments for their students (Bandura, 1993). On the other hand, those with a low self-efficacy are likely to distrust their abilities and give up more easily on students. Bandura (1997) describes experiencing success or mastery as the most powerful source of self-efficacy. Having good models (vicarious experiences), "pep talks" (verbal persuasion) and internal causes such as ability (attributions) are other sources. Mansfield and Woods-McConney (2012) found that observing successful teachers influenced the confidence of less efficacious primary science teachers.

This study will focus on the dimensions of professional knowledge that influence the enactment of PCK in elementary science teachers following their participation in a K-5 science endorsement. The conceptual framework will provide an organizational structure for how the data will be collected, analyzed and integrated. A parallel convergent mixed methods approach will be used to connect quantitative and qualitative approaches.

Methodology

Context of the Study

The context of the study is a K-5 science endorsement program offered through a regional services agency. The endorsement is a yearlong, sustained series of four courses: pedagogy, life, earth and physical science. The endorsement also includes a residency that includes multiple experiences teaching lessons and reflecting on lessons developed for K-5 students. Each content course requires the development of lesson plans with a specific pedagogical focus. In the life science class, teachers develop two to three lessons at different grade bands in order to gain an understanding of the vertical alignment of a big idea in science. During the earth science class, teachers develop a five lesson unit that integrates science with technology and at least one other subject. In the physical science class, teachers develop at least one lesson in which they specifically teach a nature of science (NOS) component; and in the pedagogy class teachers develop a five lesson unit in which they differentiate learning based upon the identified needs of their students.

Participants in the Study

The K-5 science endorsement was first offered during the 2010-11 school year with two school districts and nine participants. During the 2011-12 school year, six school districts offered cohorts of the endorsement with 82 teachers completing the requirements. An additional ten completed the endorsement during the 2012-13 school year. A cohort refers to a group of teachers who complete the sequence of courses together within their school district. All teachers meeting the requirements (n=99) were asked to participate in a demographic and a retrospective pre and post self-efficacy survey. Fifty four of 99 invited participants completed the survey. The teachers will be referred to as participants.

The participants have an average of 14.2 years of teaching experience and 12.8 years of experience teaching science. The participants were organized into the experience categories of the PCK Learning Progression Rubric (Schneider & Plasman, 2011). A small number of participants, 3.7% (n=2) were new teachers with 0-3 years of experience. Thirty seven percent (n=20) were identified as having between 4-10 years or "some" experience. Thirty nine percent were identified as having 11+ years or "much" experience (n=22). Ten or 18.5% of participants identified as "teacher leaders." Those considered leaders were K-5 science teachers or administrators.

Participants were organized as either primarily K-2 primary teachers or primarily 3-5 upper elementary teachers based upon their number of years teaching at the respective grade levels. Thirty three percent were identified as K-2 teachers while 55.6% were identified as 3-5 teachers. Of the 54 that reported their highest degree, 16% have a Bachelors (n=9), 55.6% have a Masters (n=30), 20% have a Specialist (n=11) and 7% have a Doctorate (n=4). Of the 51 that reported they are currently working in schools, 68.5% teach regular education (n=37), 9.2% teach gifted education (n=5), 12.9% are currently in leadership positions (n=7) such as assistant principal, science specialist and instructional facilitator roles, and 3.7% teach English Language Learners (n = 2).

Forty three or 85% reported they are currently teaching science. Of the 43 teaching science, 65% (n=28) are teaching science 25% of the academic day, 20.9% (n=9) teach science 50% of the academic day, 9% (n=4) teaching science 75% of the academic day and 9% (n=4) teach science 100% of the academic day. A few reported they taught science less than 10% of the academic day.

Table 5 indicates the grade levels taught by those responding to the survey and whether or not the participants teach all academic subjects (math, language arts, science and social studies) or whether they are departmentalized (teach science only or science and one other subject). As indicated in the table, only 4th and 5th grade teachers indicated they were departmentalized. Of the 16 that indicated they are departmentalized, four teach only science, nine teach science and mathematics, and two teach science and social studies.

Table 5

Demographic Data: Grade Level & Subjects Taught

	N	**Percentage**	**Teach All Subjects**	**Departmentalized**
Kindergarten	6	11.6%	6	0
1st Grade	4	7.8%	4	0
2nd Grade	4	7.8%	4	0
Lower Elementary Total	*14*	*27.5%*		
3rd Grade	2	3.9%	2	0
4th Grade	14	27.4%	6	8
5th Grade	8	15.6%	1	7
Upper Elementary Total	*24*	*47%*		
K – 5 Gifted or ELL	7	13.7%		
K-5 Science	5	9.8%		
Administrators	2	3.9%		
Total	51			

The survey included questions about how much time was spent teaching science, but the wording of the question appeared to be confusing to participants as they were asked to choose between three models, teaching science daily, weekly or alternating science. Because of this, the accuracy of those selecting alternating science is questionable. Respondents were first sorted by their choice of model. Weekly minutes were converted to average daily minutes. Of the 37 respondents, 64% (n=23) indicated they taught science every day an average of 48.9 minutes per day. This is higher than recent estimates of time elementary teacher spend teaching science each day. Griffith and Scharmann (2008) found 53% of elementary teachers spend 90 minutes or less teaching science per week. Banilower, Smith, Weiss, Malzahn, Campbell & Weiss (2013) found K-3 elementary teachers teach science an average of 19 minutes per day compared to 89 minutes for Reading/Language Arts, 54 minutes for mathematics and 16 minutes per day for social studies compared to their 4-6 colleagues who teach science an average of 24 minutes per day. In this sample, K-2 teachers taught science an average of 36.7 minutes compared to 3-5 teachers who taught an average of 43.8 minutes per day. Based on this data, 64% of teachers earning the K-5 science endorsement are teaching science twice as long per day when compared to the national average (Banilower et al., 2013). The reason for this is unclear and was not investigated in this study.

Thirty nine percent (n=14) indicated they taught science through integration with other subjects (n=5) or alternated teaching science with another subject (n=9). These participants indicated a reduced time for teaching science, but the nature of their responses made it difficult to accurately report the time science was taught per day. Based on the data, it is estimated the teachers that alternated science with social studies taught an average of 23 minutes per day. This is similar to national average of time spent teaching science each day.

The survey data was triangulated with qualitative methods in order to capture a more in-depth look at teachers who completed the endorsement. Six teachers from three different endorsement cohorts representing different school districts taught by different instructors were interviewed and observed one year following their completion of the endorsement. Three were interviewed twice, before and after the observations. Three were only interviewed once after the observations. Observations and interviews were coded using descriptive and axial coding (Saldana, 2013). Case studies were written of six of the participants in order to develop assertions from a cross-case analysis (Yin, 2009). Three of the participants, Clara, Emily and Margaret will be presented through lengthy case studies. Their cases include additional data from their endorsement portfolios. This data includes lesson plans developed during the endorsement and lessons reflections written upon teaching the lessons with students. The observation and interview data of three participants, Callie, Christina, and Meredith will be used to present abbreviated brief cases. Clara, Emily, and Margaret were chosen for the lengthier case studies for two reasons. First, they represent different cohorts taught by different instructors. Second, the lessons observed were the most reform-oriented of the teachers from the same cohort. The nature of the lessons that were less reform-oriented including reviewing for a test and did not provide as many opportunities to observe the interactions of the dimensions of professional knowledge. Table 6 below includes general demographic data of the six participants.

Table 6

Demographic Data of Participants

Participant	Gr Lvl	Years Experience	Subjects Taught	Minutes Science Taught per Day	Highest Degree	Science Courses Educator Prep	School % of Free/Red Lunch Eligible
Callie	K	32	All Subjects	30 (est)	EdS	2 or less	79%
Christina	3rd	10	All Subjects	40	MEd	2 or less	69%
Clara	4th	23	Science & Math	50	MEd	2 or less	30%
Meredith	5th	9	Science & Math	50	MEd	Science Major	30%
Emily	5th	5	Science & Math	60	MEd	2 or less	62%
Margaret	K-5	22	Gifted	varies	BS	2 or less	50%

Methods

A mixed-methods design was used in the study to gain an understanding of the influence of the K-5 science endorsement on aspects of content knowledge and self-efficacy of participants. Mixed methods study designs involve mixing different types of data, and the researcher must decide when to mix the data during the design, analysis, and/or interpretation phases of the study (Grbich, 2013). The use of a mixed-methods approach combines the strengths of both qualitative and quantitative research and helps to address the complexity of an issue (Creswell, 2009) such as the interactions of teacher professional knowledge bases of elementary teachers.

Creswell (2009) summarizes the research on pragmatism and combines these ideas with his own to provide a philosophical basis for research which includes that researchers are “free to choose the methods, techniques, and procedures of research that best meet their needs and purposes” (p. 11). Johnson and Onwuegbuzie (2004) provide insight to the general characteristics of pragmatism often associated with mixed methods studies. These points were a guide in the design of the study:

- Places high regard for the reality of and influence of the inner world of human experience in action.
- Knowledge is viewed as being both constructed *and* based on the reality of the world we experience and live in.
- Views current truth, meaning, and knowledge as changing over time. What we obtain on a daily basis in research should be view as provisional truths.
- Endorses practical theory (theory that informs effective practice; praxis)
- Places high regard for the reality of an influence of the inner world of human experience in action (p. 18).

Johnson and Onwuegbuzie (2004) also note the importance of research designs that effectively answer research questions. Research questions were written to address both qualitative and quantitative methods. The methods selected to collect and analyze data included a focus on the experiences of the participants and how the endorsement may have influenced their professional knowledge bases. There is also a focus on the practices of teaching and the enactment of teaching instructional strategies within classrooms.

Mixed methods in this study are being used to triangulate data to measure aspects of the professional knowledge bases (survey, interviews and observations). Also, inherent in the design of this study is a focus on triangulating data from quantitative and qualitative methods and mixed the data in order to expand the "breath and range of inquiry" (Greene, Caracelli & Graham, 1989).

Data Collection Procedures

Teddlie and Tashakkori (2009) identify the research questions as being the focal point of a mixed methods study. They describe the development of research questions as the funneling "…a lot of diffuse information into a narrowly focused research question…" which is expanded through the evidence that emerges from the analysis of the study data (p. 129). Table 7 provides an overview of the research questions that guide the study as well as the data collection and analysis procedures.

Table 7

Research Questions & Mixed Methods Approach

Overarching Question: The overarching research question is: *How does participation in a K-5 science endorsement influence the professional knowledge bases of in-service elementary science teachers?*

Research Question	Data Collected	Methods of Analysis
1. *How does participation in a K-5 science endorsement influence the content knowledge of science teachers? Specifically, is there a significant mean difference between pre and post scores ?? (n=54)*	**Pre/Posttests** for the 3 content classes: life, earth and physical science	**Quantitative (QUAN)** Paired pre/post content tests were analyzed using a paired sample t-test using SPSS. The demographic survey provided opportunities to look at subsamples of the data.
2. *How does participation in a K-5 science endorsement influence the self-efficacy of science teachers? Specifically, is there a significant difference between pre and post score on a self-efficacy survey?* *(n =54*)	**Participant Background Survey** **Self-efficacy** survey was adapted (Dellinger et al., 2008; Schneider & Plasman, 2011) and administered as a retrospective pretest and posttest.	**Quantitative (QUAN)** SE survey was analyzed by question using paired t-tests. The survey was organized into professional knowledge bases analyzed using paired t-test. **Multiple regression analyses** were conducted with the goal of exploratory model building to gain an understanding of the interaction of professional knowledge bases elementary teachers. (RQ 2 & 3)
3. How does a K-5 science endorsement influence the degree of connection of the professional knowledge bases of elementary science teachers? *(n= 6)*	**Observations (2-3)** – announced observations of participants (n=6). Candidates were asked to choose two to three days within five consecutive days of a unit. **Interviews (1-2)** of teachers were conducted following the observations. The interview questions were aligned with the SE survey professional knowledge bases.	**Quantitative (QUAN)** Observations were quantified using the mean scores across the categories of the RTOP (Sawada et al., 2000), PACES & POGIL (Ellett, 2009). **Qualitative (QUAL)** Observations were coded using descriptive and axial coding (Saldana, 2013). **Qualitative (QUAL)** Transcribed interviews were coded using descriptive and axial coding (Saldana, 2013). Cross-case analysis of six participants. Individual case studies of three.

Three types of data were collected: content assessment data collecting during the endorsement, the demographic and self-efficacy survey, and observations and interviews which took place following the completion of the endorsement.

Research Question One

How does participation in a K-5 science endorsement influence the content knowledge of science teachers? Specifically, is there a significant mean difference between pre and post scores on the content assessments?

The three paired pre/post assessments were developed for use with the life, earth and physical science content courses. All participants in the endorsement were administered these assessments by their instructors at the beginning of each course (n = 85).

Content Pre and Post Assessments. The assessments were developed primarily to provide evidence of whether or not the content knowledge of participants was increasing and to inform instructor instructional planning. With this information, instructors were more aware of the content strengths and weaknesses of the participants. The goal was for instructors to differentiate based upon this information by assigning different online modules or readings for candidates with indicated content weaknesses and those who would benefit from extension activities for candidates indicating strengths in multiple content areas.

Issues of validity and reliability are ongoing concerns of researchers in the development and analysis of instruments. The American Educational Research Association (AERA) publishes the *Standards for Educational and Psychological Testing* (1999) and provides guidelines for enhancing the validity and reliability of instruments (AERA, 1999). "Validity refers to the degree to which evidence and theory support the interpretations of test scores" and is "the most fundamental consideration in developing and evaluating tests" (AERA, 1999, p. 9). Furthermore, validation “can be viewed as developing a scientifically sound argument to support the intended interpretation of test scores and their relevance to the proposed use (AERA, 1999, p. 9). Steps were taken to enhance the validity of the test items administered during the endorsement and those steps are outlined in the following section.

The assessments were developed primarily from released National Assessment of Educational Progress (NAEP) and Trends in International Mathematics and Science Study (TIMSS) items available online. The items were found at: NAEP Questions Tool (NCES, 2012) and Edinformatics (2009). The released items were chosen because the content had been included on national assessments and were deemed appropriate for middle school science students. The content standards for the endorsement focus on the national science standards at the K-4 and 5-8 grade bands. The items selected represented a variety of science domains of knowledge representative of middle school science. The tests were constructed prior to the endorsement beginning. Teams of science supervisors from local school districts reviewed the test items as the first step towards providing evidence for the validity of the assessments. Course instructors also reviewed the test items prior to administration and following a summer instructor workshop using the National Science Education Standards for grades 5-8 as a reference.
To further study the validity of these assessments for the purpose of measuring pre and post test content knowledge of elementary teachers, groups of experienced middle school teachers were asked to review the test items by completing a survey with questions about the appropriateness of the items in relation to middle school level content taught. For each content area, four to five teachers with an average of ten years of experience teaching middle school students within that content area and experience with professional development in science were selected to review the test items. The reviewers were asked to rate on a scale of 1 to 5 with 5 being the highest to

what degree does each item: 1) represent what is taught to students at this grade level; 2) represent the content taught on the job with students; and 3) reflect what kids need to learn in this subject area at this grade level? Any item receiving an average of less than 3 was reviewed by the author. Four of the life science questions scored below a 3, question numbers 12, 13, 14, 16. The items were all about the characteristics and classification of animals. The items were not eliminated from the assessment because 12 and 16 were deemed to represent K-5 content and items 13 and 14 represented high school biology content. None of the earth science items scored below a 3. One of the physical science items, number 15 scored a 2 and was eliminated from the assessment. Appendix A contains the results of the review from the experts.

Research Question Two

How does participation in a K-5 science endorsement influence the self-efficacy of science teachers? Specifically, is there a significant mean difference between pre and post scores on the self-efficacy survey?

A retrospective pre and post self-efficacy survey was sent to all participants completing the endorsement between 2010 and 2013 (n=99). Fifty four percent of participants (n=53) completed the survey.

Participant Background and Self-Efficacy Survey. This data source includes a survey of teacher background, experience and retrospective pre and post test of self-efficacy. The survey was sent to participants who completed the K-5 science endorsement both electronically by email three times and by mail once (n = 85). The survey can be found in Appendix B. The first question of the survey asked participants to consent to completing the survey and provide permission for the use of the content pre/post data. A raffle for two $25 gift cards was included as an incentive for taking the survey. Of the 54 that participated in the survey, four did not complete the self-efficacy questions. Part one included information about the number of years the participant has taught science, the number of years science has been taught at the K-2 and 3-5 grade bands, how long science is taught daily, and degrees conferred.

Part two of the survey included a 30 item retrospective pre and post-test organized around the professional knowledge bases. Items were primarily modified from the Teachers' Efficacy Beliefs System-Self (TEBS-Self) (Dellinger, Bobbett, Olivier & Ellett, 2008), and the PCK learning progressions (Schneider & Plasman, 2011). Additional resources for the survey included 5E learning cycle research (Abraham & Renner, 1986; Bybee et al., 2006; NRC, 2012). The TEBS-Self was originally developed to assess "teachers' individual beliefs about their own abilities to successfully perform specific teaching and learning tasks within the contexts of their own classrooms" (Dellinger et al. 2008). TEBS-Self items were organized around pedagogical constructs, classroom management/climate, motivation of students, accommodating individual learning differences, higher order thinking, and managing learning routines. The goal of developing the PCK-SE survey was to capture the essence of the knowledge bases that inform PCK in a form that participants of the endorsement could indicate their self-efficacy to teach science in a reform-oriented manner before and after completing the endorsement. Using language from Bandura (1997), participants were asked to "indicate the strength of your personal belief in your capabilities." Dellinger et al. (2008) recommend including the items that should represent the definition of self efficacy, assess the context, and include meaningful tasks. These recommendations were considered when selecting the self-efficacy items. Appendix C includes organization of the self-efficacy questions into PCK constructs and the source of each question.

To enhance the content validity of the self-efficacy survey, the items were reviewed by individuals with expertise in professional development including science education faculty, district science specialists, and non-science curriculum specialists with expertise in teacher professional development to determine if the items selected appropriately fit into the selected PCK component categories. The experts were provided with definitions for the PCK components and asked to rate the self-efficacy items on a 5 point scale (strongly agree to strongly disagree) as to how well they fit into the categories. The survey was sent to 23 individuals with professional development expertise. Ten individuals responded to the survey and three individuals provided personal feedback on the survey. The ten respondents had an average of 13.5 years experience in professional development. Appendix C includes the results of the expert feedback. A second, revised version of the survey will be administered to approximately 500 science teachers as part of another study so that a principal component analysis (PCA) can be conducted.

Reliability, or test-retest reliability, is the consistency of measurements "when the testing procedure is repeated on a population of individuals or groups" (AERA, 1999, p. 25). Cronbach alpha is an example of a split-half reliability measure and is the most common test of reliability (Field, 2009). To address the issues of reliability of the both the content pre and post assessments, Cronbach alpha test of reliability were conducted using Statistical Package for Social Science (SPSS) statistical analysis software. Cronbach alpha measures the internal consistency of assessments. SPSS provides a summary of the alpha coefficient for each assessment. The more reliable the item, the higher the score with following criteria for acceptable values of Cronbach's alpha: below 0.60 is unacceptable, 0.6 – 0.65 is undesirable, 0.65 - 0.70 is minimally acceptable, 0.70 to 0.80 is respectable, and 0.80 to 0.90 is very good (DeVellis, 1991).

The items were organized into categories using various aspects of teaching that influence PCK: orientations, knowledge of instructional strategies, and the professional knowledge bases of content knowledge, curricular knowledge, assessment knowledge, pedagogical knowledge and knowledge of students. Cronbach alpha reliability statistics were conducted on the assigned categories PCK-SE survey. Table 8 provides a summary of the results. All of the items were in the very good range (.8 - .9), except for the Content Knowledge which was in the acceptable range on the before the endorsement survey and minimally acceptable range after, Curriculum at .691 before, and Assessment which was on the high end of the minimally acceptable range in the post endorsement survey. Cronbach alpha results for the PCK SE efficacy pre-assessment was .955 and .968 on the post assessment items.

Table 8

Cronbach alpha results for the PCK-SES Survey

SE Items	**PCK Category**	**# of SE items**	**Cronbach alpha Retrospective Pre**	**Cronbach alpha Post**
SE 1 – 5	Instructional Strategies	5	.811	.873
SE 6 – 10	Orientations	5	.811	.868
SE 11 – 13	Content Knowledge	3	.734	.661
SE 14 – 18	Understanding Students' Conceptions	5	.864	.889
SE 19 – 23	Assessment Knowledge	5	.857	.746
SE 24 – 27	Curricular Knowledge	4	.691	.864
SE 28 – 30	Pedagogical Knowledge	3	.839	.887

The self-efficacy items were administered in a retrospective pretest and posttest format for two reasons. The first is to reduce the risk of response-shift bias and the second, due to the nature of the researcher's relationship to participants. In other words, participants simultaneously rated their self-efficacy beliefs prior to and after completing the endorsement. Retrospective pretest and posttest have been shown to reduce threats to the validity commonly associated with pretest/posttest designs such as the pretest effect caused by self-reporting data, pretest sensitization and response-shift biases (Howard, 1980; Lam & Bengo, 2003). "In using self-report instruments, researchers assume that a subject's understanding of the standard of measurement for the dimension being assessed will not change from one testing to the next (pretest to posttest)" (Howard, 1980, p. 93). If the treatment, however changes the participants' understanding of the construct being measured, a response shift bias may result (Drennan & Hyde, 2008). Howard (1980) reviewed several studies using self-report pre and post data and found evidence of response shift bias when comparing data to interviews. They found that retrospective measures when compared to pre/post self-reports, were more in line with interview and facilitator estimate of changes. More recent studies also found a response shift bias when using a pretest, post and retrospective pretest to measure the self-efficacy of preservice teachers (Hechter, 2011) and the influence of a Master's program in nursing (Drenner & Hyde, 2008).

Limitations of the retrospective measures include the "possibility of contamination due to faulty memory, selective perception, social desirability, or subject acquiescence" (Howard, Schmeck & Bray, 1979, p. 131). Howard et al. (1979) recommend that retrospective pretest be accompanied by another type of measurement such as social desirability questions if a response shift bias is a concern. Part three of the survey contained four true or false social desirability questions selected from Crowne and Marlowe (1960) and Strahan and Gerbasi (1972). The addition of the social desirability questions helps to address concerns of participants' responding to survey questions in a way they consider to be socially acceptable. Social desirability is another concern of self-report measures (Furnham, 1986). Four social desirability items from Crowne & Marlowe (1960) were included on the survey. The items represented "behaviors which are culturally sanctioned and approved but which are improbable of occurrence" (Marlowe & Crowne, 1961).

The socially desirable answers are indicated in Table 9 which also includes the frequency of the responses. The majority of the respondents indicated in a manner considered to be socially desirable. Social desirability has been linked to conformity (Marlowe & Crowne, 1961). The results are an indication they may have also responded to the self-efficacy survey in a way that would be considered socially desirable as well. Becker (1976) [in Furnham, 1986] found "that putting one's name on the questionnaire actually increased the likelihood of a higher socially desirable response" (p. 391). The interviews of the six participants were used to further triangulate these data. Participant interview questions were developed in conjunction with the retrospective pre + post test design. Interview questions were developed to align with the professional knowledge bases included in the survey. The interview questions can be found in Appendix C.

Table 9

Results of Social Desirability Questions

	SD (1)	D (2)	A (3)	SA (4)	*M*	*SD*
1. On a few occasions, I have given up doing something because I thought too little of my ability. (F, #10)	11	16	11	0	*2*	*.771*
2. When I don't know something I don't at all mind admitting it. (T, #20)			18	20	*3.5*	*.506*
3. I am sometimes irritated by people who ask favors of me. (F, #30)	15	18	5	0	*1.78*	*.685*
4. No matter who I'm talking to, I'm always a good listener. (T, #13)	1	8	22	7	*2.9*	*.712*

Research Question Three

How does a K-5 science endorsement influence the degree of connections of the professional knowledge bases of elementary science teachers?

Regression Model. A stepwise multiple regression exploratory analysis of the self-efficacy survey was conducted to triangulate with interviews and observations to address the interactions of the professional knowledge bases identified in the survey. The PCK-SE categories representing the dimensions of professional knowledge were used as dependent and predictor variables in order to explore the connections among the dimensions. An explanation follows in the data analysis section.

Semi-structured interviews. Six participants were interviewed once or twice using the semi-structured interview questions in Appendix C. The interviews lasted between 30 minutes to one hour. The interview questions were aligned with the professional knowledge base categories used with the survey and included participants' ideas about planning and implementing science lessons, and include retrospective questions about components of their participation in the endorsement that had the most influence on their ideas about teaching science.

Two interviews were part of the initial plan with the first interview occurring one week prior to the first classroom observation and the second interview occurring after classroom observations. Difficulties included obtaining school district IRB approval and principal and teacher consent, thus the number of interviews varied between one and two. The first interview questions were asked in an attempt to engage teachers in a retrospective discussion about the endorsement. These questions were more vague than in the later questions as the intent was not to lead the participants into a discussion about reform orientations but to see if evidence of a reform orientation emerges. The questions include information about a typical day in their science class, goals for students and influence of the endorsement on teaching practices, lesson planning, and science pedagogy. A question about constraints to teaching was included. Hume (2012) recommends studies that investigate "what inhibits teachers from making the most effective strategies" (p. 552). The purpose was to look for insight as to whether the endorsement had an impact on the constraints that are commonly faced by elementary science teachers.

All interviews were conducted by the first author. The interviews were audio recorded and transcribed. A summary of the transcription and analysis was provided to each participant in order to member check the data. Field notes were maintained throughout the interview and data analysis process. Because the primary author is the endorsement coordinator, participants were reminded at the beginning of the interview with a statement such as, "I know that you have seen me throughout the endorsement courses and are aware of my role as the coordinator of the endorsement. During the interviews, I want you to see me in the role as researcher. As a researcher of this program, I want to get a realistic view of the endorsement and whether or not it has impacted various aspects of your teaching. I hope that you will feel comfortable providing me with honest feedback and not have any concerns about trying to provide answers that you may think I want to hear."

Observations. Six teachers were observed at least twice during a teaching unit in the year following their participation in the endorsement. The teachers were asked to select three days of a teaching unit. All of the observations were announced. The observations were the length of an entire science class period and lasted least 30 minutes. The researcher was present for the entire class period in order to see the opening, work period, and closing of the lesson for each of the three days observed. The data collected included the engagement rate of students measured in three minute intervals. At the end of each three minute period, the number of students appearing not to be on task were counted and recorded. The Reformed Teaching Observation Protocol or RTOP (Sawada, Piburn, Turley, Falconer, Benford, Bloom & Judson, 2000; Sawada, Piburn, Judson, Turley, Falconer, Benford & Bloom, 2002) was used to collect data during the observations.

The Reformed Teaching Observation Protocol (RTOP) has been widely used as a method to study reform-based practices in science and mathematics teachers. The RTOP divides PCK into two kinds of knowledge: Propositional Knowledge such as "the lesson promoted strongly conceptual understanding" or "connections with other content disciplines" and Procedural Knowledge such as "students made predictions, estimations, etc" (Sawada et al., 2000, 2002). The RTOP is composed of 25 items arranged into 3 categories: (1) Lesson Design and Implementation, (2) Content and (3) Classroom Culture and was developed based upon the goals for reform-based teachings. Reformed teaching and learning includes standards based and inquiry-based teaching and learning. The higher the score on the RTOP indicates a higher degree of reform orientation. Examples of items include "the teacher had a solid grasp of the subject matter content inherent in the lesson" and "connections with other content disciplines and/or real world phenomena were explored and valued" (Sawada et al., 2000, p. 36).

Prior to the observations, several researchers were trained to use the RTOP by observing multiple elementary teachers teach science lessons. Following a training session, paired observers separately coded observations and then discussed the ratings and negotiated consensus of observations with the each other and the trainer. The process was repeated for two other classroom observations. A note taking protocol was also established that included students on task and for the researchers to write down information about what the student is doing, what the teacher is doing, student/teacher interactions, and instructional strategies, continuously during the observation. Following the training session, the lead author conducted all of the classroom observations in the study except for one. During the second observation, another graduate student separately coded the instrument and the researchers discussed the codes to research consensus. Only two of the 25 indicators were coded differently and within one point. After the discussion, the researchers came to consensus about the scores.

Two additional instruments, the PACES and POGIL were scored immediately following the observations). The Professional Assessment and Comprehensive Evaluation System (PACES) and the Process Oriented Guided Inquiry Learning (POGIL) are components in an annotated version of the RTOP (Ellett, 2009). They include various pedagogical and inquiry indicators and have been used in other evaluation systems. A scale of 1 – 3 was used to indicate whether the indicator was observed (3), somewhat observed (2), or not observed (1). An average for each indicator was calculated in order to look across the participants for trends in practices. Researcher memos were written following every observation.

Data Analysis Procedures

Data from the various sources were analyzed using both quantitative and qualitative methods then combined by professional knowledge base and analyzed from a mixed-methods perspective. In this section, the initial data analysis procedures will be described followed by procedures used to integrate the data. SPSS statistical software was used to analyze the quantitative data (Field, 2009). The PCK components (Magnusson, et al., 1999) were used to establish a priori codes (Saldana, 2013), but other codes were allowed to emerge through the data coding process.

The data were analyzed using a parallel mixed-model design, also known as a concurrent mixed-method design in which quantitative and qualitative data is collected at the same time then integrated with analytic approaches (Grbich, 2013, p. 28)." The section that follows will describe the analysis procedures and how the data were integrated.

Research Question One

How does participation in a K-5 science endorsement influence the content knowledge of science teachers? Specifically, is there a significant mean difference between pre and post scores on the content assessments?

Pre/Post content tests (QUAN). Inferential statistics were used to analyze each paired pre/post content tests. Each paired course pre/post content test was analyzed using a t-test to look for significant differences between the group means of the pretest and post-test scores of content knowledge. A normalized gain score was calculated for each paired content assessment. The normalized gain scores are defined as the ratio of the actual average gain <G> to the maximum possible average gain, i.e.,<g> ≡ %<G> / %<G>max = (%<Sf> - %<Si>)/(100 - %<Si>),where <Sf> and <Si> are the final (post) and initial (pre) scores to give a ratio between 0 and 1. For example: Pretest score is 30 and Posttest score is 50: Formula would be: (50 - 30)/(100 - 30)=20/70= 0.285 R. C. Hendrick (personal communication, February 2014).

Research Question Two

How does participation in a K-5 science endorsement influence the self-efficacy of science teachers? Specifically, is there a significant mean difference between pre and post scores on the self-efficacy survey?

Teacher questionnaire (QUAN). The data from the demographic data section of the survey found in Appendix B was used to obtain measures of central tendency to determine general characteristics of teachers that completed the survey. These data were summarized in a chart in order to "be able to understand the data, detect patterns and relationships, and better communicate the results" (Teddlie & Tashakkori, 2009). This data was reported in the participant section and was used to analyze the content assessments and self-efficacy survey.

Self-efficacy survey. The retrospective pretest + post test of self-efficacy was analyzed using paired t-tests for each question to look for significant differences in self-efficacy prior to and following participation in the endorsement. Mean scores for pre and post survey questions were calculated and were organized by questions with the highest mean scores on the pretest, highest mean scores on the post test, and questions with the highest mean difference.

The self-efficacy questions were organized by the professional knowledge bases. Descriptive statistics were calculated for each self-efficacy item. *Compute variable* was selected and the *target variable* was named based on the PCK category represented. A numeric expression was used to combine the SE questions into the category. For example, instructional strategies (pre) were represented in the numeric expression: (SE1A+SE2A+SE3A+SE4+SE5)/5. This produced a mean score for the category. The mean score was used to run t-tests to look for a significant difference before and after the endorsement. A regression model was used to more closely analyze the results of the self-efficacy survey and will be presented with research question three.

Research Question Three

How does a K-5 science endorsement influence the degree of connections of the professional knowledge bases of elementary science teachers?

Regression Model. Multiple regression analysis using a stepwise procedure was used for exploratory model building to look for relationships among the dimensions of professional knowledge that inform PCK. Multiple regressions use several predictor variables (X) to build a more complex model than a linear regression. Fields (2009) describes this type of regression as one which "seek[s] to find the linear combination of predictors that correlate maximally with the outcome variable" (p. 210). Before the regression analyses were conducted, correlations were conducted using SPSS to look for relationships among the dimensions of professional knowledge as well as gain scores of pre and post content assessments. Significantly significant correlations were found among the dimensions so they were used in the regression analysis. No correlations were found between the dimensions and content assessments. The results will be presented in Chapter 4.

Using SPSS, models are predicted from a combination of the variables. SPSS produces a Multiple R which is the correlation between the observed Y values and the values of Y predicted by the multiple regression model. According to Field (2009), a large multiple R represents a large correlation between the predicted and observed values of the outcome. R^2 is the variation of Y explained by X and is often reported as the percentage that can be explained from the relationship. In a multiple regression, the F ratio for R^2 is a test of the overall model, but does not speak to the effectiveness of each predictor individually, so t-test need to be conducted for each predictor (Field, 2009). The ANOVA table produced in SPSS tells how well the model fits the data or how well the regression equation accounts for the variability. The sample size is a limitation for the study. Field (2009) recommends a sample size of 10 for every predictor variable tested. A sample size of 60 would have been more ideal for this study which included data from 54 participants. Each dimension of professional knowledge entered as the Y (outcome/criteria) variable with the other six dimensions added as the X (predictor variables). Fields (2009) cautions the stepwise function should be used for data exploration only and recommends using a small number of predictor variables. Correlations between knowledge bases were run to narrow the number used in the models and this will be reported in the findings section.

Semi-structured Interviews. Qualitative coding methods were used with the interview data. Descriptive coding was used as the first cycle coding method (Saldana, 2013). Using this type of coding, passages from the interviews were summarized into short phrases. The transcripts were initially hand coded and then coded a second time and transposed onto an Excel spreadsheet in order to analyze the data across participants. Individual worksheets were created for each interview question. Participant codes were organized in columns within each worksheet sheet. Codes were reduced and combined while reviewing across participant data. Memos were written to describe the steps throughout. Memos included notes about similarities of comments between participants and patterns that were emerging as the data were reviewed.

Peer debriefing of interview codes was used. The lead researcher coded all the interview data and had a second researcher separately coded the interviews. Of the nine interviews conducted, the second researcher coded six transcripts. The two researchers discussed the coding to reach consensus about the codes.

Axial coding was used as the second cycle coding method to look for emerging themes (Saldana, 2013). A summary was written for each of the participants. The interview data were merged with the observation data to generate a cross-case analysis which lead to assertions based upon the data.

Observations. Both qualitative and quantitative observation data were collected during the observations of participants. RTOP, PACES, POGIL and student engagement were collected during the observation and recorded in an Excel spreadsheet. Mean RTOP scores were calculated for each observation of each participant. Mean averages were calculated for individual construct for each instrument (RTOP, PACES and POGIL) across the participants in order to compare which practices were used most often in the classroom observed. Mean RTOP category scores (propositional knowledge, etc) were also calculated. Memos were written to describe the steps throughout. Memos included notes about similarities of comments between participants and to look for patterns that were emerging as the data were reviewed.

Observations were also coded using qualitative coding methods. A priori codes established during the interview coding were used in the observation code. A few additional codes were added to the code list when observation data were analyzed. Descriptive coding was used as the first cycle coding method (Saldana, 2013). Using this type of coding, passages from the interviews were summarized into short phrases. The codes from the observations included episodes where two or more types of professional knowledge appeared to be interacting during the observations. Peer debriefing techniques were also employed to enhance the reliability of the data. Of the 16 observations, two were separately coded by the lead researcher and another graduate student. The graduate student is not the same student that coded the interview data. Codes were discussed and the two researchers came to consensus about the codes. Once agreement had been established between the two researchers, the lead researcher coded the remaining observations then sent the coded observations to the second researcher to review and verify codes. The researchers negotiated the codes until a consensus was reached.

Case Studies. The data from the coded observations and interviews along with data from the archived portfolios of the participants will be used to develop case studies of the participants. Yin (2009) describes several applications of case studies that are appropriate to this study. They include to "explain the presumed causal links in real-life interventions that are too complex for survey of experimental or survey inquiries;" and "to describe an intervention and the real-life context in which it occurred" (p. 20). Case studies and a cross-case analysis will be used to highlight the experiences of the participants in order to provide a clearer picture of the influence of the endorsement on the participants. The use of multiple cases makes the study more robust than single case studies (Yin, 2009).

Issues of reliability and validity need to be addressed during the development of case studies (Yin, 2009). Multiple sources of evidence including archived lesson plans and lesson reflections developed during the endorsement, observations, and interviews will be used to enhance validity. These data sources help to establish a chain of evidence (Yin, 2009). Issues of reliability will be addressed by having multiple researchers code and review assertions.

Integrating the Data

One of the factors that make mixed-methods studies unique is the integration of quantitative and qualitative approaches (Teddlie & Tashakkori, 2009). The characteristics of the parallel mixed-methods research design includes at least two parallel and independent strands of qualitative and quantitative data collection and analysis designed to answer different aspects of the same overarching question (Teddlie & Tashakkori, 2009). The research questions include both qualitative and quantitative types of data that explore various aspects of the overarching idea of elementary teacher professional knowledge bases that inform PCK. The integration of the data is challenging because qualitative data is comprised of text and quantitative data is comprised of numbers (Creswell, 2009). Symbols are often used to represent various forms of data in mixed methods research. QUAN represents quantitative; QUAL represents qualitative; QUEST represents questions such as from a survey; INT represents interviews and OBS represents observations. Combining data from quantitative questionnaires and qualitative interviews, QUEST-QUAN → INT-QUAL is one of the most common mixed-methods combinations and one in which the strengths of the approaches complement each other (Teddlie & Tashakkori, 2009). The arrow → represents integration. The sections use symbols to describe the integration of various forms of data.

QUEST-QUAN → INT-QUAL and QUEST-QUAN → OBS-QUAL In this study, the interviews and observations complement the survey data by providing in-depth information from a small number of participants to elaborate on the information. The self-efficacy questions and interview questions have been organized by the professional knowledge bases in order to triangulate the data between the two sources and provide a better understanding of the interaction of the professional knowledge bases of elementary teachers. The results of the exploratory data analysis from the regression model were also integrated with the observation and interview data. The codes from the observations include episodes where two or more professional knowledge were interacting. These data were linked to the results of the model.

TEST-QUAN → INT-QUAL. The quantitative information from the content test will also be combined with the interviews, TEST-QUAN → INT-QUAL and with the observations, TEST-QUAN → INT-QUAL. The analysis of the content pre/post test provides information about the changes in content knowledge during the course by domain. Interviews also provide information about the perceived impact of content knowledge.

OBS-QUAL → INT-QUAL Axial coding was used as the second cycle coding method to look for emerging themes separately in the observation and interview data (Saldana, 2013). A summary was written for each of the participants surveyed. The interview data were merged with the observation data to generate a cross-case analysis which lead to assertions based upon the data.

Making Inferences

Teddlie and Tashakkori (2009) suggest that the process of making good inferences in a mixed-methods study begins with the study design and a coherent conceptual framework. The conceptual framework includes the professional knowledge bases, and the two amplifiers and filters associated with, efficacy and orientations. The final step of the data analysis process was to develop inferences. Teddlie and Tashakkori (2009) describe inferences as “conclusions and interpretations that are made on the basis of collected data in a study” (p. 287). They elaborate that the inference process “consists of a dynamic journey from ideas to data to results in an effort to make sense of data by connecting the dots” (p. 287). Inferences include conclusions and interpretations of the study. “Inferences are not limited to answers to research questions; they also develop new understandings and explanations for events, phenomenon, and relationships” (Teddlie & Tashakkori, 2008, p. 288). They also note that mixed-methods studies do not require agreement among the inferences.

Inferences in this study will be called assertions. Assertions will be formed through the integration of various data sources. Table 10 includes the various data sources that will be integrated to generate a characterization of elementary science teachers prior to and following their participation in the endorsement.

Table 10

Data Sources to Inform Professional Knowledge Bases

Professional Knowledge Base	**Before the Endorsement**	**After the Endorsement**
Content Knowledge (CK)	Content Assessments (3) Pre Content PKB (SE Survey) Pre Interview (Reflective Questions)	Content Assessments (3) Post Content PKB (SE Survey) Post Observations Interviews
Knowledge of Students (KS)	KS PKB (SE Survey) Pre Interview (Reflective Questions)	KS PKB (SE Survey) Post Observations Interviews
Curricular Knowledge (KC)	KC PKB (SE Survey) Pre Interview (Reflective Questions)	KC PKB (SE Survey) Post Observations Interviews
Assessment Knowledge (AK)	KA PKB (SE Survey) Pre Interview (Reflective Questions)	AK PKB (SE Survey) Post Observations Interviews
Pedagogical Knowledge (PK)	PK PKB (SE Survey) Pre Interview (Reflective Questions)	PK PKB (SE Survey) Post Observations – RTOP PACES & POGIL Interviews
Knowledge of Instructional Strategies (KIS)	KIS PKB (SE Survey) Pre Interview (Reflective Questions)	KIS PKB (SE Survey) Post Observations - RTOP Interviews

Two researchers were involved in peer debriefing by reviewing the assertions from the data. A discussion between the researchers included the opportunity to talk about the assertions in more depth.

In conclusion, the use of a mixed methods approach combines the strength of the two research paradigms to complement, enhance and triangulate the data, thus providing opportunities to take a more in-depth look at a phenomenon. By using a mixed methods approach, the study takes a closer look at elementary science teachers following their participation in a sustained professional development experience. Through the use of mixed methods, we are able to complement and triangulate survey data with observations and interviews. This will provide a more detailed understanding of the influence of the endorsement experience on their professional knowledge bases and enactment of instructional strategies. The findings of the results are presented in Chapter 4.

CHAPTER 4: FINDINGS

The literature is replete with studies about the constraints that elementary teachers face when teaching science (Lee & Houseal, 2003; Davis, Petish & Smithey, 2006; Appleton, 2007; Metz, 2009; Wilson & Kittleson, 2011. These constraints include limited time, content knowledge, confidence, and experience with reform-oriented instructional practices. This study focuses on the influence of a K-5 science endorsement on the professional knowledge bases of elementary science teachers and how those knowledge bases inform a teacher's Pedagogical Content Knowledge (PCK). Within the Consensus Model of PCK, PCK is defined as "knowledge of, reasoning behind, and planning for teaching a particular topic in a particular way for a particular purpose to particular students for enhanced student outcomes" (Gess-Newsome & Carlson, 2013). PCK is influenced by a number of Teacher Professional Knowledge Bases (TPKB), Topic Specific Professional Knowledge Bases (TSPKB), and amplifiers and filters of those knowledge bases that influence the enactment of PCK. In this study, the factors associated with the PCK Consensus Model will be referred to as dimensions of professional knowledge. This term was identified to represent the various factors associated with PCK.

The K-5 science endorsement is a sustained professional development experience with opportunities for teachers to experience topic specific instructional strategies, develop teaching units, and implement those units in their classrooms. Three research questions guide this mixed methods study.

1. *How does participation in a K-5 science endorsement influence the content knowledge of science teachers? Specifically, is there a significant mean difference between pre and post scores on the content assessments?*

2. *How does participation in a K-5 science endorsement influence the self-efficacy of science teachers? Specifically, is there a significant mean difference between pre and post scores on the self-efficacy survey?*

3. How does a K-5 science endorsement influence the degree of connections of the professional knowledge bases of elementary science teachers?

The findings are presented by research question. They will be followed by an integration of the data of using a parallel convergent mixed methods approach. Both quantitative and qualitative data were collected and analyzed separately. The data are content pre and post assessments, a retrospective pre and post self-efficacy survey, observations and interviews. The data will be reported individually in this chapter then integrated and used to propose assertions in the following chapter.

Research Question One

How does participation in a K-5 science endorsement influence the content knowledge of science teachers? Specifically, is there a significant mean difference between pre and post scores on the content assessments?

Content Pre/Post Assessments. Content pre assessments were given at the beginning and end of each of the three ten week courses: life science, earth science and physical science. The content assessments were developed from released middle school NAEP and TIMMS items. The validation process was described in Chapter 3. Paired t-tests were calculated for each paired pre and post content assessment using SPSS. Differences between pre and post assessments and were found to be significant at 0.05 alpha level. Mean difference and percentage gains are presented in Table 11.

Table 11

Paired Samples t-test

Paired Assessment	Pre	Post	% Gain (Post-Pre)	Mean Difference	St Dev	t	df	*p*
Life Science	75.8	84.6	10.4%	8.05	8.43	6.82	50	<.001
Earth Science	64.6	79.4	18.6%	14.74	12.00	8.59	48	<.001
Physical Science	64.8	80.4	19.4%	15.7	14.69	7.79	53	<.001

A significant difference in life, earth, and physical science content knowledge occurred following the endorsement courses. The life science pretest scores were higher than earth and physical science suggesting a higher degree of knowledge of life science compare to earth and physical science prior to the endorsement. This is consistent with findings that suggest elementary teachers report feeling more prepared to teach life and earth science than physical science (Banilower et al, 2012). Earth and physical science assessments demonstrate an 18.6% and 19.4% gain from pre to post, respectively compared to a 10.4% gain in life science. The post means were statistically significantly higher than the pre means for all of the science assessments.

Scatter plots of the assessment scores are in Figure 3. The scatter plots show the pre and post content assessments are positively correlated. There is a considerable amount of the variation in pre and post test scores of the participants. There is a 42% common variance between the pre and post life science assessments, 50% common variance in the earth science pre and post assessments, and a 24% common variance between the physical science pre and post assessments. A few participants did not demonstrate an improvement from pre to post while a large number of participants saw an increase in scores. A closer look at the physical science data demonstrates high individual gain scores with a large number of low pretest scores followed by high post test scores.

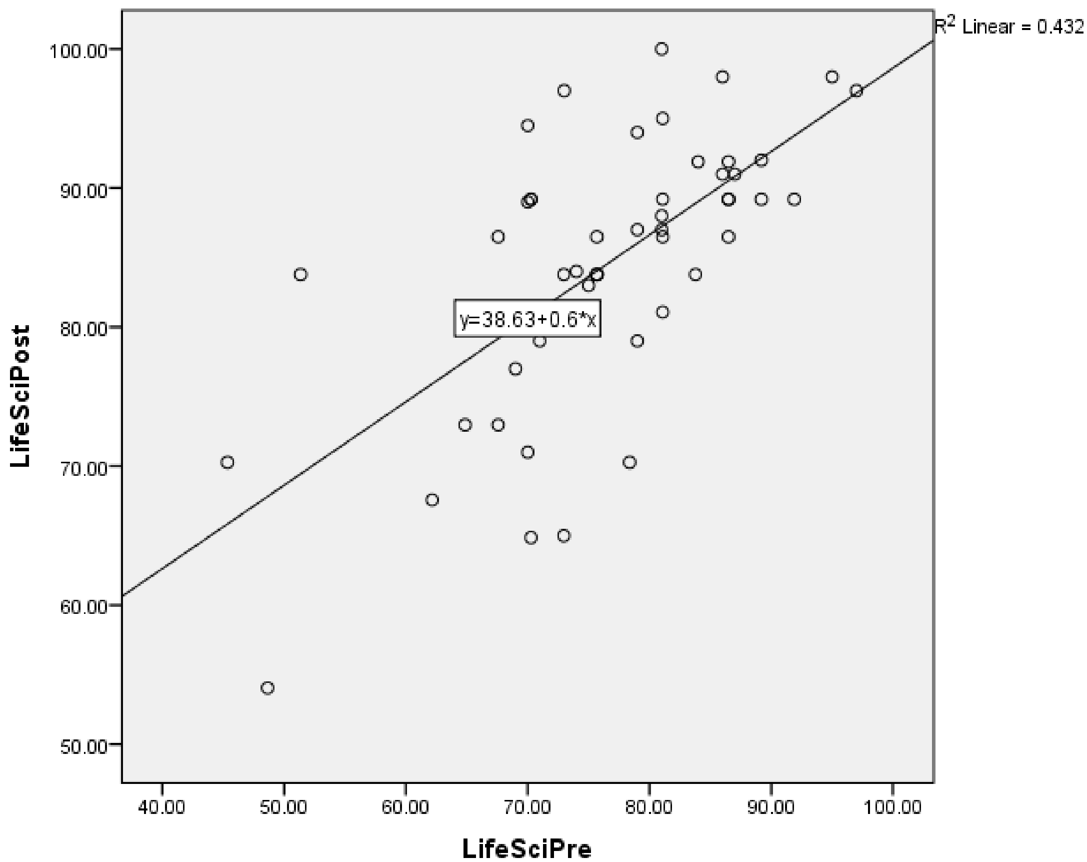

Figure 3. Scatter plot of Pre and Post Life Science Assessments

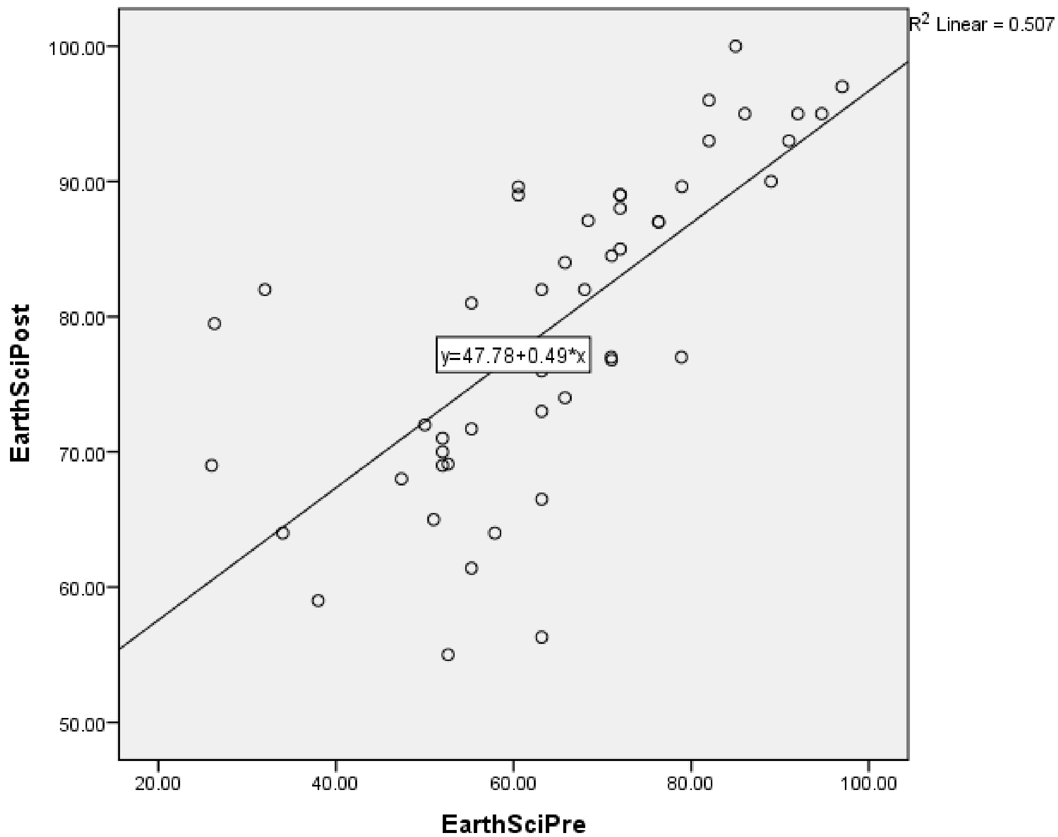

Figure 4. Scatter plot of Pre and Post Earth Science Assessments

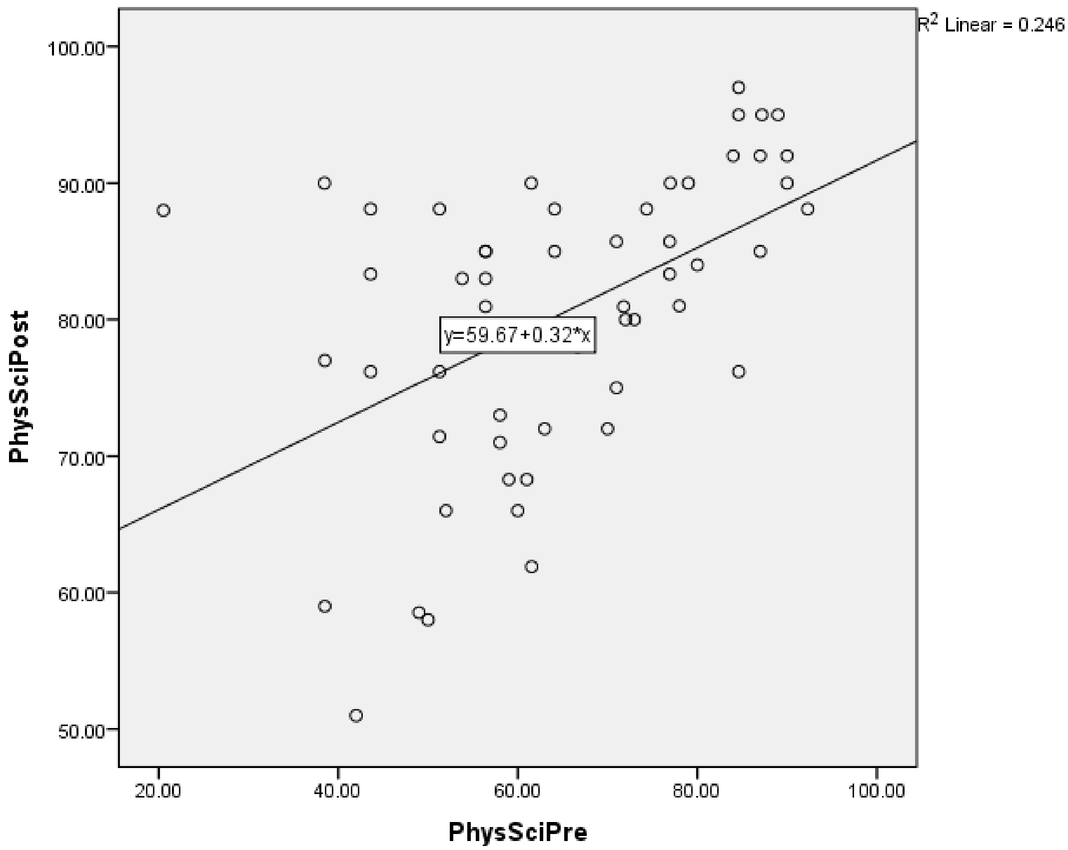

Figure 5. Scatter plot of Pre and Post Physical Science Assessments

These scatter plots show that teachers scored higher on the post assessment than the pre assessment. This change is due in part to the teachers' participation in a K-5 science endorsement professional development. It is suggested that participants' immersion in inquiry-based content development across the NSES K-4 and 5-8 grade bands (NRC, 1996) in these domains of science during the endorsement classes is the reason for the difference.

Participants were organized into two groups based upon whether their teaching experience was primarily at the K-2 (primary) or 3-5 (upper elementary) grade band. An exploration of the data using Independent samples t-test of gain scores of K-2 and 3-5 teachers demonstrated no statistical difference in gain scores of K-2 and 3-5 teachers. The results of independent samples t-test are shown in Table12.

Table 12

Independent Samples t-test of Gain Scores of Content Assessments

	K-2	3-5	Mean Difference	St Error Diff	t	df	*p*
Life Science	2.88	3.91	-1.03	.75	-1.38	49	.174
Earth Science	3.60	4.11	-.52	.68	-.77	49	.447
Physical Science	4.22	3.98	.24	.68	.35	52	.725

Although there were no statistically significant differences between the grade bands, upper elementary teachers had higher gain scores from pre to post on the life science assessment. Earth and physical science assessments showed little differences when comparing grade bands. This exploratory analysis was done to look for differences in influence of the content courses on primary and upper elementary grade teachers. This could be an area of further study.

Research Question Two

How does participation in a K-5 science endorsement influence the self-efficacy of science teachers? Specifically, is there a significant mean difference between pre and post scores on a self-efficacy survey?

The self-efficacy survey was developed and organized into dimensions of professional knowledge that make up the PCK Consensus Model. The term dimensions was used to collectively refer to Teacher Professional Knowledge Bases (TPKB), Topic Specific Knowledge Bases (TSPKB) and other factors that influence the enactment of pedagogical content knowledge (PCK). Participants were asked to rate their efficacy before the endorsement retrospectively at the same time they rated their efficacy after the endorsement. The difference between the self-efficacy ratings on each item before the endorsement and after the endorsement was statistically significant. The survey was sent to participants following the completion of the endorsement. The scale on the instrument was a 1-4 rating with 1 representing weak beliefs, 2 representing moderate beliefs, 3 representing strong beliefs, and 4 representing very strong beliefs. The items represent reform-oriented ideas organized into categories indicated by dimensions of professional knowledge.

PCK Self-Efficacy Survey. Paired sample t-tests were conducted on each of the paired self-efficacy survey questions and significant differences were found between each pair of the 30 questions (n=49) at the 0.05 alpha level. Of the 54 participants who took the survey, five did not complete the self-efficacy survey items. Tables 13 - 19 includes the results of the t-test organized dimensions of professional knowledge. The items with the highest mean difference between pre and post are italicized.

Table 13

Paired Samples t-test of Self-Efficacy Survey: Knowledge of Instructional Strategies

	Before (Pre)	**After (Post)**	**Mean Difference (Post-Pre)**	**SD**	**t**	**df**	***p***
1. Implement inquiry based instructional strategies for the purpose of designing investigations, collecting evidence and making claims	2.08	3.2	1.16	0.69	11.8	48	<.001
2. Involve students in discussions in which students communicate claims and evidence from investigations	*2.12*	*3.33*	*1.204*	0.79	10.67	48	<.001
3. Implement strategies that provide students with opportunities to explore science concepts before they are explained	*2.02*	*3.33*	*1.31*	0.85	10.80	48	<.001
4. Actively engage involve students in critical analysis and/or problem solving	2.12	3.20	1.08	0.70	10.78	48	<.001
5. Implement teaching methods at an appropriate pace to accommodate differences among my students	2.17	3.21	1.04	0.77	9.36	47	<.001

Table 14

Paired Samples t-test of Self-Efficacy Survey: Orientations

	Before (Pre)	**After (Post)**	**Mean Difference (Post-Pre)**	**SD**	**t**	**df**	***p***
6. Effectively plan engaging science lessons that develop student understanding	*2.33*	*3.51*	*1.184*	0.67	12.42	48	<.001
7. Provide opportunities for students to learn science through exploring ideas or problems	2.16	3.30	1.142	0.71	11.31	48	<.001
8. Communicate to students ways that the content is relevant to their lives	*2.16*	*3.37*	*1.20*	0.74	11.46	48	<.001
9. Communicate to students the purpose and/or importance of learning tasks	2.29	3.29	1.00	0.65	10.84	48	<.001
10. Communicate to students the specific outcomes of the lesson	2.16	3.20	1.041	0.73	9.92	48	<.001

Table 15

Paired Samples t-test of Self-Efficacy Survey: Content Knowledge

	Before (Pre)	**After (Post)**	**Mean Difference (Post-Pre)**	**SD**	**t**	**df**	***p***
11. Communicate to students content knowledge that is accurate and logical	2.18	3.27	1.08	0.64	11.83	48	<.001
12. Provide opportunities for students to learn at more than one cognitive level	2.06	3.02	0.96	0.76	8.80	48	<.001
13. Understand concepts well enough to be effective in teaching elementary science	2.39	3.55	1.163	0.72	11.35	48	<.001

Table 16

Paired Samples t-test of Self-Efficacy Survey: Knowledge of Students

	Before (Pre)	**After (Post)**	**Mean Difference (Post-Pre)**	**SD**	**t**	**df**	***p***
14. Motivate students to perform at their fullest potential in science	2.39	3.33	0.94	0.75	8.79	48	<.001
15. Clarify student misunderstandings or difficulties in learning science concepts	*1.88*	*3.31*	*1.43*	0.76	13.09	48	<.001
16. Adjust teaching and learning activities as needed in order to develop student understanding	2.22	3.20	0.98	0.69	9.91	48	<.001
17. Present ideas that challenge students' thinking about science	*2.08*	*3.25*	*1.16*	0.75	10.92	48	<.001
18. Ask a variety of questions throughout the lesson to engage students in higher order thinking	2.25	3.31	1.06	0.89	8.26	48	<.001
19. Provide students with specific feedback about their learning	2.08	3.10	1.02	0.78	9.19	48	<.001

Table 17

Paired Samples t-test of Self-Efficacy Survey: Assessment Knowledge

	Before (Pre)	**After (Post)**	**Mean Difference (Post-Pre)**	**SD**	**t**	**df**	***p***
20. Provide students with suggestions for improving learning	2.08	3.08	1.00	0.764	9.17	48	<.001
21. Use formative assessments to find out more about student ideas about science	2.02	3.12	1.10	0.82	9.38	48	<.001
22. Use assessments to inform planning and instructional decisions	2.18	3.20	1.02	1.07	6.67	48	<.001
23. Use a variety of types of assessments (journals, student presentations, lab reports)	*2.08*	*3.32*	*1.25*	1.23	7.06	48	<.001

Table 18

Paired Samples t-test of Self-Efficacy Survey: Curricular Knowledge

	Before (Pre)	**After (Post)**	**Mean Difference (Post-Pre)**	**SD**	**t**	**df**	***p***
24. Integrate science with other subjects	2.14	3.20	1.06	0.80	9.27	48	<.001
25. Use knowledge of the vertical alignment of the curriculum to make connections to content taught at other grade levels	*1.71*	*3.10*	*1.39*	0.84	11.60	48	<.001
26. Implementing standards based instruction	*2.61*	*3.49*	*0.88*	0.69	8.82	48	<.001
27. Adjust teaching and learning activities as needed	2.39	3.29	0.89	0.68	9.18	48	<.001

Table 19

Paired Samples t-test of Self-Efficacy Survey: Pedagogical Knowledge

	Before (Pre)	**After (Post)**	**Mean Difference (Post-Pre)**	**SD**	**t**	**df**	***p***
28. Maintain a classroom environment in which students work cooperatively	2.61	3.35	0.73	0.78	6.55	48	<.001
29. Effectively manage routines and procedures for learning tasks	2.59	3.33	0.73	0.70	7.34	48	<.001
30. Monitor students' involvement during learning tasks	2.63	3.31	0.67	0.72	6.56	48	<.001

The items were sorted and organized in three ways: the areas teachers felt the most efficacious before the endorsement, following the endorsement, and the items that had the highest mean difference between pre and post. Table 20 contains the ten indicators that received the highest efficacy ratings before and after the endorsement and the indicators with the highest mean difference.

Table 20

Most Efficacious Ratings Before and After the Endorsement

Before the Endorsement	After the Endorsement	Highest Mean Difference
30. Monitor students' involvement during learning tasks	13. Understand concepts well enough to be effective in teaching elementary science	15. Clarify student misunderstandings or difficulties in learning science concepts
26. Implementing standards based instruction	6. Effectively plan engaging science lessons that develop student understanding	25. Use knowledge of the vertical alignment of the curriculum to make connections to content taught at other grade levels
28. Maintain a classroom environment in which students work cooperatively	26. Implementing standards based instruction	3. Implementing strategies that provide students with opportunities to explore science concepts before they are explained
29. Effectively manage routines and procedures for learning tasks	8. Communicate to students ways that the content is relevant to their lives	23. Use a variety of types of assessments (journals, student presentations, lab reports).
13. Understand concepts well enough to be effective in teaching elementary science	28. Maintain a classroom environment in which students work cooperatively	8. Communicate to students ways that the content is relevant to their lives
27. Adjust teaching and learning activities as needed	29. Effectively manage routines and procedures for learning tasks	2. Involve students in discussions in which students communicate claims and evidence from investigations
6. Effectively plan engaging science lessons that develop student understanding	14. Motivate students to perform at their fullest potential in science	1. Implement inquiry based instructional strategies for the purpose of designing investigations, collecting evidence and making claims
9. Communicate to students the purpose and/or importance of learning tasks	23. Use a variety of types of assessments (journals, student presentations, lab reports)	17. Present ideas that challenge students' thinking
18. Ask a variety of questions throughout the lesson to engage students in higher order thinking	2. Involve students in discussions in which students communicate claims and evidence from investigations	

Before the endorsement, participants reported the most efficacious scores on the items (28, 29, & 30) which were categorized as Pedagogical Knowledge, and (26, 27) both categorized as Curricular Knowledge. Banilower et al., (2012) reported 72% of elementary teachers reported they felt very well prepared to "manage classroom discipline", but only 25% felt very well prepared to "encourage students' interest in science and/or engineering " (p. 28). The items with the least efficacious scores before the endorsement were 25, 15, and 5. These items were related to vertical alignment of the curriculum, clarifying student misunderstandings, and allow students to explore concepts before explaining.

The most efficacious scores reported after the endorsement were related to understanding science well enough to teach elementary students, suggesting the influence of the endorsement on the content knowledge of participants. Planning engaging science lessons received the second highest efficacy rating, suggesting the cycle of developing, implementing, and reflecting on lessons influenced the participants' confidence in their ability to develop lessons to engage their students in science. This may have also influenced their confidence in developing standards based units. The endorsement included a focus on the vertical alignment of standards across the K-12 grade bands. Participants also reported high efficacy in pedagogical knowledge items of maintaining a cooperative learning environment and class routines. Participants also reported feeling efficacious for motivating students in science as well as using journals. Using claims and evidence with students was also indicated as an area in which they felt a high degree of efficacy. Participants maintained their own journals throughout the endorsement.

Perhaps even more telling are the mean differences between pre and post efficacy scores. The items with the highest mean difference were related to clarifying student misunderstandings, using vertical alignment to make content connections, exploring before explaining, using a variety of assessment, communicating ways science is relevant to their lives, and communicating claims and evidence. The items with the smallest mean difference were related to pedagogy and curriculum (30, 28, 29, 26, and 27). These included monitoring students, maintaining a cooperative environment, managing routines, and implementing standards based instruction.

Based on these data, teachers reported higher efficacy in pedagogy (28, 29, 30) before the endorsement and shifted towards higher efficacy in science instructional strategies (1, 2, 3), understanding students conception in science (13, 14, 15, 17), and assessment knowledge (23, 25) after the endorsement. This was also seen in a high degree of efficacy towards reform orientations in items 6 and 8. This suggests the endorsement influence on their confidence to enact a variety of reform-oriented constructs after their participation in the endorsement. These data will be merged with observation and interview data to see if these items are enacting in the classrooms of participants. This will be discussed in Chapter 5.

Dimensions of Professional Knowledge. As described in Chapter 3, the self-efficacy retrospective survey questions were organized into dimensions of professional knowledge that influence a teacher's enactment of PCK within the context of their classrooms (Gess-Newsome & Carlson, 2013a). Within these dimensions are Teacher Professional Knowledge Bases (TPKB), Topic Specific Knowledge Bases (TSKB) and amplifiers and filters of the knowledge bases such as Orientations. The TPKB are Assessment Knowledge (AK), Pedagogical Knowledge (PK), Content Knowledge (CK), Knowledge of Students (KS), and Curricular Knowledge (KC). The TPKB inform Topic Specific Knowledge Bases such as Knowledge of Instructional Strategies (KIS). Paired sample t-tests were conducted on the self-efficacy survey dimensions and are shown in Table 21. There were significant differences in pre and post categories of the dimensions of professional knowledge bases.

Table 21

t-test of SE Dimensions of Professional Knowledge Before and After the Endorsement

	After	Before	Mean Difference	SD	t	df	*p*
Instructional Strategies	3.26	2.10	1.17	.59	13.47	47	<.001
Orientations	3.34	2.22	1.12	.54	14.32	47	<.001
Content Knowledge	3.28	2.22	1.06	.53	13.86	47	<.001
Student Conceptions	3.28	2.17	1.12	.61	12.62	47	<.001
Assessment	3.16	2.10	1.06	.77	9.56	47	<.001
Curriculum	3.28	2.22	1.06	.60	12.17	47	<.001
Pedagogy	3.33	2.62	1.17	.59	13.48	47	<.001
SE Total	3.27	2.21	1.06	.52	14.07	47	<.001

Research Question Three.

How does a K-5 science endorsement influence the degree of connection of the professional knowledge bases of elementary science teachers?

Multiple types of data were collected and analyzed to answer this research question. These include the self-efficacy survey data, demographic and experience survey data, observation data, and interview data of participants. The first is a series of multiple regression analysis of the survey data followed by case summaries of six participants.

Quantitative Data: Exploratory Model Building. Multiple regression analyses using stepwise function were conducted to explore the relationships among the dimensions of professional knowledge represented in the survey. Prior to the multiple regression analysis, correlations among the dimensions of professional knowledge and pre, post and mean differences of content assessments. Statistically significant correlations were found among the dimensions of professional knowledge and are presented in Table 22.

Table 22

Correlations of the Dimensions of Professional Knowledge on the SE Survey

Measure	1	2	3	4	5	6	7	M	SD
1. KIS	-							3.26	.599
2. O	.893**	-						3.34	.54
3. CK	.647**	.724**	-					3.28	.53
4. KS	.762**	.786**	.818**	-	.			3.28	.61
5. AK	.789**	.684**	.642**	.746**	-			3.16	.77
6. KC	.775**	.899**	.730**	.786**	.702**	-		3.28	.60
7. PK	.682**	.710**	.576**	.674**	.641**	.627**	-	3.33	.59

**. Correlation is significant at the 0.01 level (2-tailed)

Correlations among all the dimensions of professional knowledge were significant at the 0.01 alpha level. In order to further explore these relationships, multiple regressions analyses were conducted. Each dimension of professional knowledge was entered individually as a dependent or outcome variable (Y) with the six other dimensions entered as predictor variables (X). The stepwise regression function in SPSS looks for the best combination of predictors that correlate to the dependent (outcome) variable (Fields, 2009). SPSS produces a Multiple R which is the correlation between the observed Y values and the values of Y predicted by the multiple regression model. R^2 is the variation of Y explained by X and is often reported as the percentage that can be explained from the relationship (Field, 2009). Table 23 presents the results of the model with each dimension listed as the dependent variable and the predictors presented from the model with corresponding R^2 values.

Table 23

Multiple Regression Model of SE Survey Post Results

Dependent Variable (Y)	Predictors Presented in the Model (X)	R	R^2	df	F	Beta	*p*
Instructional Strategy	Orientations	.893	.797	47	180.756	.893	<.001
Content Knowledge	Student Conceptions	.840	.705	47	100.468	.840	<.001
Student Conceptions	CK & Instructional St (Model 2)	.873	.762	47	92.955	.599 .399	<.001
Curriculum	Orientations & Student Conceptions (Model 2)	.839	.704	47	53.544	.475 .413	<.001
Assessment	Students	.746	.557	46	57.783	.746	<.001
Pedagogy	Orientations & Assessment (Model 2)	.741	.549	45	27.362	.510 .292	<.001

Instructional strategies had a significant ($p < .001$) zero-order correlation with orientations. Based on the regression value ($R^2 = .797$, F (1, 46) = 180.756, $p < .001$) for the proposed model, we conclude that 79.7% of the variability in the outcome is accounted for by knowledge of instructional strategies. This suggests evidence of the importance of instructional strategies in informing teaching orientations. The relationship between the two seem logical since the use of reform oriented instructional strategies would have the potential to influence a reform oriented teaching orientation. Knowing this, professional development activities that focus on reform oriented instructional strategies might consider incorporating the development of teacher orientations. Park and Chen (2012) found links between orientations and knowledge of instructional strategies representations when mapping PCK episodes of teaching. From their observations of secondary biology teachers, they found a didactic orientation influenced the use of reform oriented instructional strategies and inhibited connections to other categories of PCK. Entering Instructional Strategies as the dependent variable found Orientations to account for 80% of the variability in the model. This suggests further support of the relationship between instructional strategies and orientations.

When Content Knowledge was entered as the dependent variable, Knowledge of Student Conceptions was found to account for 70% of the variance. When Knowledge of Student Conceptions was entered as the dependent variable, Content Knowledge and Knowledge of Instructional Strategies was found to account for 79% of the variance between the variables. This suggests evidence of the relationship between a teacher's content knowledge and their understanding of how students think about science concepts. It is important for teachers to understand common student misconceptions in science. Studies have shown that elementary teachers sometimes have misconceptions that are similar to that of their students (Smith & Neal, 1989). The endorsement focused on developing science content and understanding student misconceptions. This was done through the use of the series of *Uncovering Student Ideas in Science* formative assessment probes (Keeley, Eberle, & Farrin, 2005; Keeley, Eberle, &Tugel, 2007; Keeley, Eberle, & Dorsey, 2008; Keeley & Tugel, 2009). This suggests that the focus on student misconceptions may have enhanced the content knowledge of the participants and their understanding of how students think about science concepts. Park and Chen (2012) found knowledge of instructional strategies and knowledge of students were frequently integrated during the observations of high school biology teachers. This study suggests a relationship between elementary teachers' content knowledge, understanding of student conceptions in science, and knowledge of instructional strategies. This provides support for professional development that includes topic-specific instructional strategies combined with a focus on topic-specific student misconceptions.

When Curriculum was entered as the dependent variable, two models were presented. The first model included only Orientations and the second included both Orientations and Knowledge of Student Conceptions. Together, they accounted for 70% of the variance between the variables. This suggests a focus on enhancing curricular knowledge may have an influence on orientations. Two of the projects in the endorsement focused on developing lessons that integrated science with other subjects and understanding the vertical alignment of the standards.

Two models did not demonstrate as strong of a relationship as the ones presented previously. When Assessment Knowledge was entered as the dependent variable, Knowledge of Student Conceptions in Science accounted for 57% of the variance. It does provide support for a relationship between assessment knowledge and understanding students. When Pedagogical Knowledge was entered as the dependent variable, Orientations and Assessment Knowledge accounted for 55% of the variance.

Regression models were also conducted on the retrospective self-efficacy pretest, but the relationships were not as strong. Orientations were again the predictor for Instructional Strategy, but only accounted for 52.1% of the variance. Three models for orientations were presented for Orientations. Curriculum and Instructional Strategies together accounted for 66% of the variance. Student conceptions were again the predictor for content knowledge accounting for 52.4% of the variance. Curriculum and subject matter knowledge were the predictors for student conceptions accounting for 65.3% of the variance. Student conceptions again were the predictor for assessment accounting for 49.7% of the variance. Orientations, pedagogy and student conceptions were the predictors for curriculum accounting for 78.1% of the variance. Curriculum was the predictor for pedagogy accounting for 53.2% of the variance.

In summary, the purpose of the multiple regression analyses was to explore the relationship among the dimensions of professional knowledge measured in the self-efficacy survey. There were higher degrees of connections among the dimensions following the endorsement suggesting professional development may strengthen connections among these dimensions of knowledge. The self-efficacy items represented reform-oriented strategies, orientations, and assessments. This data suggests that enhancing the confidence across multiple dimensions strengthens an elementary teachers' confidence to teach science in a reform-oriented manner. The three dimensions represented in the model that showed the most connections were Knowledge of Student Conceptions, Orientations, and Knowledge of Instructional Strategies. This could have implications for professional development and will be explored further in Chapter 5. It should be noted that this is an exploratory model of the relationships and data from participant observations will be used to further explore the relationships.

Quantitative Data: Observations

Six participants were observed following the endorsement. Four of the participants were observed teaching three times, and two of the participants were observed teaching twice. Three instruments were used to collect observation data of participants. The Reformed Teaching Observation Protocol or RTOP (Sawada et al., 2000, 2002) which indicates the degree to which a lesson is reform oriented. The Professional Assessment and Comprehensive Evaluation System (PACES) and the Process Oriented Guided Inquiry Learning (POGIL) were also used to look for evidence of instructional practices (Ellett, 2009). Because the self-efficacy survey results were reported for the group of participants, observation results are also reported for the group as whole. A mean score of each indicator of each instrument was calculated.

The three instruments were used to measure various indicators of professional knowledge. The RTOP is an instrument that measures the degree to which a lesson is reform-oriented. The PACES includes various instructional practices, and the POGIL includes indicators of an inquiry oriented lesson. The PACES and POGIL were rated on a scale of 1-3. A rating of 1 indicated the indicators were not observed; a 2 indicated the indicator was somewhat observed; and a 3 indicated the indicator was observed. The mean was calculated across the 16 observations of the six participants. Table 24 includes the means of the PACES indicators with the highest score.

Table 24

PACES Indicators with the Highest Means

Indicator	M	SD
Students were actively engaged and/or involved in developing concepts.	3.00	0.00
Students were actively engaged and/or involved in developing principles, rules, and/or generalizations.	2.63	0.72
A variety of questions that enable thinking were asked and/or solicited.	2.63	0.72
Students were actively engaged and/or involved in developing associations.	2.56	0.73
Students were actively engaged and/or involved and encouraged to generate and think about examples from their own experiences.	2.56	0.73

All 16 lessons observed in involved students being actively engaged in concepts. Engaging students actively in developing principles, asking a variety of questions, and developing associations were frequently seen in the classes observed. The indicators that were observed the least frequently (2 or less) were involving students in creative thinking (1.5), extending learning to different context (1.8), mental imagery (1.9), problem solving (2), and reflective thinking (2). This suggests a focus across lessons on developing science concepts by through questioning strategies, and making associations, but not on problem solving and extending learning.

Table 25 includes the means of the POGIL indicators with the highest means.

Table 25

POGIL Indicators with the Highest Means

Indicator	**M**	**SD**
Students used specially guided inquiry materials that included data/information and leading questions.	2.63	0.62
The teacher made regular assessments of student learning during the class.	2.63	0.72
Students were provided with opportunities at the close of investigations to review and reflect on what they had learned.	2.56	0.73
Students were part of an interactive learning community.	2.44	0.73
Guided inquiry activities allowed students to construct their own understandings.	2.44	0.73

A review of the POGIL data across the observations indicates participants were frequently involving students through guided inquiry approaches. The classes observed also included students being involved in a learning community. The students were less likely to be involved in designing their own investigations (1.69), logical thinking and teamwork (1.88), and students working together to come to consensus about what was learned (1.94). Collectively, these lessons were more teacher-centered than student centered. A few of the individual lesson were more student-centered, but overall there was a higher degree of teacher control than student control.

The RTOP indicators are measured on a scale of 0-4 with 0 indicating the indicator was not observed and a 4 indicating very descriptive. Table 26 has the RTOP indicators across the 16 observations.

Table 26

Means of RTOP Indicators

RTOP Indicators	Mean	SD
Students were involved in the communication of their ideas using a variety of means and media.	2.67	0.82
The lesson involved fundamental concepts of the subject.	2.53	0.99
In general the teacher was patient with students.	2.47	0.74
The instructional strategies and activities respected students' prior knowledge and the preconceptions inherent therein.	2.27	0.88
There was a climate of respect for what others had to say.	2.20	0.86
The lesson was designed to engage students as members of a learning community.	2.13	1.06
Students used a variety of means (models, drawings, graphs, symbols, concrete materials, manipulatives, etc.) to represent phenomena.	2.00	0.93
The teacher had a solid grasp of the subject matter content inherent in the lesson.	1.93	0.96
Connections with other content disciplines and/or real world phenomena were explored and valued.	1.93	1.16
The lesson promoted strongly coherent conceptual understanding.	1.80	0.86
The teacher's questions triggered divergent modes of thinking.	1.80	1.08
Active participation of students was encouraged and valued.	1.80	1.01
Elements of abstraction (i.e., symbolic representations, theory building) were encouraged when it was important to do so.	1.67	0.82
Students were actively engaged in thought-provoking activity that often involved critical assessment of procedures.	1.60	0.99
Intellectual rigor, constructive criticism, and the challenging of ideas were valued.	1.60	0.99
The metaphor "teacher as listener" was very characteristic of this classroom.	1.60	0.83
The focus and direction of the lesson was often determined by ideas originating with students.	1.53	1.30
There was a high proportion of student talk and a significant amount of it occurred between and among students.	1.53	1.06
Students were encouraged to generate conjectures, alternative solution strategies, and/or different ways of interpreting evidence.	1.53	0.99
In this lesson, student exploration preceded formal presentation.	1.47	1.19
Student questions and comments often determine the focus and direction of classroom discourse.	1.33	0.98
The teacher acted as a resource person, working to support and enhance student investigations.	1.33	1.11
Students were reflective about their learning.	1.27	0.88

This lesson encouraged students to seek and value alternative modes of investigation or of problem solving.	1.07	0.88
Students made predictions, estimations and/or hypotheses and devised means for testing them.	1.07	1.16

Consistent with the PACES and POGIL, the participants created a positive learning environment and developed essential concepts. The students communicated their ideas using a variety means and were engaged in grade level appropriate strategies. The lowest scores on the RTOP included students making predictions, estimations and/or hypotheses and devising means for testing them (1.07); lessons that encouraged students to seek and value alternative modes of investigation or of problem solving (1.07); lessons in which students were reflective about their learning (1.27), and student questions, comments often determine the focus and direction of classroom discourse (1.33), and the teacher acted as a resource person to support student investigation (1.33).

The mean RTOP score of the 16 observations was a 47.44. The range of lessons observed were 21 to 95 indicating a wide degree of differences in the lessons. A score of 50 is considered to be reform-oriented for middle school teachers (Sawada et al., 2002). When comparing the mean scores of the RTOP categories, Propositional Knowledge and Classroom Culture had means of 9.87 and 9.53, respectively. Propositional Knowledge included fundamental concepts, content knowledge and conceptual understanding. Classroom Culture included respect for what other have to say and students communicating their ideas through different media. A few of the indicators within this category, specially the high degree of student talk and students determining the direction of the discussion were not seen across all of the observations. Procedural Knowledge had the lowest mean at 7.53. Procedural Knowledge includes students making predictions, devising test, engaging in critical assessment and reflection. These results are consistent with the findings of Choi and Ramsey (2009) who compared the RTOP scores of 16 inservice elementary teachers following a three hour science methods course. They also found Student-Teacher Relationships and Classroom Culture to have the highest means and procedural knowledge to have the lowest. It is interesting to note when developing the RTOP, Sawada et al. (2009) divided PCK into two types of knowledge, propositional and procedural. Few studies were found that reported the RTOP scores of inservice elementary teachers. These data suggests that elementary teachers, who have participated in a science endorsement, demonstrate effective pedagogical knowledge, are able to develop science concepts conceptually, but demonstrate emerging use of reform strategies. It should be noted there was a wide degree of variability in the lessons resulting in wide degree of variation in RTOP scores. Participants were observed two to three times within a unit and the particular lessons observed were a snapshot in the teaching practices of the teachers. A limitation of this study is that the teachers were observed during only one unit. An idea for a future study would be to observe these teachers across multiple units.

The self-efficacy survey provided evidence of confidence to enact reform-oriented, student-centered strategies. In contrast, the lessons observed provided evidence of an emerging enactment of reform-oriented strategies. Most of the lessons were teacher-centered with a focus on creating a positive learning environment, and engaging students in structured or guided inquiry lesson. To further explore the dynamics involved, case summaries will be presented to take a deeper look at the influence of the endorsement on six participants.

Qualitative Data: Case Summaries

Six endorsement participants were observed and interviewed following their completion of the endorsement requirements. Four of the participants, Clara, Meredith, Callie, and Emily were observed three times. Two of the participants, Margaret and Christina were observed twice.

Three of the participants, Clara, Meredith, and Emily were interviewed twice. Christina and Margaret were interviewed once. Logistics in scheduling accounts for the variation. In this next section, case studies of the participants will be presented. Three of the participants, Clara, Margaret, and Emily will be presented in depth. These three participants were in three different cohorts and taught by three different instructors. The instructors were exemplary middle and high school teachers many of whom have leadership roles such as assistant principals and science coaches in their districts. These three teachers demonstrated the highest degree of reform among the participants in the lessons observed. Meredith, Callie, and Christina will be presented in abbreviated cases.

Multiple types of data were used to present cases demonstrating evidence of the use of and integration of their professional knowledge bases. The data analyzed were interviews, observations, and review of the participants'endorsement portfolio. Additional documents such as instructor observations were added to support the development of the case. Each case contains a quote that stood out in an interview. The participants' background and classroom context will be described at the beginning of the case, followed by a summary of the dimensions of knowledge and how those knowledge bases were integrated during enactment of PCK when teaching science topics. A demographic data table of the participants can be found in Chapter 3.

Clara

"Science is scary sometimes, you know, especially like I said, we're not scientists. We're elementary science teachers"

Clara has been teaching elementary science for 23 years. She teaches 4th grade science and mathematics at a magnet school. She completed the K-5 science endorsement in 2012 and was observed and interviewed one year after the completion of the endorsement. She has taught at the upper elementary grade bands of grades 3 – 5. She has a Master's degree and has earned both the K-5 science and mathematics endorsement on her teaching certificate. In the interview, Clara described herself as a “PD junkie” and seeks opportunities to enhance herself as a teacher. She enrolled in the K-5 science endorsement because she “wanted to be a better science teacher”. She wants her students to love science, and she wants to make sure her students do not lose interest in science. She has participated in other professional development within the past five years including a Mathematic Science Partnership (MSP) grant with a local university and a special summer academy for elementary mathematics and science teachers.

The constraints Clara faces as an elementary teacher vary, but do not seem to have a negative impact on teaching. In the interview she reported that she was an elementary education major and had only taken only one science class in her educator preparation program. She referred to that class as “kind of a Mickey Mouse physics. She said that she has had to learn science by herself. This effort is very apparent by the varied types of professional development she has been involved in. In the interview, she said time would have been a constraint for her in the past, but she is fortunate to be in a school where she can teach science everyday for 50-60 minutes.

Classroom Context. The observations occurred during the first class period of the morning. The students entered the classroom wearing uniforms. The uniforms are several different colors of polo shirts with their school mascot embroidered on them. There were between 26 and 28 students in the class depending on the day. The student sat at tables in groups of four to six students. At the beginning of the school day, students are sitting at tables some reading others finishing breakfast. Each day begins with the pledge of allegiance and morning announcements. The period began with a community building activity following the morning announcements. For example, the second observation included an active listening experience which began with the students sharing a weather story at the same time for 30 seconds. She led them into a discussion about listening skills. There was a different community building activity each day.

The essential question is written on the dry erase board in front of the room. On the left side wall, there is a file cabinet, cabinet with sink, a cabinet with a class pet (lizard) and a bird clock that chirps different bird calls on the hour. In the back of the room, there is a closet with a class set of laptop computers and another closet for book bags. One of the doors has a shoe rack with a class set of calculators and another with earphones for the computers. A screen is pulled down in front of the center of the dry erase board. An LCD projector hangs from the ceiling and projects on the dry erase board. There is a bulletin board on the right side which includes class rules.

Clara also has access to a 4th grade science lab in another building. The students have to walk out of their classroom, through a courtyard to the science lab. The science lab is enormous – probably the size of two classrooms. There are 8- 10 science lab tables each with 4 student desks. In the front of the room, there is a computer in the left corner, a dry erase board, screen and LCD projector mounted on the wall. Behind me on the right side of the room (facing the front) are several round tables with a class set of weather materials. There is a refrigerator, a wall of cabinets, a sink, bookshelves and science supplies. The laboratory is stocked with materials donated by a local business.

Clara was observed for three days within a weather unit. One the first day, students were engaged in collecting weather data. They used a Beaufort scale chart, a weather vane, cloud chart and thermometer to collect weather data in the schoolyard. As a part of the unit, students maintained a weather journal. Each day, they obtained weather information from the Weather

Bug website. The students kept records and they were asked to predict the weather for the next day. Table 27 provides a summary of the lesson observed, RTOP score, and highlights aspects of knowledge bases observed.

Table 27

Summary of Clara's Lessons

Topic	Instructional Strategies	Assessment Knowledge	Pedagogical Knowledge	RTOP Score
Weather data collection	Guided inquiry Journaling		Transition to Labs Routines 5, 4, 3, 2, 1	31
Air Pressure Demonstrations	Models (implicit) Multiple Representations Journaling	Use of Wonderings	Transition to Labs Routines 5, 4, 3, 2, 1	50
Weather fronts	Models (implicit) Multiple Representations Journaling	Ticket out the Door A & D Statements	Transition to Labs Routines 5, 4, 3, 2, 1	30

Orientations. Magnusson et al. (1999) describe the PCK component of orientations towards teaching science as the "…teachers' knowledge and beliefs about the purposes and goals for teaching science at a particular grade level" and further elaborate "…these knowledge and beliefs serve as a 'conceptual map' that guides instructional decisions" (p. 97). Friedrichsen et al. (2011) organized orientations into two categories, teacher-centered and student-centered/reform-oriented. *Didactic* and *academic rigor* (verifying challenging problems) was considered teaching centered. *Process, activity,* and *discovery* oriented represent the reforms of the 60's and 70's. *Inquiry, guided inquiry, problem-based* and *conceptual understanding* orientations represent current reforms. Schneider and Plasman (2011) identified three components of teaching orientations: “purposes and goals for teaching science, the nature of science, and the nature of teaching learning science for students” (p. 538).

Goals and Purposes for Teaching. In the first interview, Clara describes her goals and purposes for teaching:

> I want them to discover science. I want them to learn through discovery. I think they're going to own the material more. I think they're going to understand it more. My lab is not a quiet place. It’s a noisy, messy, sometimes very it looks confusing if you don't know what's going on. It's sort of like organized chaos. But, that's how I want them to learn, because I think that's the best way for them to learn. I learn something new from them every day too, and that's a goal of mine too. Is for me to be really good at whatever it is that I'm teaching.

From her description in the interview, Clara appears to align with a discovery orientation. Two parts of this quote are particularly telling. First, is her belief of the importance of students owning the material. She emphasized the use of hands-on, discovery, wonderings, and discovery science throughout the interview. The lessons observed were primarily teacher directed with a focus on student discovery or confirming science principles. Students were involved in collecting weather data outside in the schoolyard on the first day, watching demonstrations of air pressure on the second day, and watching videos about weather fronts on the third. Her RTOP scores were 31, 50, and 30, respectively. These scores indicate a lower degree of reform although observations and interview provide a different picture. The RTOP scores are based on a scale of 0 to 100 with above 50 indicating the use of reform-oriented practices. The lessons had a standards-based focus and included essential questions developed by the teacher and shared with students at the beginning of each day. There was a high degree of teacher talk in the lessons observed. The students were using tools to collect and record weather data on the first day; she was conducting demonstrations related to air pressure on the second day; and the students were observing videos modeling weather fronts on the third day. The lessons were primarily teacher-centered with the students engaged in teacher-directed demonstrations (air pressure/weather fronts), and structured inquiry (weather instruments).

Another example of a discovery orientation can be found in a portfolio reflection written during the endorsement. In the reflection she describes an activity on weather fronts:

> This lesson starts out as a "cookbook" lesson. I instructed students to combine hot red water and cold blue water and observe what happens. This lesson went well. The students worked in groups of 4. The great thing about lessons like this, even though I have to give specific directions on what to do, the students still have to discover the answers from their observations. In this experiment, the hot water stays on top of the cold water. As the students were drawing the diagram in their journals, I heard one group talking about how hot air rises. "You know, like it is always hotter upstairs during the summer." They were making connections. Essentially, I gave them the tools to discover their learning.

Unit planning. Unit plans can provide insight to orientations (Beyer & Davis, 2012). She shared an example of a teaching unit which exemplifies her ideals of teaching during the first interview. The unit included opportunities for her students to conduct motion experiments and then write their own laws of motion based upon their data. She purports "I want them to experience; I want them to come up with the concepts. I want them to write the rules. Because they'll get it, even in fourth grade." She describes her students as high achievers and asserts they "want more than reading in a book and answering questions." These ideas suggest support for an emerging inquiry orientation. Friedrichsen, et al. (2011) purport teachers may have more than one orientation at a time.

A review of lesson plans in her endorsement portfolio includes the lesson plans mentioned in the interview. The use of the 5E model (Bybee, 1997) and structured inquiry experiences were evident in the lessons developed for the endorsement vertical alignment assignment. For this assignment, she developed force and motion lessons for second and fourth grade. In a second grade lesson on friction, the Explore was for students to collect data from an experiment in which they hit a tennis ball with a device called a "Whacker." The Whacker enabled the students to exert a similar force on the tennis ball as it rolled across different surfaces. The Explain section includes an opportunity for students to review their data and to discuss misconceptions that students might have. (IAN represents InterActive Notebook)

Explain:

After all groups test all surfaces, bring the class back together.

Ask students to look at their data and discuss what they observed. Write a sentence explaining observation under *What Happened* in IAN.

This is the point that misconceptions will be addressed. Talk about why the ball slowed down and stopped. Talk about friction – which surfaces had more friction?

Pedagogical Knowledge. Clara's strong pedagogical knowledge was evident in all lessons observed. There were clear classroom routines observed in transitioning to a science lab and keeping journals. She created a positive classroom environment. This was evidenced by constantly praising students who were exhibiting desired behaviors (standing in line without talking, following directions, etc). Clara complimented students that were demonstrating appropriate behavior by saying: "I like the way [student] is following directions. This occurred frequently and seemed to be done instead of “calling out” students that are not exhibiting appropriate behavior. She also had routines to get students attention such as “if you can hear me, look at me” and “5, 4, 3, 2, 1, eyes on me”.

Her strong pedagogical knowledge and enthusiasm for teaching science seem to provide a foundation for teaching orientations and selection of instructional strategies. This was seen through the use of notebooks to keep records of class activities.

Linking Orientations to Knowledge of Instructional Strategies. There were links between her teaching orientation and her use of instructional strategies. She utilized reform-oriented instructional strategies through the use of student journals, the use of implicit models and multiple representations to develop science concepts. Her self-described “inquiry and discovery” orientation guided the selection of instructional strategies.

She implicitly used nature of science ideas. This was evident through her use of models. She referenced water cycle models from previous lessons and conducted demonstrations to model air pressure and weather fronts. With her guidance, students maintained journals to keep track of their work as well as their wonderings. On several occasions she asked students “what’s your evidence” and required them to use evidence based answers. Towards the end of a class period she said:

> I am going to let you think about your wonderings for a second. I know some of you have wonderings. You should use lots of details to describe. As scientists, I want you to label so when we go back, you will remember water was warm in the tub.

She also made her thinking visible to students when she talked about wonderings she had. An example of one of her wonderings was why a demonstration didn’t work.

Knowledge of Instructional Strategies. Her science instructional strategies during the weather unit were varied and relevant to the development of the concepts. She used models to develop concepts related to air pressure. These included demonstrations of air pressure and videos modeling weather fronts. She also used journals as a place for students to keep track of data, notes, and their wonderings. She said she was deliberate about connecting student activities to the standards.

Instructional Strategy: Modeling. She used several models to develop student understanding; although she was not explicit about the use of models. In addition to the air pressure demonstrations which were used to model air pressure, she used video clips that modeled the movement of air during weather fronts. She also had students act out expanding and contracting air by moving their arms. She physically engaged them in standing up and expanding their arms out to indicate expansion of warm air. They also moved their arms inward to indicate contracting cold air.

Instructional Strategy: Journaling. Each day, the students kept a journal that included a record of the day's lessons, but also focused on their wonderings about science. The journal seemed to have multiple purposes. The journals were used to keep a record of the class activities and data from observations such as the daily weather. She also included wonderings which were a record of student thoughts about what they were learning throughout the year. She encouraged them to write down their ideas and thoughts about the class activity as a way to keep a log for potential science fair projects. In the interview she mentioned the endorsement brought journaling to the forefront as she experienced journaling as a student. It helped her realize her students needed to do this too.

Instructional Strategy: Multiple Representations. She used multiple representations to engage students in developing weather concepts. This was evident by the use of journals to keep track of weather data for an extended period of time, collecting weather data using instruments, demonstrations of air pressure, interpreting a weather map, and videos that modeled weather fronts.

Linking Instructional Strategies & Content Knowledge. The instructional strategies selected were used to develop student understanding of the science content. Her own understanding of the content, however, impacted her ability to fully utilize the demonstrations to development student understanding. Overall, she demonstrated a sophisticated level of content knowledge for teaching fourth grade science. The demonstrations, however, were teacher-centered with her explaining the concepts without much input from students. For example in the 15 pounds of pressure demonstration, she turned the cup upside down and asked the students what was happening. Their ideas included “you are making a vacuum,” “water is sticky,” “water doesn’t like to let go of things”. She reminded them they had talked about the adhesive and cohesive properties of water. Those are sophisticated ideas for fourth grade students. She went on to explain the demonstration was an example of evidence of air pressure acting on all sides of the cup.

Two of the demonstrations contained some evidence of confusing the concepts of molecular motion and the concept of air pressure. The lessons engaged students and demonstrated a focus on developing student conceptual understanding of air pressure. She selected four demonstrations to help students develop an understanding: 15 pounds of pressure (filling a cup with water, covering it with an index card then turning it upside down to see the water stays inside the cup), egg in the bottle (putting a lit match in a bottle and placing a hardboiled egg on top of the bottle), covered candle (putting a lit candle in a dish covered in water then putting a jar on top), and putting a blown up balloon in a freezer). With the 15 pounds of air pressure, she accurately identified air pressure as the force that kept the water from spilling out of the cup. She pointed all around the cup and commented that air pressure acted equally on all sides of the cup. This strategy was teacher-centered. In the interview, she purports she wants student to discover the concepts. She did provide an opportunity for them to discover through her demonstration, but she did not try to uncover student misconceptions during the demonstration and address them as discussed in the interview.

Content Knowledge. During the egg in the bottle and covered candle demonstrations, she had challenges getting the demonstrations to work. The egg should have squeezed through the opening of the bottle due to a difference in air pressure on the inside due to cooling and contracting air after the match burns out and on the outside of the bottle. She tried it twice and explained to the students what should have happened when the egg did not move into the bottle. It did move in a little on the second attempt, and became stuck and was not easy to pull out. Her explanation of the phenomena suggested an incomplete understanding of the phenomena observed. She related the movement of the egg to the expansion of air when the match was lit and said the air was “sucked into” the bottle. This was partially accurate in that the air would have expanded due to the heat from the match. It is the cooling of the air after the match burns that would have caused the lower pressure on the inside of the bottle and area of higher pressure on the outside. She did not provide an accurate description of the air pressure difference causing the egg to be pushed into the bottle.

She also explained the difference between expanding air and expanding water during another demonstration. She took a deflated balloon stretched over a bottle out of a freezer. She asked students to predict what happened. She gave an accurate description of the air inside the bottle expanding when the bottle was placed in warm water. She related this to changing the pressure inside the model. The behavior of molecules in a fluid might have been a better explanation. Moving between the concepts of molecular motion and air pressure seemed to be a source of confusion.

Clara described the endorsement as being important in her gaining content knowledge evidenced by a quote, “because of science endorsement and misconceptions, I had some misconceptions that were straightened out and things that I'd be teaching my whole life.” In the second interview she described a time that her instructor, Olivia had observed her teaching a lesson in which it was apparent Clara had a misconception. Clara appreciated Olivia’s honesty when she told her “this is what you know and this is really happening.” She attributed the feedback of her instructor as a source of empowerment. Olivia provided positive feedback, but also provided gentle feedback if they were “off a little bit.”

A follow up question in the interview asked about the factor in the endorsement that had the greatest influence on uncovering her misconceptions. She said it was the way the Olivia delivered the *Uncovering Student Ideas* probes was the primary source. She elaborated:

> She was able to see what I put down on the probe and say ‘okay, let’s talk about this’ and we talked about it together. You know, you process through all of the information through the probes. They were helpful, really, really helpful.

Endorsement instructors are observed once per endorsement course and provided feedback. As the endorsement coordinator, it is my role to observe instructors. In a review of the feedback form of Clara’s instructor, Olivia following a physical science class, I had written following comments:

Class began with an *Uncovering Student Ideas* probes: "Floating logs high and low". In the probe, Sam put a solid ball in the tank of water and it floated 1/2 way in the water. What can he do to get it to sink to the bottom? You asked the participants, what did you choose? As a group, you narrowed it down to C & G. The participants discussed the options and their ideas for each response.

The probe discussion was powerful. You worked with them and modeled a think aloud strategy to go through the answers. You made comments such as:

a - bigger doesn't mean it is denser (but that is a misconception - they think bigger is heavier); same size less dense - would float; you told them size isn't what matters when it comes to density

As with the earth science class I observed, you did a great job deconstructing the answer choices and model for them how students might support those claims and ways to break down the misconceptions – you followed up with "what kind of activities that we could do?"

Clara also claimed the endorsement also influenced her content knowledge through the required online modules from the National Science Teachers Association (NSTA) Learning Center. Participants were required to complete one ten hour module called a SciPack per course. SciPacks are composed of four or five two-hour modules that engaged teachers in science content. Clara said she did not like them at first and that she even had to complete one three times in order to pass the assessment at the end.

Assessment Knowledge. In the interview, Clara mentioned developing a significant understanding of student misconceptions during the endorsement. She talked about the need to find out what students' misconceptions are. She says that she now uses formative assessments to find out what her students know. The increase in formative assessments followed discussions during the endorsement about how to assess students. During the first interview, she claims "I think I have a better understanding of how to do a quick assessment. It doesn't have to be a big long multiple-choice test or anything." She discusses the importance of knowing whether students "got it or not". She elaborates "I need to know whether they understand the material or they don't. You know, do they own it or do they still have questions." She talked about the importance of assessment in helping to plan instruction. She gave examples such as using a one question ticket out the door

Several formative assessments were evident during the observations and used to inform her instruction. One was a ticket out the door in which students had to look at a current weather map of the United States that she projected on the board. She asked them to "look at the map and tell me about some weather event you think is happening in the country". In doing this ticket out the door, students were asked to apply their knowledge of weather systems and fronts to predict the weather somewhere in the U.S. The assessment was opened ended and allowed the students to look at the map and make their own interpretations.

Another example was the use of A&D statements. Clara described A&D statements as "agree and disagree statements". Using this strategy, she assessed students' knowledge of weather fronts and pressure. She asked the students to stand in a circle and asked them to indicate their answer to a question by stepping inside the circle if they agreed and outside if they disagreed. After they indicated their responses, she asked them to work in a group of five to discuss the question. She moved around the room, listened to their discussions and clarified their understanding before moving to the next question.

During the second interview she discussed using probes at the beginning of the weather unit to explore misconceptions that her students may have. She also mentioned a new strategy she had learned about from another teacher called a point bank. Point banks are study guides given at the beginning of a unit instead of at the end. There are activities students can do to reinforce concepts and to have additional points added to their unit assessment. Examples of activities for the weather unit included flash cards, crossword puzzles, writing weather stories, and recording daily weather. She said that she noticed students came in to class with prior knowledge because they were doing activities on the point bank. She said they were aware of barometric pressure prior to their class activity on using a barometer.

Assessment strategies were also found in a review of the lessons in her endorsement portfolio. Formative assessments were a section in her unit outline along with know/do and experiences. The formative assessments included Frayer diagrams, double bubble/compare and contrast, answer EQ (essential question), and ticket out the door.

Connecting Knowledge of Assessment with Knowledge of Students. During the second interview she also discussed the impact on hearing a speaker, Rick Wormelli discuss his book *Fair is Not Equal* at a Master Teacher Institute. From the presentation, Clara learned the importance of making allowances for students who struggle with the content. She relayed an example of a student that failed every test she gave her. She gave the girl the test orally and realized she knew everything.

> So, I figured, well, my job is for the children to master the content no matter how that happens. And if she can tell me what I need to know, either through questioning or through the point bank, or through a test. My job is done.

Through this experience, Clara said she had realized kids learn in different ways and "one test isn't going to tell me how a kids learn."

Knowledge of Student Conception in Science. Clara's understanding of elementary science students is apparent through her use of probes to address student misconceptions and her use of various assessments. In the second interview she was asked how her understanding of her students influenced the instructional decision she made in the weather unit. She said that her students are motivated, high achievers. She said "they are looking for more than reading a book and answering questions. They get tired, bored. And they get antsy, and then get into to trouble."

Questioning Strategies. Although there was a high degree of teacher talk during the lessons. This was evident by a period of brief questions and answer with students. The wait time between the Q&A was very brief. An example of a common dialogue occurred during the first observation. She and the students were comparing the weather of the day with the weather of the previous day.

Teacher: What kind of weather is coming from the plains?

Student 1: Drier weather

Teacher: Is the humidity going up or down? Does anyone know what humidity is?

Student 2: It is the amount of water vapor in the air.

Teacher: What do you think we will see tomorrow? Why are we seeing changes?

Student 3: Clouds move a lot.

Teacher: Why?

Student 4: Because of the wind.

Teacher: Why else would clouds look different?

Student 5: Because of the Sun.

Teacher: What else does the sun do to the water?

Student: Evaporate

This was a typical series of short questions followed by brief student answers. She tended to move quickly through questions. In the first interview she mentioned that student learn best from her asking them questions, but the type of questioned ask tended to be recall. There were times during the observations that questions were used as a formative assessment. For example, during an observation on the third day following the weather fronts videos, she asked students "who can tell me the difference between a warm front and cold front?" She allowed students time to respond with a variety of answers than she clarified the definition.

There were multiple times where students were asked to interpret a diagram before she talked about it. For example, during the first observation, she gave them a handout with the Beaufort wind scale. She asks them to look at the diagram and explain what they think it is about. She gave students time to explore it and discuss it before she provided details about how they were going to use it during the weather observations. The students were also involved in comparing the data from their observations with the computer program Weather Bug. During each observation, I noticed that students were writing down the data. Several times she asked them to talk about why the weather was different from the day before or to predict what they thought the next day's weather would be like.

Curricular Knowledge. The endorsement requirements include developing an integrated science unit, developing vertically aligned lessons and observing other teachers at the elementary grade bands of K-2 and 3-5. In the first interview, Clara was asked if the endorsement influenced her knowledge of the K-12 science curriculum. She replied:

> Yes, that was the first thing, the vertical alignment. Yeah, big time. And what I saw was stuff in kindergarten. I watched it build through the years all the way up to high school. And the other way that helped me was that we had to do some observations of one another and I actually went to a high school class. I think I was the only one that went and visited high school. In her classroom she had food chains and food webs. And, I was like 'hey, I do this in my room.' Things we did, but of course, in more depth. But it was like, okay. My kids are going to learn this in fourth grade, and they're going to carry it through high school, and this is where they're going to use it again.

Having the opportunity to look more closely at the standards across grade levels coupled with the opportunity to observe a high school teacher strengthened her understanding of the curriculum. Her vertical alignment lessons discussed previously provided evidence of her knowledge of developing grade level appropriate activities at second and fourth grade. She elaborated that her school was currently having discussions about the vertical alignment of science and mathematics classes. As the department head of the math and science department, she is leading those discussions.

Efficacy. In the first interview she was asked if the endorsement influenced her beliefs in her capabilities to teach science effectively. She said that it strengthened it. She commented "I think I already felt capable, but it made me feel stronger in science." She elaborated "I feel more confident in teaching science…I'm confident enough that, I can make a mistake and I don't know everything. It's fun when the kids know more than me."

Integration of Dimensions of Professional Knowledge. Clara is a veteran teacher with who constantly seeks professional development opportunities to refine her teaching. Based on the observations and interviews with her, she is working towards engaging her students in multiple ways so they experience science. Her orientation to teaching science could be characterized as discovery/emerging inquiry. This was consistent in the review of her lesson plans. The observations and interviews demonstrated further evidence of her providing opportunities for students to discover concepts through opportunities such as interpreting diagrams and data. Students were also engaged in collecting weather data both through a website and outside using instruments they had developed. There was a high degree of teacher control in the lessons observed. This was evident by the degree of teacher talk in the lessons, teacher direction of the activities, and teacher guiding the learning experiences. She solicited student understanding through questioning and formative assessment, but the sequence of the content development was directed by Clara. Despite the high degree of teacher control, Clara appeared to be pushing herself to take risks with topic-specific instructional strategies. Even though her demonstrations were not completely accurate, she sought ways to engage students through the development of content related to air pressure and weather fronts. She also utilized her knowledge of topic-specific instructional strategies such as demonstrations to engage students in the development of the content. Her struggles with the content inhibited the development of the content.

Her pedagogical knowledge (PK) worked in conjunction with other knowledge bases, particularly her content knowledge (CK) and assessment knowledge (AK). She utilized her pedagogical knowledge to establish class rituals and routines that created a positive learning environment for the students. She used positive reinforcement strategies and praised students who were exhibiting desired behaviors. She has clear routines for transitioning to labs, working in groups, and using lab journals. Her strong PK and her efficacy for teaching science also seemed to provide her with the confidence to take risks with topic-specific instructional strategies such as the air pressure demonstrations when developing content. In the interviews she repeatedly made comment such as it is okay if I don't know and it is okay if the students know more than I do. Her efficacy for teaching science and her strong PK helped her overcome content limitations.

Her assessment knowledge worked with her knowledge of students. This was evident through her knowledge of student misconceptions and the use of formative assessments. She used these to inform her instruction. She was also flexible in how she assessed student as evidenced through the use of the point bank and finding alternative ways to assess students who did not test well on traditional assessments.

In summary, there are many sources of knowledge that appear to be interacting as Clara enacted instructional strategies related to her students understanding of different aspects of weather. Her strong pedagogical knowledge appeared to be integrated with several other knowledge bases. Her strong sense of efficacy and pedagogical knowledge provide her with the tenacity to find ways to engage students in content and discover concepts for themselves.

Margaret

"To try it, to ask, to brainstorm, on well, if I did this in my room, this is how it would work. We never have that kind of time. To learn that way I mean - we want our kids to learn that way. We are teaching them to learn that way, but we as educators don't often get that opportunity."

Margaret has been teaching science for 22 years at primarily the first and second grade levels. In her role as a primary teacher she has taught all academic subjects to her students. This is her first year as a K-5 teacher of students identified as gifted. She teaches through interdisciplinary units which she plans with her students. She teaches a different grade level on each day of the week. I visited her on Tuesdays, which is the day of the week she teaches 4th grade. She reports that she enrolled in the endorsement because of her love of science. She said her science lessons were the most fun lessons she taught. She described the endorsement as an intense experience. She described the way the instructors developed the content through experiments as the most beneficial component of the endorsement. She relished the opportunity to try things out she was learning with her students and go back to class to talk about what worked and to ask questions she might have. She did not find the online content modules as helpful. She actually found them to be a stressful component of the endorsement.

She completed the K-5 science endorsement in 2012 and was observed and interviewed about a year and a half after the completion of the endorsement. The data collected included two 90-minute observations during a 4th grade unit on technology design challenges. She was interviewed once and the portfolio she developed during the endorsement was reviewed.

The constraints that Margaret faced did not appear to have negative impact on her teaching science. She reported that she only had one science class during her educator preparation program, but mentioned she took several courses in high school. Margaret discussed the constraints of having to meet district benchmarks and standards when she taught in a general education classroom. She explained these constraints led her to teach in a traditional format. In the interview she compared how she taught science before the endorsement to how she teaches now. She said before the endorsement she would have had students read about a topic, complete one experiment, and then move on to the next topic. She called that a “typical structure” of her lessons. She describes her science lessons after the endorsement as:

> more about searching for answers in different places or different lessons or activities. Now they could be getting up and walking around and doing a survey. And then sitting down and doing an experiment and then watching a video clip by a professional or hearing a read-aloud and finding science in all those different places.

As the K-5 gifted teacher, the district standards do not constrain her in the same way as they did when she taught in the general education classroom. She works with the general classroom teachers of her students to extend the learning in the general classroom. She said the gifted classroom allows her to challenge students in their area of interest, use higher yield strategies, and apply concepts to the real world. In the interview she said:

> I don't have to be guided by the standards. I am aware of the standards; I talk to the grade level teachers about what standards they really need help reinforcing. But I look more at their themes. Instead of looking at the standards to guide me, I look at themes and topics they are studying.

Classroom Context. In her new position as a teacher of K-5 gifted students, Margaret teaches in a "pull out-push in" model. She "pushes in" to the general education classroom to provide enrichment on certain topics. For example, she provided enrichment in the area of genetics and heredity by "pushing in" to a 5th grade class. She also "pulls out" students from the general classroom for gifted services for one day per week for a total of 225 minutes (per week). During that time, she provides additional enrichment and support for the grade level standards, but has the flexibility to determine how best to meet those standards. She says she uses theme based units, often driven by student interest, to guide her instruction. In the interview she said "In the gifted classroom, I can change my plans to go where they want to go as long as we are sticking in the general guidelines of the standards and not going too far out."

Her classroom has a chalkboard, an active board and a dry erase board across the front of the room. I noticed Essential Questions (EQ) on the board for multiple grade levels. Several colorful pictures such as a book worm and a thinking cap were painted on the wall. As the students entered the room on the day of the first observation, she asked them to get out their

MONKEY books. In the interview she told me that one of her endorsement instructors introduced them to the idea of MONKEY books. They are organized as a way for students to keep a record of their work. MONKEY stands for *My Organized Notebook Keeps Track of Everything Yeah!* During the endorsement, her physical science instructor required the participants to maintain a MONKEY book during the course. MONKEY books are interactive notebooks that use the pages on the right side of the notebook for *input* such as class notes and quick writes, which are first attempts at answering questions. Quick writes are opportunities for students to make their thinking about a concept visible. An interactive feature of the notebook includes strategies such as students drawing a line under their initial thoughts as a “line of thinking”. The left side of the notebook is for *output* and includes opportunities to process lab data or apply their learning to different situations. It includes places for ah-ha’s they experience during learning and cloud bubbles for “clouds of evidence”. Students decorate unit pages to highlight the content and to create buy in for using the notebooks.

On the day of the first observation, one of the students came in and was looking for the Lego table. She announced that their Lego team placed first in a recent competition. Later in the interview, I learned she coached the school Science Olympiad and Lego teams. In the back of the classroom there is an oval blue carpet with the alphabet written around the edge. There is a rocking chair on the carpet. During the second observation, she called the students to the back of the classroom and read them a story. The classroom had several bookshelves with games, manipulatives, and books for students to check out.

The two lessons that were observed were related to technology design challenges. The first lesson was an opportunity for students to redesign a structure made of uncooked spaghetti, string, and tape that could hold a large marshmallow without falling over. The second day was an introduction to a bridge challenge in which students brainstormed ideas to build a bridge to fit within certain parameters. There were 17 students present during the first observation and 18 presented during the second observation. Table 28 includes a summary of Margaret's lessons.

Table 28

Summary of Margaret's Lessons

Topic	**Instructional Strategies**	**Content Knowledge**	**Pedagogical Knowledge**	**RTOP Score**
Marshmallow Challenge	Guided inquiry Design/redesign Testing solutions Journaling	Questioning to develop understanding	Routines Supportive classroom environment	83
Bridge Challenge	Use of Evidence (implicit) Multiple Representations Journaling	Integrating science with literacy, geography, history Developing CK of bridges	Routines Touch your shoulders Supportive classroom environment	95

Margaret's case will be presented by going through the dimensions of her professional knowledge bases. I found Margaret's knowledge bases to be very integrated. This was evident in her lesson plans and during her enactment of the technology lessons with her students. There seemed to be seamless connections among her dimensions of knowledge. This made it more challenging to tease them out in the narrative that follows.

Orientations. Schneider and Plasman (2011) identified goals and purposes for teaching science and the nature of science in their learning progressions for orientations. Margaret's orientation to teaching science could be described as reform-oriented with inclinations towards the use of inquiry and conceptual understanding. This was evident through her RTOP scores of 83 and 95 which indicate a very high degree of reform practices. A score of 50 is associated with a reform orientation. Other evidence to support this orientation is the way Margaret involved students in determining the direction of the lessons and the student-centered nature of her instruction.

Her unit plan was an outline for a unit on the technology design loop. She said it was incomplete because student ideas would determine the direction of the lesson. Her approach to teaching was very constructivist in nature as she shifted responsibility to the students. For example, the Essential Questions for the unit were going to be written by her students. Their ideas would determine the direction of the lessons. This included the types of activities and their research interest. Students were also involved in designing assessments, such as a rubric to assess a writing assignment.

The inquiry nature of the experiences included students designing, reflecting, and redesigning structures which also provide support for an inquiry orientation. The students were engaged in a technology design loop that included a focus on engineering structures. She used technology as the focus, but the inclusion of building bridges and structures were also indicative of practices of engineering (NRC, 2013). Students were engaged in a design and redesign process. She provided guided inquiry engineering challenges such as the “marshmallow challenge” and “the bridge challenge”. The students were given constraints such as limited time and limited materials, but they were able to determine how to meet the challenge. She used these challenges to develop content on forces, structures and technology.

Due to the nature of the how Margaret developed the content, her orientation could also be described as one of conceptual understanding (Magnusson et al., 1999; Driver et al., 1994). She used multiple instructional strategies and representations to develop the content of forces and structures. She developed the content in a logical coherent manner using a variety of means. Her reform-orientation is also demonstrated through her choice of reform-oriented instructional strategies. In the interview, she stated that one of her goals for teaching is “to have them [students] look at something and think about what can I do next? How can I make it better?” She credited the endorsement for helping her realize that she could use different instructional strategies to meet the needs of her students. She realized she could let go of her previous idea of a typical lesson which she described as “this is the way we are going to ask question, and then do an activity, and then we are going to wrap it up.” She realized she could use multiple resources and activities to develop student understanding.

Goals and Purposes for Teaching. When asked about her goals and purposes for teaching she replied “I want them to know that science is all around them and that it's really cool. I want them to know that it's a part of every single day in their life and that whatever they're doing, they're doing science. I want them to make connections.” This was evident in the nature of the technology design lessons observed. A review of her endorsement portfolio found engaging, grade-level appropriate activities. This included lab stations for second grade students on changes in matter and a unit on the impact of humans on dolphins and turtles in the oceans.

Nature of Science. There was evidence of her implicitly using Nature of Science (NOS) ideas during the observations. Students were making observations, designing and testing, and supporting their understanding through the use of evidence. In the interview she relayed a previous classroom experience in which she used jigsaw puzzles to discuss talk with students about how scientists communicate ideas.

In the interview she discussed the unit she designed to teach students ideas of the nature of science. This was a required assignment in the endorsement that included researching the history of a big idea in science and developing lessons to introduce the nature of science ideas to students. She chose to design a unit on the Big Bang Theory with her second grade students. She reported that she made sure students knew it was "just a theory" and used an art lesson to let students explore their creativity to propose what happened in the big bang. In a review of her endorsement portfolio reflections, she writes:

> This activity helped us all focus on the idea that a theory is a scientific understanding that has data to support it but the data may not have convinced everyone. My goal for this lesson was for the students to understand that Space has changed. It has not always been an endless thing filled with planets, stars, and other objects. After viewing the You-tube video Bad-Astronomy.com with astronomer Phil Plait video entitled "What is the Big Bang theory and is it real?" the children created art which reflected an understanding that the universe has changed over time.

These ideas were not explored with Margaret during the interview, but the use of "just a theory" suggests she may not have a clear understanding about what a theory is.

Knowledge of Instructional Strategies. After the completion of the endorsement, she reports that she uses multiple strategies to develop a topic. She elaborates that now “science is more about searching for answers in different places, or in different lessons or activities. Now they [students] could be getting up, and walking around, and doing a survey and then sitting down and doing an experiment, and then watching a video clip by a professional or hearing a read-aloud. And finding science in all of those places.”

Margaret attributes the way in which the instructors presented science concepts in multiple ways allowed her the freedom to “jump around” in order to develop a concept in a way that she felt was best for her students. She realized that she had the flexibility to select multiple instructional strategies to help her meet the needs of the diverse learners in her class. She gave an example of this when describing an integrated science unit she developed and implemented during the endorsement. The lesson was on human impact on the environment and she was able to represent the content in multiple ways. She showed her students pictures of an aquarium and of the great garbage patch in the Pacific Ocean, watched a video about reducing garbage, played I-spy with pictures of garbage and organized them in which ones could be recycled, and watched a video about the dirtiest beach in the world. A review of this unit plan in her portfolio provided further evidence of this. An example of using different strategies was found in a lesson in the unit developed during the endorsement. She selected a second grade life science standard on life cycles and an earth science standard on the influences of changes in an environment for the unit. A lesson from that unit includes:

> Show a video clip from “National Geographic's Really Wild Animals: Deep Sea Dive”
>
> After viewing the video segment, generate a class list of the animals we saw in the video

clip. Identify the animals by name & kind of animal (mammal, reptile, fish, bird, amphibian, or insect) if possible.

Teacher reads aloud Picture Book (literature connection) *Into the Sea* by Brenda Z. Guiberson. Students work in groups of 3 on a marine animal card sort.

Distribute a prepared envelope of laminated marine animal cards. Students sort cards into categories. Characteristics for sort are chosen by the small groups and will vary from one group to another. Encourage groups to sort cards in multiple ways.

Discussion questions provided to guide conversations and keep groups on task.

What do we already know about their life cycles and how these organisms grow?

What do the organisms have in common in each group?

Which additional marine animals could be added to your sort groups?

Using Active board reconvene with students to access “Sea life fact files” at http://www.bbc.co.uk/nature/blueplanet/factfiles.shtml.

1. Student groups share the different ways they sorted the marine mammal cards. Record paired characteristics used in sorts on front board.
2. Based upon the sort sharing, select various animal fact files to explore with students. Identify the life cycle, habitat (specific areas of the marine habitat), and kind of animal.

In this lesson, Margaret used multiple instructional strategies such as classifying animals from a video, reading a children’s trade book, a picture card sort, discussion questions, and website to develop student understanding of marine animals. This was followed by lessons about the life cycles of sea turtles and dolphins as well as lessons about human impact on those organisms.

Her use of multiple connected instructional strategies was also evident during the second observation of her 4th grade class. The students were working on technology design challenges. She began the class with a review of a straw challenge they had completed. Students had answered two questions about whether or not a bendable straw should be considered technology and a structure. They had been given a definition of the two terms and had to provide evidence to support their answers. She had graded their responses based upon a rubric the students had designed. She elaborated on what an acceptable response would be. This was followed by a read aloud fictional story about building a bridge while she sat in a large rocking chair with her students sitting on the floor.

She shared their next design challenge: "Design and build a bridge that will cross a 16-inch space between two desks and be strong enough to hold 21 rolls of pennies." She guided students in a discussion that related the 16-inch span to the length of a ruler, and they estimated the mass of 21 rolls of pennies (125 g or 4 oz).

Content Knowledge. When asked about the endorsements influence on her content knowledge, she said that she came into the endorsement with a stronger knowledge of life science and a weaker knowledge of physical science. In the first interview she describes the role the instructor played in helping to develop her physical science content knowledge:

> Being able to try things to, play with, speed and motion, and understand force within the classroom. That was always something that I was, kind of, you know, physics was always my downfall, I guess. And, being able to really work through it with the instructor, who had that as a strength. Someone who focuses on that in the classroom. To give that to me hands on and allow me to ask questions and to brainstorm with the other people in the classroom on how it would be used.

After she introduced the design challenges, she engaged students in multiple strategies to develop their content knowledge. She also used questioning strategies to develop the content. During the first observation, she engaged students in questions about the marshmallow structure they built on the previous day. Questions such as "does the design cycle remind you of anything?" and comments such as "Reflect on the structure you created, that is evaluate it. What worked, what didn't?" She walked around to groups of students as they worked on their structure. She asked questions such as:

What are you changing?

Did you sketch it?

It looks different, how did you change it?

Tell me what you did last time.

She asked students to keep records in their MONKEY book and to use that information to consider how they would be redesigning the structure. She appeared to be asking students to make their thinking visible as they recorded information in their notebook.

During the observation on the second day, she started by putting a picture of a suspension bridge on the screen and asked students "what do you notice?" She showed students a series of images of bridges on the screen. The bridges were a variety of styles, such as suspension bridges, and were built in different parts of the world during different time periods. She was patient with students as they studied the bridges. She asked students what they noticed. She waited for responses. She led them through a discussion about foundations, suspensions, etc. She showed a picture, asked a question, and gave students time to explain. For example, she showed a Roman bridge built in the 4^{th} to 8^{th} century with an Etruscan foundation. What do you think is holding it up? She asked the students if it was built with metal, and related the bridge to the time period it was built in. They talked about how they would not have been using metal at that time. Throughout the process, she connected students to geography by showing them bridges throughout the world and different time periods. In this way, she was able to leverage her knowledge of history and geography as they discussed bridge foundations and support. She also used a children's trade book to engage them in bridge building. During the discussion she referenced a Magic School Bus video the class had seen previously and brought in the idea of triangles being the strongest of the shapes.

The lesson continued with an eight minute video on building modern bridges. The video included information about using concrete and rebar. It addressed parapets which keep cars from falling of the sides. She paused the video and told students that feature would be important in their next challenge. This was followed by organizing the challenge in their MONKEY books.

Linking Content Knowledge and Instructional Strategies. Her choice of instructional strategies was integrated with her knowledge of science content to develop the content of her students. The inquiry oriented design challenges, questioning, use of videos, journals and discussions guided her students towards developing content understanding. For this reason, specific details about how she integrated these knowledge bases will be presented here.

Instructional Strategies: Questioning Strategies. Margaret used questioning as an instructional strategy to develop science concepts. Through the use of bridge images she was able to lead her students to an understanding of bridge structure and foundations. Things that were important to their upcoming design challenge. She provided her students with time to answer questions and was supportive and encouraging of their answers.

Instructional Strategies: Inquiry & Engineering Design. Observations of her classroom provided evidence to support her use of inquiry strategies through the implementation of an engineering design process. The use of inquiry based strategies with students was evident during both observations. In the interview she said “We've touched on a lot of inquiry lessons and what inquiry learning was. And just being able to look at something and change 1 variable and then redo it. And that's really what my goal is. To have them look at something and think about what can I do next? How can I make it better? How can I change 1 variable?" This was evident in the use of the design and redesign technology challenges.

Instructional Strategies: Lesson Planning. Even though Margaret doesn't formally use the 5E's in her lesson plans because of "how lengthy they are", she reports that she is constantly thinking about ways she can use them. In the interview she shared, "I'm still thinking that way. I'm still about how am I going to engage them, how am I going to enrich them you know, how am I going to take this and extend it. So I'm constantly thinking those."

Both of the lessons observed included opportunities to engage students at the beginning of the lesson and time for exploration and building content. The first observation was the students' second opportunity to complete a "marshmallow challenge." She also included time for students to evaluate their first structure to begin planning for their second structure.

It was also evident that students guide the direction of class. In planning the unit, she began with the standards and an opening task (marshmallow challenge), and then encouraged students to guide the direction of the rest of unit by developing essential questions. She says student development of the questions let her know what her student know and what they want to learn in a unit. Her unit started with a broad theme of the technology design loop with standards related to fourth grade force and motion. In a following lesson, her students were going to brainstorm what they wanted to learn and write essential questions for the unit. This provides an example of student-centered instruction. Students' guiding the direction of the class was also evident in a student created rubric that was to assess the straw challenge task. The students decided on the indicators and the point value of the responses. This was done prior to the observation.

Knowledge of Students. Margaret knows her students and cares deeply for them. She knows they learn differently and have various exceptionalities. These included gifted abilities and disabilities. She strives to build confidence in all of her students. She leveraged her knowledge of students through connecting with students on an emotional level during the integrating science unit completed during the endorsement. Margaret described the integrated science unit she developed and implemented with her second grade students on human impact on the environment. This assignment required endorsement candidates to integrate science with at least one other subject in the context of a local or global issue. Margaret chose the human impact issue of plastics in the environment. She engaged her students with the movie “Dolphin Tale” about a dolphin, Winter who lost her tail after being trapped in a crab trap in the ocean. The students were engaged in activities that developed their understanding of how human use of plastics can be harmful to the environment. She also connected the story of Winter to students with prosthetics and wheelchairs. She noted their school has a number of differently-abled students. She describes the unit as one that connected her with her students on a very emotional level. She said there were tears at the end of the unit, her and her students. In the unit reflection in the portfolio she writes:

> The Earth Science Unit was rewarding to teach, kept the children focused, allowed us to meet our science performance standards, and captivated each student. I truly believe this is one of the best units I have ever developed. Yes, my class was unique. The population of children, which included three children with physical impairments, were able to relate to the sea turtles and dolphins affected by human environmental forces. The children experienced empathy, frustration, relief, and even anger. All of these emotions allowed them to connect to our studies and made them eager to learn more.

During her interview she discussed how the endorsement helped her gain a sense of confidence in doing "what is best for the students". She leveraged her knowledge of her students with a new understanding of instructional strategies and lesson planning to engage her students in understanding human impact on the environment during the endorsement. She currently teaches gifted students, but in previous years she has taught a diverse population of learners. She reports that she strives to meet the needs of all learners through her use of varied instruction. She reports the knowledge of instructional strategies gained during the endorsement has helped her overcome constraints often associated with high stakes assessments including district benchmarks and standards. Having experienced varied methods of instruction as a participant in the endorsement, she discovered a new way to present science concepts to her students. This provided her with more flexibility in how to meet standards and develop student understanding in a new way.

Pedagogical Knowledge. It was evident that Margaret has a strong knowledge of pedagogy. She has created a safe environment for students to ask questions, explore topics, and design tests. During the observation, I found her to be patient, kind, and supportive of her students. Encouraging statements such as "look what you did!" and "I think your structure beat all of the teachers" were some of the ways she supported her students. She uses strategies such as "everyone tap your shoulders" as a way to get student attention. Her students transitioned well when they "jump around," and she keeps them actively engaged through multiple instructional strategies. During the first observation, she wanted her students to clean up quickly. She issued a challenge to see who could clean up first and open their notebook to be ready for the next task. The students worked quickly and efficiently to clean up their materials. She has established rituals and routines in the classroom that allow her to be able to keep the students active in multiple strategies throughout a class period.

Knowledge of Assessment. Margaret's knowledge of assessment was evidence in multiple ways. During her unit on human impact, one of the culminating tasks was: "Students write letters to an organization involved in the conservation or rehabilitation of sea turtles, dolphins or other marine organisms." This type of assessment demonstrated her integration of literacy in the classroom. Her knowledge of assessment was evident in her use of a rubric developed by students to assess the straw challenge. She also encouraged students to evaluate their own structures to make changes during the redesign phase of the marshmallow challenge. In the interview she describes how she used questioning during the marshmallow challenge to check for student understanding. Questions such as "What was your strategy? Did you change your strategy as you went through it? Now that you've come up with a new idea, as you're building it, are you changing what you're doing?" were used. This was also evident during the observation.

Curricular Knowledge. Margaret's knowledge of curriculum was through her standards based focus. Each endorsement unit reviewed included the science standards for the grade level. Daily lesson plans demonstrated the use of multiple instructional strategies as described previously. Another way that Margaret's curricular knowledge was evident was the frequency in which she integrated science with her subjects. This occurred in the environmental impact unit through the use of literacy through children's books and letter writing as well as social studies. It was also apparent in the second observation through the use of bridges to tie in social studies and a fiction children's book about building a bridge in a community. A review of instructor feedback during an observation of Margaret for the residency requirement referenced the integration of literacy and social studies in those lessons.

Efficacy. Margaret described the importance of having a safe place to ask questions during the endorsement was important in her content development and confidence. Having instructors say "I don't know, but I'll tell you next week" provided participants the freedom to say to their students "I don't know, but we can find out." This seemed to be an important factor in their confidence to teach science. From the observation, Margaret provided a safe and supportive environment for her students to learn science. Her praise of the students was evident as they designed and tested their structures. Her questions guided them as they redesigned their structures. She provided specific support to each individual group by bringing up aspects of their first design. Comments to groups such as "you had the tallest – your challenge is to make it taller" seemed to motivate a group. Student efficacy was observed by the comment "this is going good" by a team of three quiet girls. You could feel their excitement. When that team of girls won the marshmallow challenge, Margaret exclaimed "Wow! Look what you did! It's amazing!"

Summary of Margaret. Margaret's teaching experience has primarily been in K-2 classrooms. Her teaching has involved teaching multiple subjects which is common when teaching in the primary grades. She recently assumed a new role of teaching K-5 gifted students at her school. Her use of topic-specific instructional strategies suggests an inquiry orientation to teaching science. There is a high degree of student centered instruction in her current gifted classroom, but also appears to be evident in the lessons developed during the endorsement. When looking more closely at her dimensions of professional knowledge, there appears to be a considerable amount of integration. The knowledge bases seem seamlessly connected to each other. Park and Chen (2012) posit a didactic orientation inhibits connections among other knowledge bases. In Margaret's case, her strong inquiry orientation as an elementary teacher demonstrates strong connections among other areas of her professional knowledge.

During the observations and interviews, she exhibited the tendency to structure her classes using student-centered inquiry strategies. Based upon her description of how she taught before the endorsement and the practices observed, there appears to be a shift towards a more inquiry oriented approach. There was a shift from read about it, "maybe do one experiment" then move on, to finding multiple instructional strategies with the goal of developing student understanding. Learning about the 5E model and experiencing engaging instruction during the endorsement classes, signal a shift to "units that work" (Appleton, 2002).

Emily

"It [the endorsement]really shed some light on the importance of science and what students can take away from understanding not only the different science concepts at the different grade levels, but the process of science and how science works."

Emily has been teaching elementary science for six years and currently teaches 5th grade science and mathematics. She reports that she only had few science classes during her educator preparation. She mentioned she had a college instructor that focused on inquiry so she was comfortable with engaging student in inquiry before the endorsement. There were 28 students present in the class on the days I observed. She teaches science and math – each class is approximately sixty minutes.

Classroom Context. Emily's classroom has bright white walls and bright lights. Even though the room is very bright, it seems very inviting. The room has colorful decorations and looks very clean. She teaches in a newer school building. Here room is a large square room with five sets of desks combined together to form a table with five or six students each. In the front of the room, there is an interactive board, two dry erase boards on each side of the interactive board and a bean shaped table used for conferences with students. In the back of the room, there was a book shelf with assorted books and resources and another table. On the left side of the room, there was a bulletin board divided into two sections. One section was for math and the other for science. In each subject area section, there was the standard, an essential question, and a list of five to seven vocabulary words. The science section of the board included the words microorganism, bacteria, fungus, protist and beneficial. On the right side of the room, there were shelves with large boxes and hangers for student book bags. There was a very creative hall pass block that looked like something you would see in a sorority dorm room in the colors brown, pink, white and polka dots. Four to five hall passes to various school locations were also hanging.

Emily was observed for three days within a unit on microorganisms. She spent a great deal of time developing student understanding of microorganisms as indicated by the standard "describe examples of microorganisms that are helpful and harmful". She provided multiple opportunities to develop student understanding of the content within the standards. The three days that were observed included multiple opportunities for students to use a variety of representations to gain an understanding of microorganisms.

During the first observation, she engaged the students with an image of bread with an inset diagram of yeast on the interactive technology board. She reviewed a previous lesson that had introduced the standard by asking students where it is found, if it is harmful of beneficial, why it is harmful or beneficial, and which category it belongs to (fungi). This was followed by a few more images and the same general questions. She asked the students to work in groups and rotate to nine stations looking at pictures and answering the following questions: where it is found, if it is harmful of beneficial, why it is harmful or beneficial, and which category it belongs to (bacteria or fungi). The students used a graphic organizer to keep a record of their answers. She encouraged the importance of using evidence in their answers. At the end of the class she engaged students in a discussion about how they used models. Table 29 includes a summary of Emily's lessons.

Table 29

Summary of Emily's Lessons

Topic	**Pedagogical Knowledge**	**Nature of Science Explicit**	**Assessment Knowledge**	**RTOP Score**
Harmful Beneficial Stations	Standards based instruction Summarizer	Using Models	Questioning to check for understanding/ develop content	46
Harmful Beneficial T-Charts using Pictures from Magazines	Standards based instruction T-chart Summarizer	Models Claims & Evidence	Formative Assessment: Response System	71
Harmful Beneficial T-Charts	Standards based instruction T-chart Summarizer	Models Claims & Evidence	Formative Assessment: 10 Question Quiz (Pictures of Microorganisms)	60

Orientations. Emily's teaching could be characterized as a reform-orientation. This is evident by her explicit Nature of Science instruction during the three days observed as well as the lesson plans development during the endorsement. A review of her lesson plans found detailed references to NOS. The NOS lesson that she developed for the endorsement included NOS references about the development of the theory of plate tectonics. I observed her presentation of this unit during an observation of her instructor. Using a PowerPoint presentation, she discussed the major contributions of scientists in the development of the Theory of Continental Drift through the Theory of Plate Tectonics. I remember thinking at the time I had never seen NOS presented in that way. She listed each scientist's contribution on a slide and then identified how their particular contribution was an example of a NOS idea. For example, she included slides with contributions from Alfred Wegener and Arthur Holmes. Wegener provided biological and geological evidence that the continents had once formed a single land mass. Holmes proposed convection currents in the mantle were the driving force behind the movement. But as Emily explained, these ideas were speculative and science "demands and relies on empirical evidence." Once Harry Hess provided evidence of seafloor spreading, the theory was accepted. Classroom activities included in the unit were using paper and newspaper cut-outs to develop the ideas of puzzle pieces. She elaborated with sources for evidence of the movement of the contents and provided maps to model elements that matched up geological features like mountain chains and glacial grooves, ocean rifts, and patterns of earthquakes and volcanoes. Based on the evidence, she asked students to decide if they would have been "followers or debaters" of Wegener and then provide evidence for their choice.

The reflection that followed her implementation of this unit with her student demonstrated the implementation of explicit NOS ideas.

> Although most of the delivery of the nature of science has been implicit in most of my lessons prior to this course, I was surprised to see that students had a fairly good understanding of how science works. However, after the implementation of this lesson my students had a deep understanding of why models are used, how science evolves and changes, how science can be creative, the impact of technology, and social influences. Students were able to build this deep understanding of the nature of science while learning science content as well. Students now have a good understanding of science.

The reflection continued with an elaboration of the sources of her knowledge of the content and nature of science:

> My knowledge of the science concepts of both the content and nature of science helped my students form a deep understanding. As my knowledge has evolved, I have become a better teacher and deliverer of these concepts. Without the knowledge of these concepts my students would have not been able to explicitly see and connect to the nature of science. They are now better scientists because of that.

Goals and Purposes for Teaching. In the first interview, she described three goals and purposes for teaching: for students to understand both science content and process; wanting students to apply science to other subjects; and wanting them to understand how science works in the real world. The endorsement requires participants to develop and teach lessons for grade bands other than the one they currently teach. Emily teaches 5th grade, but developed a second grade lesson during the endorsement. In a review of a lesson developed for the endorsement, she had included NOS questioning in a laboratory experience developed for

> Why must scientists record their findings?
>
> Why is data needed to draw conclusions?
>
> Why are conclusions that are not supported by data not accepted?

Nature of Science. She reported that she was implicitly using the Nature of Science with her students prior to the endorsement, but learned to explicitly use NOS with her students during the endorsement. She said, “in the past I would have accepted that a microorganism was beneficial or harmful, and now I expect evidenced based support.” In the interview she claimed “I had not realized it was important for students to give evidence based support for their answers.” She credited her instructor with helping her understand the importance of this by presenting research on how students learn information and by modeling how to provide evidence based support for answers. She relayed that it was important for scientists to provide evidence based support and back up what they are saying.

Her use of NOS was evident during classroom observations and through a review of her lesson plans. A review of her lesson plans from the year prior to and the year after the endorsement found NOS embedded throughout her lesson plans completed during the endorsement. Below is an example found in her lesson plans:

> Science Notebook Activity: Sort, Classify and Explain the following microorganism.
>
> **NOS Questioning:**
> Why do scientists record data and notes?
> Why is it important to be able to clearly explain yourself and your thinking?
>
> **NOS Questioning:** In your graphic organizer, you had to explain why these microorganisms were either beneficial or harmful. Why is it important in science to justify and explain your thoughts with proof and evidence?
>
> How did we act as scientists today?

She engaged in similar discussions with students throughout the three days observed. Another exchange included the use of evidence to support their understanding. It was apparent she wanted students to think like scientists. This included her discussions of models and using claims and evidence below.

Knowledge of Instructional Strategies. Emily utilized a variety of instructional strategies during the three days of observations. These included using pictures and guided practice to develop their understanding of harmful and beneficial microorganisms. Her choice of instructional strategies reflected her goals and purposes of explicitly using NOS with her students. She engaged the students in conversations about how the pictures represented models and required evidence based support for their answers.

Instructional strategies: Models. When asked about her use of models in the second interview she replied "We use a lot of models and that is a good way for them to understand what models are because they are able to see that we have to use models and replicas, representations of these because we don't always have direct access to things. They have really started to understand the importance of models in science, especially through this unit." This was evident in a dialogue during the first observation when she shared the picture of bread with an inset of yeast. As she explained the tasks to students she engaged in the follow discussion with several different students providing responses.

> Emily: When we talk about microorganisms, we use a lot of pictures. Why? Do we have to use these pictures that have been enlarged?
>
> Student: it's so small, it has to been seen with a microscope.
>
> Emily: We use these pictures and representations called models. We use them a lot in science. Why?
>
> Student: "so you can get a visual picture."
>
> Emily: Who can add to that?
>
> Student: "If someone asks you the scale, someone can show you the picture"
>
> Emily: Why?
>
> Student: so I can show people

> Emily: Why?
>
> Student: to explain my thinking
>
> Emily: But also so we can learn more about things we don't have direct access to. They are all over the place, but do we have direct access? (no) We use pictures and models to help us understand them better.

Instructional Strategies: Claims and Evidence. She stressed the importance of students supporting their answers with evidence. She said the way her endorsement instructor carried out investigations during the endorsement classes helped develop the content as well as help them understand the reasoning behind concepts. This was evident in the first observation when she asked her students, "Why in science do we have to support or back up our answers?" And, during the second observation when she reminded them "Your evidence on how and why you sort them is your evidence and proof."

When asked during the first interview if the endorsement influenced her knowledge of instructional strategies, she replied:

> Michelle brought to us many different ways of teaching science. Some of them I had experience with, and some of them I did not. But, the way she carried it out. And, even through her teaching made us see a different way of explaining, and carrying out that content instruction. It was the reasoning behind it. In my science classes before the endorsement, I really hadn't thought it was really a big deal for them to provide that evidence based support for their answers. Like for example, in here if there were able to tell me if a microorganism was beneficial, that was good enough (reference to lesson I observed). But, through that endorsement and the way Michelle taught us, and presented ideas to us and gave us research on the most effective way students learn information and

act like scientists. Scientists provide evidence based answers to support and back up what they are saying really builds a concrete understanding

Instructional Strategies 5E Lesson Planning. Her lessons demonstrated use of the 5E lesson planning. In the interview, she said she was aware of 5E lessons prior to the endorsement, but reports she became more explicit about their use in her classroom after the endorsement. She said the 5E's provide a structure for her to determine what she wants to get out of a unit, how students are going to explain what they know, and how she is going to assess it. A review of her lesson plans explicitly included E's for each day. In reviewing her lesson plans prior to the endorsement, she was using activating strategies but not explicitly using the E's.

During the three days of observations, she engaged students at the beginning of each period. She used pictures on an interactive whiteboard on the first day, a response system for students to indicate *harmful* or *beneficial* the second day. On the third day, she engaged the students with images from a website followed by a paper quiz. Each day included a review and practice identifying harmful and beneficial organisms. She also included how each organism was classified (bacteria, fungi, protist) and specific information about how it was harmful or beneficial. She mentioned this was an opportunity to preview the classification of organisms which was part of an upcoming unit.

Each day included an opportunity to explore. The first day included rotating to different stations with pictures of organisms to classify. On the second and third day of the observations, students explored using magazines to classify organisms as helpful or harmful. Students worked in groups of three. They were given a piece of chart paper and instructed to make a T chart with *harmful* and *beneficial* as the categories. The requirement was to include three pieces of information about each organism selected: name of the organism, what it does, and a description of why it was labeled as harmful or beneficial. She provided an example using yeast on the board. She modeled her expectations for students by identifying yeast in bread as a beneficial organism. She engaged students in an interactive discussion that answered the questions.

Assessment Knowledge. In the interview, she reported the endorsement opened her eyes to that depth of knowledge you can get from assessments. She realized that assessment was more about "ABC circle your answers." She now feels that she is able to assess them with more open ended higher order thinking questions. She used a formative assessment with the response system on the second day. The responses of each student were recorded on her computer to give her information about their progress meeting the standards. The third day included a brief ten question quiz about harmful and beneficial. The end of each period also included a series of questions that reviewed the activity. A few of her endorsement lesson reflections provides evidence for her use of formative assessments. Following the implementation of a lesson on heredity she writes:

> Student objectives were measured in a formative journal entry. 90% of students met their performance objectives of comparing and contrasting learned behaviors and inherited traits. This formative assessment helped me plan my flexible groups for the next day's lesson.

Pedagogical Knowledge. She demonstrated a command of pedagogical strategies. She used a variety of graphic organizers to support student understanding. She also appeared to create a supportive classroom environment. She had several pedagogy strategies used to get students attention, "give me five," "everybody freeze." She also used a classroom management system called Class Dojo to award students points for good behavior and to take away points for misbehaving. She used a timer to give students specific time at their stations. She walked around the room and monitored their progress by checking for understanding.

She also included a summarizing strategy at the end of each class period. She reviewed what they had done. At the end of the third class period observed she said to students "I want you to tell your elbow partner – one harmful and why; one beneficial and why." This was followed by a review of their responses.

Content Knowledge. She provided great detail during the discussions with students specific ways the microorganisms were helpful and harmful. She was very focused on the standard. She used questioning strategies to develop student understanding of the content. She was consistent in asking the students to provide details about how the microorganisms were classified, where they were found, and in what ways they were helpful or harmful. She provided details to support the student responses.

Curricular Knowledge. When asked if the endorsement influenced her knowledge of curriculum she replied the vertical alignment project was helpful in developing an understanding of the K-12 curriculum. She elaborated:

> I was really familiar with 5th grade and I knew kind of what concepts were taught in the upper grades, 4th grade for sure. Not hardly any in the younger grades and I was clueless about what was taught in the middle and high school. So, to see that progression and how it builds had definitely influenced my instruction. Because I am able to apply that to my teaching. I know what is required in 6th grade. I can get them ready for that material. I definitely was exposed to it in a way that I had never been before. But I know now the depth of knowledge I need for them to have to progress with the next level of science.

For her vertical alignment project she reviewed the heredity standards found in Kindergarten, fifth grade and seventh grade. She was surprised that kindergarteners were learning about heredity. In her reflection of the lesson she taught to Kindergarten student she wrote:

> I was very nervous to teach a lesson with such young children, being a fifth grade teacher, however I was pleasantly surprised with how well it went. Specifically, the nature of science concepts and ideas were well received with the students. This was the first time they had ever been taught the nature of science and connections to the things they were doing to how scientists work. The students understood how they were acting like scientists in the lesson by sorting pictures, working with their classmates, and record their ideas. Students also understood parent and baby relationships very well. They could easy sort and match pictures of parents with their babies.

Her tenaciousness at teaching the nature of science is apparent through her introducing those ideas to kindergarteners during their lessons about parents and babies.

Self-efficacy. She said that endorsement improved her confidence in her ability to teach science. She reported that science was a strong suit, but the endorsement gave her a better sense of confidence and understanding. She said that going through investigations in the courses was a factor in improving her confidence.

Summary of Emily. She compared the endorsement to other classes that she had taken. “In previous classes, you do the work, say the right thing, your get your grade and move on. You just go through the motions in other classes, but not the endorsement.” She talked about how she was required to implement what she had learned into her classes. She elaborated “you had to look at YOUR setting and YOUR classroom and what you were teaching. You had to apply it to your classroom." Emily described the endorsement as one of the hardest things she had ever done. She commented it was "more challenging than undergrad and grad work, but was the most worthwhile. She continued "It challenged me in ways I needed to be challenged."

Like Margaret, Emily demonstrated a higher degree of enacting reform-oriented instructional strategies in her classes. There were seamless connections between her professional knowledge bases. She used a variety of pedagogical strategies such as graphic organizers and pictures to represent models to develop content related to harmful and beneficial microorganisms. She was successfully able to integrate science process with science content which is a goal of the reform in the Frameworks.

Abbreviated Cases

Three additional teachers were observed and interviewed. They will be presented in abbreviated cases and included in a cross-case analysis.

Meredith

Meredith currently teaches fifth grade. She has a Bachelor's degree and has been teaching for ten years. She teaches two classes of mathematics and two classes of science each day. Her class periods are approximately 60 minutes in length. She was observed three times and interviewed twice. The observations occurred at the end of a unit on cells. The three days observed were primarily review days. Her students had completed a unit on cells, a cell engineering lab, and were reviewing the properties of cells. This first observation was of the students participating in a research project in which they were researching a specific single celled microorganism they had been assigned. She had provided various technology tools for the students to use. Students could use their journals or use one of the class sets of laptops to review the cell resources on a class website.

She was deliberate in her intentions for students to make the connections between their assigned microorganism and the properties of cells. The students were finishing a unit on different types of cells and their parts. Each student had been assigned to research a protist, bacteria, or fungi. She asked students to compare the structures of their assigned microorganism to the basic parts of cells. Following this day of research would be two days of students developing the questions for a review game and playing the review game.

Meredith used various pedagogical strategies such as a review game, semantic grids, and journals to engage students in a review of the concepts. A review of her cell unit plan included lessons planned using the 5E model. The unit included topic specific instructional activities such as labs on gummy bear osmosis, using a microscope, and plant and animal cells. A sample of a lesson plan included:

> Engage (Activating Strategy): Students will be given gummy bears in different forms to view. We will discuss properties of gummy bears.
>
> Explore: Students will use gummy bears to explore how a cell membrane works. Students will use measurement to compare the two gummies.
>
> Explain (Instruction): We will make a class graph documenting the data collected. Students will draw what happened to their gummy (water molecule movement) after a class discussion.
>
> Extend: Students will hypothesize about what will happen to a gummy bear left in salt water overnight.

Meredith was a science major in college and loves teaching science. She enrolled in the endorsement because she wanted to enhance her knowledge and to find new and creative teaching strategies. When asked about her goals and purposes for teaching she said that she wants students to know why science is important. She doesn’t just want them to read out of a book. She elaborated "if kids get their hands on materials, it seems to make a better connection." She said that she was a hands-on teacher before the endorsement, but she learned to probe students for more details when she asked questions. She said she previously asked overarching questions and now she probes for deeper understanding.

Meredith identified her particular group of students as high achieving students who are very inquisitive. She said they are not satisfied with reading a book and answering questions. She described implementing a lab, gummy bear osmosis that she learned in the endorsement. She hooked them with a "gross out factor." Gummy bears are made from collagen which is an animal protein. Although the class days observed were engaging, the students were not involved in hands on experiences.

Meredith credits the endorsement for helping gain strategies to pre-assess students. Prior to the endorsement she considered her students to be blank slates, but the focus on formative assessment probes have helped her understand the importance of uncovering student misconceptions. During the second interview she elaborated the importance of pre-assessments and information gathering activities:

> Most of the time, their misconceptions match up with what I already think they're going to have. And I have a plan in place to address that. And then if I, if something comes up that I don't have a plan for, I have resources, and I have strategies that I can use to pull from to make sure I can get that addressed as soon as possible.

She has realized that all students, even her most high achieving students, have misconceptions. The time spent in the endorsement talking about student misconceptions has helped her to develop a plan to assess her students and find more ways to help students understand the content. She and Clara had the same instructor, Olivia. As mentioned in Clara's case, I observed Olivia teaching multiple times throughout the endorsement. Each visit included Olivia dissecting the choices in an *Uncovering Student Ideas* ((Keeley, Eberle, & Farrin, 2005; Keeley, Eberle, &Tugel, 2007; Keeley, Eberle, & Dorsey, 2008; Keeley & Tugel, 2009) probe. Olivia went through each answer choice and engaged the participants in a discussion why students might have chosen that answer. The probe choices were designed based upon the research base on student misconceptions. The series of probes is one of the instructor resources for the endorsement.

The didactic nature of the lessons observed are likely not indicative of Meredith's orientation to teaching science. Based on the interview and review of her lesson plans, she is more like to have an emerging inquiry or inquiry orientation. Using the 5E's in her lesson plan, engaging students in laboratory experiences related to cells, cells processes and cell engineering suggest an inquiry orientation. Her goals and purposes for teaching suggests her ideas about student engagement. Her assessment knowledge was apparent through her ideas about formative assessment and misconceptions. Her strong pedagogical knowledge was also apparent through her organization of the lesson, use of technology, classroom management and use of graphic organizers.

Christina

Christina currently teaches third grade. She has a Master's degree and has taught for ten years. She has taught all of the elementary grade levels except for first. She spent three years teaching third grade and three years teaching fifth grade. Her class periods are approximately 40 minutes each day. She reports this time is divided between science and social studies. She alternates science and social studies units. She was observed two times and interviewed once. She described a typical day in her class as including opportunities for exploration, questioning, and preparation for standardized assessments. Christina was observed twice during a unit on adaptations.

In the interview, she said she did not have a firm understanding of science content before the endorsement. She was most comfortable teaching life science topics before the endorsement. She has taken two courses during her educator preparation. The courses were Life Science for Elementary Teachers and Physics for Elementary Teachers. She said the endorsement helped her understand big ideas in science and how to "break up concepts for understanding." She identified the 5E model of science as "like a progression of learning." She felt like addressing the content standards across multiple grade levels with the vertical alignment project was beneficial to her understanding of the content.

She enrolled in the endorsement to learn science content in-depth. She wanted to have a bigger view and new ideas to teach science. She said the vertical alignment was particularly impactful as she felt she had a better understanding of what students need to know at different grade levels. Christina said the going through scientific investigations as a learner helped her to have a "better sense of confidence and understanding."

During the interview, she said the instructor asked questions that made her and asked to think about different visuals she could use to represent different topics. Christina also discussed the way in which the instructor provided them with opportunities for hands-on experiences and visual representation of the content. Christina claimed that she wanted to be able to show kids examples of science concepts. This was evident during the observations of her teaching. On multiple occasions, she was observed demonstrating a concept instead of talking about it. She used multiple types of media, a Smartboard with pictures of plants, an ongoing lima bean seed growth lab, reading from their textbook, and a camouflage of seeds lab to provide science concepts. When she wanted her students to understand waxy, she has the student peel off the label off a crayon and dip it into water. The purpose of this was for students to be able to understand the waxy covering of leaves is an example of a plant adaptation. The students were participating in an ongoing investigation occurring by germinating seeds in wet paper towels growing inside a plastic bag. They recorded data in their science notebooks.

Christina's content knowledge about adaptations seemed fragmented. She seemed to alternate between adaptations of a population and the adaptations of an individual. For example, she gave examples of plant adaptations such as waxy leaves. But, on several occasions she talked about a plant in the classroom and told students, "the plant will try to adapt". She was referencing the plant had been moved from her home to the classroom. The conditions of temperature and amount of light were different in these two locations. For these reasons, it appeared she was holding common misconceptions about plant adaptations. Adaptations of populations of organisms are complex and difficult to understand.

She demonstrated an emerging use of nature of concepts. She had a sign above her SmartBoard that said "Show me the Evidence" and several times I saw evidence of discussing with students about the nature of science. She explicitly talked about using models in science.

Christina's professional knowledge bases seem to be moderately connected. Her pedagogical knowledge is evident by the use of graphic organizers and science notebooks. Her content knowledge of the topic of adaptations is fragmented. Her use of topic-specific instructional strategies to develop understanding of adaptations was emerging. Her orientation seems to be one of discovery/process which was classified by Friedrichsen et al. (2011) as in line with the early reform of the 60's and 70's.

Callie

Callie is a 32 year veteran teacher currently teaching first grade. She has a specialist degree and reports she has completed multiple teaching endorsements. She reports she teaches science 60 – 120 minutes per week. She also has the constraint of alternating science and social studies. She was observed three times during a unit on claims and evidence and interviewed once.

In the interview, she identified her goals and purposes for teaching science to first grade students are to help her "students understand they all have gifts to save the world." She uses the group names of professors, scientists, explorers and engineers. The purpose is for the students to be able to explore these different types of jobs. She reported she also used the jobs to be able to review the different perspectives and strengths of members of those professions. Another goal she mentioned was encouraging students to be willing for a challenge, persistent, and dedicated to learning.

She chose to enroll in the endorsement because she wanted to enhance her ability to help her students think more critically. She said science has always been a passion of hers. She believes her instructor was modeling critical thinking, and she now emphasizes critical thinking with her students. She commented "Going through the science endorsement, helps me see I am capable of guiding my children to be critical thinkers." Callie repeatedly commented "it's okay to say I don't know". She indicated that the risk free environment of the endorsement and the modeling of the instructor helped her to develop a sense of confidence to teach science. She used the term empowerment to describe how she felt after the endorsement.

She described her content knowledge before the endorsement as a constraint. She gave numerous examples of how the endorsement influenced her content knowledge. She learned about electricity and the concept of open circuits. Although she was aware of how to conduct scratch tests, she received more exposure to attributes of rocks. She gave that as an example of an area she has her knowledge extended. She learned how earth plates move and enhanced her understanding of weather fronts. One of her favorite activities during the endorsement was the dissection of a flower.

In terms of her curricular knowledge, she reports that she was already integrating the subject areas but claimed the endorsement solidified her understanding of how to do that. She indicated the vertical alignment project was important in her feeling she is able to assist teachers and school administrators in their “understanding and accepting the importance of science. They must see the growth and direction science needs to empower the students as thinkers.” She chose the Nature of Science as her topic for vertical alignment.

Her use of claims and evidence were observed during the three days I visited her class. She was working with first graders to develop an understanding of how we use claims, evidence, and justification. She engaged her students in the mystery of Big Foot, provided them with opportunities to look at data related to sightings, and draw their own conclusions about their beliefs about whether or Big Foot exists. She maintained a high degree of teacher-control during the lesson. She attributed this to the need for younger students to establish routines.

She is an emerging leader of elementary science in her district. She was tapped to coordinate three professional development days for teachers in the district with her instructional coach. She says she focuses on the importance of critical thinking skills and inquiry-based skills.

Based on the observations and interviews, Callie appears to have an emerging reform-orientation. Her use of critical thinking skills and NOS concepts of claims and evidence provide support for this orientation.

Summary

Based on the observation and interview data, the endorsement program appears to have influenced on several aspects of professional knowledge bases related to the professional knowledge bases of elementary teachers. The following ideas emerged from data of these participants.

Pedagogical Knowledge, Reform Orientations & Knowledge of Instructional Strategies

The self-efficacy survey provided support that the elementary teachers had confidence in their pedagogical knowledge prior to the endorsement. Participants demonstrated a strong knowledge of pedagogy during the classroom observations. They developed safe classroom environments and established rituals and routines in their classes. They demonstrated strong classroom management. They also used graphic organizers and technology to support development of content.

The self-efficacy survey results also provided support for a shift towards reform-oriented instructional practices in their classrooms. This was evident in the inquiry nature of the lessons observed. Emily used models to develop student understanding of helpful and harmful bacteria; Margaret used a guided inquiry to develop student understanding of the technology design process; and Clara used demonstrations and structured inquiry to develop student understanding of weather and air pressure.

Content Knowledge, Lesson Planning & Integrating Science

The content assessments demonstrated an increase in content knowledge during the endorsement. The self-efficacy survey demonstrated an increase in confidence in understanding of student misconceptions and planning lessons that develop student understanding. Appleton (2002, 2003) recommends the 5E model be used with beginning teachers to help develop PCK for teaching science through a conceptual change approach as a way to move teachers beyond "activities that work" (Appleton, 2002, p. 393). Clara reported she was "not just doing fun activities" and not "doing all the fluff" but was becoming more thoughtful of what and how she is teaching. She begins a unit by first reviewing the standards and then determines the assessment. She also reported that she focuses more now on student misconceptions.

The themed lessons of the endorsement provided participants with understanding of vertical alignment of big ideas, integrating science, and the nature of science. Participants reported they only knew the curriculum at their respective grade levels prior to the endorsement and that the endorsement opened their eyes to concepts at other grade levels. For Margaret, the nature of science allowed her to develop student understanding of the Big Bang theory.

They also reported they felt more capable to integrate science with other subjects, particularly literature and mathematics. All of the participants engaged their students in the use of science journals. Margaret also engaged her students in geography and history as she developed student understanding of bridges.

Emerging Leadership in Elementary Science

Most of the participants reported leadership roles in elementary science. Emily and her instructor are writing an article about the NOS unit she developed during the endorsement class. They are working on a submission to the National Science Teacher Association journal, Science and Children.

Margaret reported that she coordinates the Family Science Night at her school as well as coaches the First Lego League and Science Olympiad teams. She commented that it is important for her that those events are opened up the entire school and are not limited to the gifted student she teaches. She and her husband who is a scientist, presented at a regional NSTA convention.

Clara reported that she is teaching inquiry and engineering professional development for her school district on professional development days. She is planning three different one day workshops for teacher in her district. She reports being surprised that teachers are not currently implementing inquiry in her classrooms. Callie also reports leading district-wide professional development.

All three of the participants reported being a science resource person at their school. They all share science lessons with their colleagues at their schools. Emily and Clara have maintained contact with their instructors. All three reported they stay in touch with their colleagues from the endorsement and continue to share ideas with them even though they are at different schools. The SE survey found 12.9% of those surveyed in leadership positions including school administration, instructional coaches and K-5science lab teachers.

Chapter 5 will include a merging of all of the data and present a discussion about the implications of an endorsement on the professional knowledge bases of elementary science teachers.

CHAPTER 5: DISCUSSION

The purpose of the study was to explore the influence of a K-5 science endorsement on the dimensions of professional knowledge of elementary teachers. The K-5 science endorsement is a sustained professional development experience that involves four cycles of developing, teaching and reflecting on lessons. The endorsement program is a unique professional development experience in that 1) it includes a residency in which participants develop “themed” 5E lessons with opportunities to teach and reflect on the lessons implemented with their students; and 2) is a collaboration between a state agency and a school district to offer in-service elementary science teachers the opportunity to add a K-5 science field to their teaching certificate upon completion of the requirements. Three research questions guided this parallel, convergent mixed methods study. The overarching research question is: How does participation in a K-5 science endorsement influence the professional knowledge bases of in-service elementary science teachers? The three sub questions are:

1. How does participation in a K-5 science endorsement influence the content knowledge of science teachers? Specifically, is there a significant mean difference between pre and post scores on the content assessments?
2. How does participation in a K-5 science endorsement influence the self-efficacy of science teachers? Specifically, is there a significant mean difference between pre and post scores on the self-efficacy survey?
3. How does a K-5 science endorsement influence the degree of connections of the professional knowledge bases of elementary science teachers?

Research Question One

How does participation in a K-5 science endorsement influence the content knowledge of science teachers? Specifically, is there a significant mean difference between pre and post scores on the content assessments? Two questions, one qualitatively oriented and the other quantitatively oriented, addressed differences in participant content knowledge before and after the endorsement. Statistically significant differences in content knowledge were found from pre to post on life, earth and physical science assessments. These differences indicated increases in content knowledge during the endorsement. The assessments were based on NSES standards at grades K-4 and 5-8. Exploratory data analysis did not find significant differences in gain scores when comparing teachers of grades K-2 and grades 3-5.

Research Question Two

How does participation in a K-5 science endorsement influence the self-efficacy of science teachers? Specifically, is there a significant mean difference between pre and post scores on the self-efficacy survey? Statistically significant differences in self-efficacy were found on a newly developed self-efficacy survey organized into dimensions of professional knowledge that influence PCK. Individual items and categories demonstrated statistically significant differences in means of the pre and post self-efficacy survey. The retrospective pre self-efficacy survey indicated high means indicators that represented pedagogical knowledge. This indicates elementary teachers began with endorsement with a higher degree of efficacy for pedagogy than for reform-oriented constructs. Higher means on the observation instruments, RTOP, PACES and POGIL found the six teachers observed to have strong pedagogical knowledge as evident by their classroom practices. Khourney-Bowers & Fenk, (2009) found similar results of higher efficacy of elementary teachers for teaching chemistry following a professional development experience with opportunities to experience the content, interact with peers and experts.

Higher mean differences in reform-oriented practices after the endorsement suggests the endorsement influenced knowledge of instructional strategies. The opportunity to experience reform-oriented instruction with content experts coupled with developing, teaching and reflecting on lessons enacted in their classroom, is suggested to be the reason for these differences. These results are similar to the findings of Park and Oliver (2008) study of chemistry teachers working through the National Board Certification (NBC) process. They posited the NBC process influenced the PCK development of the teachers indicated by their becoming more reflective about their teaching as they implemented new instructional strategies.

In considering implications to implementing the ideas in the Frameworks (2012), these findings suggest elementary teachers' strong pedagogical knowledge. It will be important to build on the strengths of elementary teachers. The findings suggest classroom management would not be a hindrance to implementing reform-oriented instructional strategies. Martin-Hansen (2009) found classroom management to be a roadblock to implementing inquiry.

Research Question Three.

How does a K-5 science endorsement influence the degree of connections of the professional knowledge bases of elementary science teachers? Multiple data sources were used to look for connections among the professional knowledge bases. Multiple regression analyses of the dimensions of professional knowledge within the PCK SE Survey were conducted to determine the degree of connectedness of the knowledge bases. Observations and interviews were used as a means to triangulate the data and explore the relationship of the knowledge bases enacted in practice. The findings suggest the strongest relationship between the dimensions:

Orientation and Instructional Strategies. This relationship supports Park and Chen (2010) findings related to the connections between a didactic orientation and challenges implementing reform.

Margaret, Emily, and Clara demonstrated the strongest degree of enacted reform in their classrooms. Avraamidou & Zembal-Saul (2010) found differences in the types of inquiry enacted in the classrooms of new elementary teachers. Varying degrees of reform were observed in the classes of the six participants. The observations of Margaret demonstrated the most seamless connections of the dimensions of knowledge. Margaret's ability to integrate her content knowledge with topic-specific elementary strategies demonstrated a high degree of PCK for enacting reform-oriented strategies. Margaret's case provides support for the statement that the roots of PCK "reside in a teacher's understanding of the content along with the instruction of the content" (Lee & Luft, 2008, p. 1344). Emily's enacting NOS with her students also provides an example of highly integrated knowledge bases.

Teaching orientations are complex and influenced by a number of factors (Friedrichen & Dana, 2005; Friedrichsen et al., 2011). They suggest teachers may have more than one orientation; and orientations are influenced by a number of factors including constraints to teaching and professional development. The findings from this study suggest that fragmented content knowledge may provide challenges with enacting reform-oriented practices as indicated by observations of Clara and Christina. These participants were developing content related to pressure and adaptations. Both of the concepts are challenging to teach. The teachers in the study were only observed during one unit. These findings represent their enactment of specific content and may not be indicative of teaching different concepts.

Other dimensions of knowledge demonstrated strong relationships from the multiple regression analysis were Knowledge of Student Conceptions with Content Knowledge of Assessment. A goal of the endorsement that appears to have influenced this connection is the focus on student misconceptions through the use of formative assessment probes (Keeley, Eberle, & Farrin, 2005; Keeley, Eberle, &Tugel, 2007; Keeley, Eberle, & Dorsey, 2008; Keeley & Tugel, 2009). Working through common misconceptions of students led teachers to gain a better understanding of the content and ways that students think about content. This was particularly evident from interviews with Clara, Meredith, and Callie. These participants had the same instructor who focused on these concepts.

The vertical alignment lessons the participants developed during the endorsement impacted their curricular knowledge. As evidenced by interviews, candidate gained a better understanding of the vertical alignment. This has implications for the ideas related to learning progressions in the Frameworks (NRC, 2012). These findings suggest that providing teachers with opportunities to research the progression of ideas and develop and teach lessons at different grade bands solidifies their understanding. Multiple regression analyses found a relationship between curriculum knowledge and knowledge of student conceptions in science.

Integrating the Data

In a convergent, parallel design, the quantitative and qualitative data are collected at the same time, analyzed separately, and merged together. In order to integrate the data, a chart was developed that listed the dimensions of professional knowledge in rows. The sources of analyzed data and findings were presented in columns. Table 27 provides a summary of the data.

Table 30

Integrating the Data

	Quantitative	Qualitative Interviews	Qualitative Observations
Pedagogical Knowledge	SE survey indicated high efficacy in pedagogy indicators <u>before</u> the endorsement: Items (27-30, pedagogy); 13, 16, 18, 9 Orientations and Assessment accounted for 54.6% of the variation in pedagogical knowledge in the regression analysis.	Constraints varied across the participants. Several identified content knowledge was a constraint prior to the endorsement. Emily mentioned ways to differentiation was a constraint before and her instructor provided ideas she could use to help. Several mentioned their instructors gave them ideas for inexpensive materials that could be used for labs which reduced that as a constraint. Pedagogical skills did not come up as a constraint.	Pedagogy and Management Strategies observed across all participants. Patience with students was a characteristic of all teachers. Propositional Knowledge and Classroom Culture categories of RTOP were highest across all observations. Highest RTOP indicator: 16. Students were involved in the communication of their ideas using a variety of means and media. PACES and POGIL indicated high use of pedagogical strategies; lower use of reform-oriented strategies
Content Knowledge	There was a significant difference between pre and post scores of life, earth and physical science content. Considerable variation in pre test scores indicates participants came in with differing degrees content knowledge.	Instructor focus on questioning strategies, formative assessments, and student misconceptions helped developed their CK and understanding of how student learn about science. Engagement in constructivist experiences at multiple	Accurate content was portrayed in most lessons. Two of the lessons demonstrated incomplete teacher knowledge about the concepts such as adaptations and air pressure. Highest RTOP indicator: 6. The lesson involved fundamental

	Student Conceptions accounted for 70% in content knowledge.	grade levels also developed their CK.	concepts of the subject.
Knowledge of Students	Highest mean difference: 15. Clarify student misunderstandings or difficulties in learning science concepts 17. Present ideas that challenge students' thinking about science Multiple regression: Predicted by CK and KIS 76%	Differentiation for different learners. Awareness of learner differences.	Patience with students was a characteristic of all teachers.
Assessment Knowledge	Highest mean difference: 23. Use a variety of types of assessments (journals, student presentations, lab reports). Multiple regression: Students 70%	Knowledge was gained about the use of formative assessment and questioning strategies to inform instruction.	Formative assessments T-Charts Graphic Organizers Journals
Curricular Knowledge	Highest mean difference: 25. Use knowledge of the vertical alignment of the curriculum to make connections to content taught at other grade levels Predicted by Orientations & Knowledge of Student Conceptions 70%	Influence of endorsement on understanding of curriculum Participants entered the program with knowledge of Integrating the curriculum. The program enhanced their understanding of the vertical alignment of standards.	Sequence of lessons Explore before explaining

Knowledge of Instructional Strategies	Highest mean difference: 1. Implement inquiry based instructional strategies for the purpose of designing investigations, collecting evidence and making claims 2. Involve students in discussions in which students communicate claims and evidence from investigations 3. Implementing strategies that provide students with opportunities to explore science concepts before they are explained Orientations accounted for 80% of the variance with instructional strategies.	Review of Lesson/Unit Plans Knowledge gained to develop instructional sequences Influence of endorsement on instructional practice	A range of structured to guide inquiry was observed. Most participants demonstrated an emerging use of reform-strategies in the elementary classroom. Demonstrations Use of Modeling Evidence-based support
Orientations	Highest mean difference: 8. Communicate to students ways that the content is relevant to their lives Predicted by Knowledge of Students 80%	Goals and purposes for teaching, typical day in science	Varying degree of reform; range from emerging reform to reform-oriented; use of NOS strategies Varying degree of teacher control during the lessons observed.
Efficacy	There was a significant difference between pre and post scores across all SE items and survey categories. Considerable variation in scores on individual indicators indicate participants came in with differing degrees of confidence in the dimensions of professional knowledge	Confidence to teach science Enhancing CK and the freedom to say "I don't know, but we can look it up" enhanced efficacy for teaching science.	Taking risks - Clara – demonstrations Student Centered Teaching – Margaret, Emily NOS – Emily

Assertions

Assertions were developed based upon trends across the data. These data were results from the quantitative observation scores, pre and post content assessments and self efficacy survey; and qualitative data from across the individual cases.

Assertion One. *The results from the self-efficacy survey indicated a high degree of general pedagogical knowledge prior to the endorsement and a shift in confidence in using reform-oriented strategies and skills following the endorsement.*

All six participants observed demonstrated evidence of solid pedagogical knowledge in their general classroom practices. Classroom management strategies such as: 5, 4, 3, 2, 1, eyes on me" were used in classes to focus students on the lessons. Semantic grid analysis, t-charts and other graphic organizers were used to provide students with scaffolds and summarizers of content. Rituals and routines during group work, transitioning to laboratory experiences were also evident across all classrooms. Martin-Hansen (2009) asserts that difficulties with classroom management may be a roadblock to implementing reform. For these teachers, classroom management and general pedagogical knowledge seem to be strength.

The use of reform-oriented instructional strategies was also evident during classroom observations. All participants observed used science journals as an instructional strategy. Clara and Meredith's use of science journals to keep track of "wonderings" and data from experiments and Margaret's MONKEY books provided opportunity for students to keep records of their work. This was also reflected in the self-efficacy survey item 23) "use a variety of types of assessments (journals, student presentations, lab reports). It was one of the items with the highest mean difference.

Other examples of reform-oriented instructional strategies included Margaret's technology design loop during the marshmallow challenge; Callie's evidence based reasoning; Emily and Allison's explicit use of NOS when focusing on models. These were examples of reform-oriented strategies they learned about during the endorsement, practiced, and reflected upon for future practice.

Margaret attributed having the opportunity to experience learning "the way we want our students to learn" as being one of the most beneficial aspects of the endorsement. She also reported that having the time to implement strategies learned during the endorsement with her students then followed by time to discuss the implementation with instructor and colleagues was beneficial. These ideas were echoed by other participants.

All of the journals include laboratory and class activities and were used to keep records of data and wonderings. This is consistent with the reform-practice of keeping accurate records. In the interview with Clara she reported that her students maintain a journal throughout the school year. One of the ways that she uses journaling is for the students to keep track of their wonderings. She models having her own wonderings during instruction and encourages students to write down their wonderings in their journals. She has students keep this running record of wonderings as a resource for them to generate science fair ideas. Margaret has her students maintain MONKEY books. As her students completed various engineering challenges, they kept records in their MONKEY books.

"Involving students in discussions in which students communicate claims and evidence from investigations" was another self-efficacy survey question with one of the highest mean difference from pre to post. All participants referenced claims and evidence, using models, making predictions or acting like scientists during their observations. This was particularly evident during observations of Emily and Christina. These two participants were very explicit about how they were using models.

Assertion Two. *Instructors modeling probing questions influenced elementary teachers' content knowledge and efficacy.*

Participants reported that instructor "think alouds" and thought provoking questions had significant impact on their growth as teachers during the classes. Meredith reports "and now I can actually say, I can make them look at a deeper level" while Christina said the going through scientific investigations as a learner helped her to have a "better sense of confidence and [content] understanding." For Callie, this manifested itself as critical thinking. She believes her instructor was modeling critical thinking and she now emphasizes critical thinking with her students. She commented "Going through the science endorsement helps me see I am capable of guiding my children to be critical thinkers." Callie repeatedly commented "it's okay to say I don't know". She indicated that the risk free environment of the endorsement and the modeling of the instructor helped her to develop confidence to teach science. This was evident in her claims and evidence unit when students were required to justify their claims with evidence.

Margaret described the important of having a safe place to ask questions. Having instructors say "I don't know, but I'll tell you next week" provided participants the freedom to say to their students "I don't know, but we can find out." This seemed to be an important factor contributing to their confidence to teach science. From the observations, it was evident Margaret was providing a risk free environment for her own students.

Assertion Three. *Repeated opportunities to teach and reflect on lessons written using a learning cycle model influenced participants' ability to plan purposeful, standards based lessons.*

Appleton (2002, 2003) recommends the 5E model be used with beginning teachers to help develop PCK for teaching science through a conceptual change approach as a way to move teachers beyond “activities that work” (Appleton, 2002, p. 393). Clara reported she was “not just doing fun activities” and not “doing all the fluff” but was becoming more thoughtful of what and how she is teaching. She begins a unit by first reviewing the standards and then determines the assessment. She also reported that she focuses more now on student misconceptions. Margaret’s ideas of “jumping around” provide opportunities to engage students in multiple instructional strategies to develop the content. Meredith explained that all of the parts of 5E lessons were in her lesson before the endorsement, but she is more explicit about it in her lessons now. The themes of the lessons, particularly the vertical alignment and integrated lessons had an impact on the participants. Four of six participants discussed the impact the vertical alignment project had on their understanding of science ideas across the various grade levels.

This was also evident in the two of the self-efficacy items with the highest mean difference including 25) “use knowledge of the vertical alignment of the curriculum to make connections to content taught at other grade levels;” and 3) “implementing strategies that provide students with opportunities to explore science concepts before they are explained.”

The 5E lesson planning model was new to all of the participants, but in the interviews they all discussed how they were planning with the E’s in mind. "And I think that was a really big thing with the units. You know, you write, you plan for the unit, you write it, you teach it but then you need to go back and reflect on it. And I think that was something I really learned to do" was a quote from Emily.

Margaret described the integrated science unit she developed and implemented with her second grade students on human impact on the environment. This assignment required candidates to integrate science with at least one other subject in the context of a local or global issue. Margaret chose the human impact issue of plastics in the environment. She engaged her students in activities that developed their understanding of how human use of plastics can be harmful to the environment. She also connected the activities to students with prosthetics and wheelchairs. She noted their school has a number of differently-abled students.

Assertion Four. *Observations of participants demonstrated evidence of connections between several dimensions of knowledge. This connection was particularly evident between content knowledge, knowledge of students and knowledge of instructional strategies.*

This was also evident during classroom observations. Emily very thoughtfully developed the concept "identify microorganisms that are helpful and harmful" from the standards. During the three days of observations, Emily provided the students with multiple opportunities to engage in understanding the concept using 5 E lessons. These strategies included a station lab in which they looked at pictures of microorganisms, classified them as harmful or beneficial, and provided evidence of why they chose that classification. This was followed by finding pictures of microorganism in a magazine and sorting them into a T-chart as to their classification.

The participants reported that a focus on content knowledge and instructional strategies by an instructor with enthusiasm and expertise was beneficial. The instructors provided a safe environment for their learning. Margaret discussed the benefits of having opportunities to try out strategies with students and being able to go back and discuss with instructors and other colleagues was beneficial. Park and Oliver (2008) found that "teacher understandings of student misconceptions was a major factor that shaped planning, conducting instruction, and assessment" There is a synergy that seems to be taking place between elementary teachers, with strong pedagogical skills and knowledge of elementary students with an instructor that is an experienced middle or high school science teacher. Collectively, they hold a lot of knowledge about science content, instructional strategies and students. Evidence suggests an interplay between the focus on student misconceptions, content knowledge, and instructional strategies. Margaret describes the way in which the instructors presented science content in multiple ways that allowed her the freedom to "jump around" in order to develop a concept. In an interview she compared how she taught in the endorsement to how she teaches now. She said before the endorsement she would have had students read about a topic, complete one experiment and then move on to the next topic. After the endorsement, she reports that she may show a few short video clips, play a game, complete experiments, have discussions in order to develop a topic.

"Because of science endorsement and misconceptions, I had some misconceptions that were straightened out and things that I'd be teaching my whole life" was a quote from Clara. Her discussion about science misconceptions was a theme throughout the interviews. It was also one of the self-efficacy questions with the highest mean difference from pre to post was 15) "clarify student misunderstandings or difficulties in learning science concepts."

Assertion Five. *K-5 science endorsed teachers demonstrate emerging leadership as elementary science teachers in their schools and districts.* All six interviewed reported that teachers in their schools and district had begun to look to them for resources and to lead professional development. All six candidates demonstrated leadership in one or more of the following ways:

Delivering professional development. Clara and Callie were leading district-wide professional development on inquiry and STEM practices. Both worked in conjunction with their endorsement instructor who is a district science coach. They developed a series of professional development workshops for teachers. Clara's focus was on the integration of STEM.

Supervising a Student Teacher. Two of the participants, Clara and Emily had a student teacher from a local university present in class during observation days. As recorded in observer field notes, Emily's student teacher reported that she wanted to teach like Emily.

Source of Science Information. All six participants interviewed had become science leaders in their schools by serving as a resource for science teachers at other grade levels. Since they had completed the endorsement, other teachers often came to them for science resources and ideas. They also reported they remained in contact with the other teachers from their endorsement cohort. They reported they emailed resources to each other and shared ideas.

Journal articles and conference presentations. Emily is working with her endorsement instructor as co-authors for a paper in a practitioner's journal about using the Nature of Science with elementary students. This instructor also co-presented at a regional science teacher conference with another participant not included in the study. Margaret presented at a regional science teacher conference with her husband, a scientist at a local university.

Science Leadership Roles. A number of teachers completing the self-efficacy survey reported they had transitioned from the classroom into various science roles in their schools or districts. These roles included K-5 science lab teachers, science facilitators, and teachers of gifted students.

Assertion Six. *Instructor areas of interest and expertise have been translated by and implemented in the classroom of the participants.*

The K-5 participants are from multiple districts and have had different instructors who are science leaders in their respective school districts. All participants have taken the same series of courses. It is interesting to see the similarities and differences of how they are integrating what they have learned into their current teaching situations. Participants have tended to integrate teaching strategies emphasized by their instructors. For example, three participants, Meredith, Clara and Callie, who had the same endorsement instructor, have stressed the importance of understanding and probing for science misconceptions before they begin a unit. In observation of the instructor during the endorsement, it was documented in the instructor observation how carefully she explored student misconceptions with her participants. The two other participants, Emily and Christina stressed the nature of science with their students. Nature of Science was the dissertation topic of her instructor.

Social Cognitive Theory

It is important for elementary teachers to experience reform-oriented practices as indicated in the Frameworks (NRC, 2012). The results of the study indicate teachers that experienced a reform-oriented endorsement and implemented reform-oriented strategies with their students. This study is consistent with findings from previous studies. Elementary teachers that participated in a constructivist oriented professional development showed gains in content knowledge, personal science teaching self-efficacy, and pedagogical content knowledge (Khourney-Bowers & Fenk, 2009). Varma, Volkmann, & Hanuscin (2009) found that elementary preservice teachers gained an appreciation for the importance for using constructivist methods after they experience those methods.

Increases in self-efficacy across all the professional knowledge bases were evident in the PCK differences found in the self-efficacy survey. Observations and interviews provided a more detailed picture of how the endorsement influenced self-efficacy. This can be viewed through the lens of Social Cognitive Theory which outlines four types of experiences that influence self-efficacy. The next section outlines how these experiences may have influenced the dimensions of professional knowledge of the endorsement participants.

The endorsement provided opportunities for *mastery experiences.* Participants developed lessons and units throughout the endorsement. The units were theme based and focused on vertical alignment, integrating science, differentiation, and the nature of science. Participants were given feedback from their instructors during the development of the unit. Lessons were implemented with students followed by a required unit reflection. Through interviews with participants, it was evident that the theme of the lessons and instructor support during the implementation of the lessons increased their confidence in developing lessons. The repeated cycle of lesson development, implementation, and reflection of lessons helped the participants develop mastery.

The vertical alignment of the content allowed participants to experience mastery at various grade levels in various domains. Participants were required to develop at least two lessons at different grade bands, K-2 and 3-5. They were required to teach those lessons to students. As a part of the process of developing the lessons, they had to research a science concept across multiple grade levels.

The endorsement provided an opportunity for the participant to have *vicarious experiences*. Instructors modeled reform-oriented instructional practices and “jumped around” to develop science content. Participants described their instructors’ use of *Uncovering Student Ideas* formative assessment probes as providing a model for understanding students’ misconceptions about science. They also described how their instructors’ use of questioning and critical thinking strategies had provided models for how they could adapt those in their classrooms.

The endorsement provided an opportunity for *verbal persuasion.* In observations and interviews, participants discussed the important role the instructors played in enhancing their content knowledge and confidence to teach science. The instructors provided encouragement for the participants as they developed their content knowledge and lessons.

The endorsement provided an opportunity for candidates to enhance their individual *attributes.* The candidates began the endorsement with different backgrounds and experiences. There was a high degree of variability in content pre/post assessments. The endorsement provided opportunities for participants to experience content at the NSES, K-4 and 5-8 levels. The candidates also had choice in determining the topics upon which to base their units. There were opportunities for individual growth in both areas of interest and grade bands.

The next section will focus on the implications on this study on policy, professional development and teaching practices.

Implications on the Study

Policy

The stakes are extremely high for elementary science teachers. We expect them to teach multiple subjects, implement research based pedagogical practices, master content across multiple domains of science, and teach science in a reform-oriented manner to an increasingly diverse students (Davis & Smithey, 2009; Wilson & Kittleson, 2011). We measure how successful they are at meeting of those goals through the use of high stakes assessments. This tension between how they are expected to engage students and how their success as teachers is measured leads to a number of constraints. One of those constraints is the degree of teacher versus student control of the learning (Loughran, 2007; Treaguest, 2007). We expect teachers to engage students in student centered practices, yet the nature of teacher assessment lends itself to more teacher centered methods (Font-Rivera, 2003; Hamilton et al, 2007; Anderson, 2011. The challenges surrounding giving up teacher control of learning is particularly challenging for elementary teachers who often have limited science content knowledge and experience with reform-oriented practices (Appleton, 2007; Davis, 2006; Park Rogers, 2006).

Reform documents in science education such as the Frameworks (NRC, 2012) and the Next Generation Science Standards (NRC, 2013) include goals of engaging students in science and engineering practices, cross-cutting practices and disciplinary core ideas of the domains of science. A difference in the NGSS from the NSES is the focus on embedding the practices within the content. Reform-oriented instructional strategies delivered in a student center manner will be critical to realizing the goals of the reform (Duschl, Schweingruber, & Shouse, 2007; Loughran, 2007). A research base exists that supports the importance of teachers experiencing reform-oriented methods and challenges in implementing those methods. This study suggests that it takes time for in-service elementary teachers to integrate new instructional strategies into their classrooms. The teachers observed demonstrated emerging use of reform-oriented strategies approximately one year following their participation in the endorsement.

In order to realize the goals of the Frameworks, it will be important for broad, overarching programs with goals of increasing multiple dimensions of teacher knowledge. An endorsement model provides a professional development opportunity that may help teachers meet both the goals of the policy that is associated goals of science reform documents. The study highlights the strong pedagogical knowledge that elementary teachers brought to the endorsement. This study suggests they started the endorsement with a high degree of confidence in pedagogical knowledge. There was a shift towards more confidence in use of reform-oriented instructional strategies. In considering professional development to realize the goals of the

Frameworks, this prior knowledge and experiences of in-service teachers will be important to consider. For elementary teachers, it will also be important to focus on content and topic specific, reform-oriented instructional strategies with consistent messages of engaging students and going beyond "activities that work." By experiencing science content through reform-orientated instructional strategies, endorsements enhance the array of instructional strategies of elementary teachers. As evidenced by the findings from this study, an endorsement has the capacity to move teachers towards student-centered, reform-oriented practices.

Another constraint for elementary teachers is the time allotted for teaching science (Center for Education Policy, 2007; Banilower et al., 2013). In many schools, NCLB requirements for mathematics and reading have led to decreased time for teaching science. As this study suggests, teachers who have completed the endorsement teach science more frequently and for longer class periods than the national average (Banilower et al., 2013). The reason for that is unclear and could be explored in a future study.

Professional Development

Professional development that includes a focus on the multiple domains of content and strategies is especially important for elementary teachers. The K-5 science endorsement model is consistent with the recommendations of good professional development (Duschl, Schweingruber and Shouse, 2007; Opfer & Pedder; 2011; Singer, Lotter, Fetter & Gates, 2011). It involves sustained contact, a focus on integrating science content and process, and provides an opportunity for teachers to apply their learning into their classroom with their particular group of students. It also supports the recommendation of Appleton (2003) that includes providing a supportive environment in which teachers develop *units that work* to move elementary teachers away from activities *that work.*

The endorsement goals paint a broad stroke across the dimensions of teacher professional knowledge. A compelling feature of the endorsement is that it met elementary teachers where they were at the beginning of the endorsement. As evidenced by the diverse pretest scores of the content assessments at the beginning of each course and the retrospective pretest, participants came in to the endorsement with a wide array of knowledge and skills. The goals of the program included a focus on enhancing content knowledge, knowledge of instructional strategies, assessment knowledge, and curricular knowledge. The findings also suggest that teachers were able to adapt certain aspects of the endorsement fully into their classrooms. The strategies enacted were also varied. Margaret's lesson focused on guiding inquiry of structures with fourth grade students; Emily's lesson focused on using content representations of models in order for students to understand the concepts of microorganisms with fifth grade students; Clara's demonstrations engaged students in an understanding of air pressure; Callie used claims and evidence to understand a mystery with first grade students; Christina used crayons to help third grade students understand the idea that the waxy covering on plants represents an adaptation; and Meredith focused on connecting the ideas of cell structures of the cell structures found within microorganisms with fifth grade students. Each participant uniquely adapted what she learned in the endorsement to implement with her particular students in her classroom. Professional development experiences to prepare teachers for the ideas in the Frameworks (2012) needs to include opportunities to meet teachers where they are at and apply what they learn into their classrooms.

These findings suggest elementary teachers, in general, have strong pedagogical knowledge and are able to integrate multiple subjects. The endorsement provides an opportunity to enhance those skills through a focus on topic specific instructional strategies. Elementary teachers are already integrating subjects, have strong pedagogical knowledge, and know their students. It seems many elementary teachers may be like Margaret who said before the endorsement she would give students the vocabulary, do a lab, and then move on to the next concept. Or like Christina, have them read about it.

Practice

The practices of elementary teachers are often constrained by limited content knowledge and lack of experience with reform-oriented practices (Appleton, 2007). The endorsement model of professional development provided an opportunity for teachers to enhance their content knowledge, knowledge of how students learn science, and experience reform-based strategies. There is suggested influence including emerging reform instructional strategies seen in the classrooms of participants.

The individual cases in the study demonstrate that teachers took different elements from the endorsement and enacted various strategies with their students. A critical feature of professional development is how that professional development is translated in the classrooms of participants with their students. All of the teachers exhibited a focus on reform-oriented strategies within their particular classrooms. For Emily, it was a focus on NOS and content development for her diverse learners. For Margaret, it was a focus on developing content and using inquiry strategies for her learners identified as gifted. For Callie, it was a focus on evidence based reasoning for her students, many of whom were learning English. For Clara and Meredith, it was a focus of actively engaging high achieving students. Each of their classrooms represents a diverse group of students with varying needs. The RTOP scores also indicated a high degree of variability. This could be attributed to differences in how the teachers are adapting what they have learned or challenges with giving up teacher control. This could also be due to the nature of particular lessons observed. A limitation of the study is that only one unit was observed.

Emerging teacher leadership is an unexpected outcome of this professional development. All six participants shared emerging new roles of leadership in science. Writing journal articles, leading professional development in their districts, presenting at conferences, and functioning as a science resource person at their schools were some of the ways their new leadership roles were evident.

Limitations of the Study

There are limitations associated with every study and this study is no exception. The lead author of the study coordinates the endorsement. This was considered both a strength and weakness of the study. As the coordinator, I had an intimate knowledge of the program. Being familiar with the goals and the teaching practices of the instructor was considered a strength. I had observed Olivia's use of formative assessment probes to address student misconceptions and aware of the dissertation topic of Emily's instructor. I had also observed Emily's NOS presentation during a routine observation of an endorsement class. To add trustworthiness to the study, peer debriefers were involved in the coding of all data. Multiple debriefers collaborated in a review of the assertions. The lead author was trained to use the RTOP and collected practice data with dissertation advisor.

Another limitation is the sample size of participants. Field (2009) recommends a sample of ten participants per predictor variable when conducting exploratory data analysis using stepwise multiple regressions. This sample size was smaller than recommended. For this reason, these data was corroborated with observations and interviews.

Conclusion

A parallel, convergent mixed-methods approached was used to explore the influence of the K-5 science on the professional knowledge bases including PCK of elementary teachers. The study provides insight to aspects of their professional knowledge bases following a sustained professional development. The study also adds to the research base that can inform the implementation of science and engineering practices in the Frameworks (NRC, 2012).The PCK consensus model provides a new direction for PCK research.

This study focused on how an endorsement influences the dimensions of knowledge of elementary science teachers and how those knowledge bases are enacted in the classrooms of participants. Elementary teachers often have limited time to teach science, limited content knowledge, and are required to teach multiple subjects. This study provides a closer look at how a professional development experience such as a K-5 science endorsement may influence some of those constraints by focusing on various aspects of teacher knowledge. This model is particularly useful for working with inservice elementary teachers on the goals presented in the Frameworks (NRC, 2012). The findings suggest important components to consider when working with teachers on the goals of the Frameworks. Here are recommendations based upon the findings from this study. Some of the findings confirm previous research and are noted.

1. Increase content knowledge and knowledge of instructional strategies through experiencing reform-oriented professional development (Duschl et al., 2007; NRC, 2012).
2. Build on the strengths of elementary teachers. The participants in the endorsement came into the program with strong pedagogical knowledge and knowledge of integrating science with other subjects.

3. Engage teachers in 5E lessons and providing them with opportunities to develop and implement 5E lessons (Bybee et al., 2007).
4. Make explicit connections to Nature of Science concepts (Lederman, 2007).
5. Focus on student misconceptions and vertical alignment of learning progressions with formative assessment and content development.

Ideas for Future Studies

The results of this study lead to more questions about the dimensions of professional knowledge of elementary teachers and how those knowledge bases influence their PCK. Ideas for future studies include a focus emerging leadership of teachers that have experienced a sustained professional development experience. The research on teacher leadership in science is an emerging field (Criswell & Rushton, 2013; Schneider & Plasman, 2011). It would be insightful to explore more deeply the leadership roles of elementary science teachers.

Other ideas for future studies include how elementary teachers navigate integrating science with other subjects. With decreasing in time for teaching science due to constraints associated with NCLB, it would be interesting to explore how elementary teachers use the integration of science and other strategies to address science standards. Other ideas for future studies include looking more closely at how the context of the classroom influences elementary teachers' PCK.

Ideas for extending the findings of this study include a longitudinal study with these participants and looking at the student achievement data of endorsement participants several years following their participation. This type of study that looks more closely at the student achievement data of participants could connect the dimensions of knowledge to enacted PCK and the achievement of students. It might be possible to compare achievement data prior to the endorsement with several years following the endorsement. Opfer and Pedder (2011) suggest it takes several years for professional development to be fully implemented into practice. This could be part of a longitudinal study that followed the participants over the years as they continue to refine their PCK.

Plans are underway for a future study would be to further test the model of the PCK Self-efficacy survey would provide an opportunity to confirm the model. Finding suggests the connections among the knowledge bases were stronger after the endorsement than before. The model could also be tested with a wider audience. This survey could be sent to a large audience of elementary teachers as well as secondary teachers. Teachers need to be able to access and integrate multiple professional knowledge bases during lesson enactment with students. This model provides information about the strength of the connections related to the efficacy of the practices.

In conclusion, this study provides support for sustained professional development in realizing the goals of increasing the content knowledge and reform-oriented practices of elementary science teachers. In order to minimize the implications of NCLB of reduced time for teaching science and increase the use of reform-oriented practices of elementary science teachers as indicated in the Frameworks, it will be essential to provide professional development that provides elementary teachers opportunities to engage in science content and practices. This professional development should be sustained with opportunities for teachers to implement practices in their classrooms (Duschl, Schweingruber & Shouse, 2007; Opfer & Pedder, 2011; Singer, Lotter, Fetter & Gates, 2011). It will be important to consider the strengths of elementary teachers when planning professional development. Finding ways to help teachers leverage their pedagogical knowledge and knowledge of students will be essential in integrate these new ideas.

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APPENDIXES

APPENDIX A

EXPERT MIDDLE SCHOOL TEACHER REVIEW OF CONTENT PRE/POST ASSESSMENTS

Expert Review of Life Science Assessment

Five middle school teachers deemed middle school life science "experts" were asked to review the life science pre/post content assessment given at the beginning and end of the life science endorsement class. Demographic data of the experts was collected in the survey. Their average teaching experience is 20 years and they have taught middle school life science an average of 13.6 years. One of those surveyed has earned a Master's in education, three have earned a Specialist in education and one has earned a Ph.D. in education. Four of the five experts reported they had delivered professional development to science teachers and presented at local and state science conferences. One of the experts has taught the science endorsement while another worked as a residency supervisor.

The experts were asked to review each assessment item and given the directions, "Using a Likert Scale of 1 - 5 with 5 being the highest, please indicate to what degree do the following assessment items represent:"

1. Represent what is taught to students at this grade level?
2. Represent the content taught on the job with students?
3. Reflect what kids need to learn in this subject area at this grade level?

Q #	1	2	3
1	5	5	5
2	4.6	4.4	4.6
3	4.8	5	4.8
4	4.8	4.8	4.8
5	4.8	4.8	4.8
6	5	5	5
7	4.2	4.2	4.4

8	4.4	4.6	4.6
9	4.6	4.6	4.8
10	3.6	3.4	3.6
11	4.8	4.8	4.8
12	2.75	2.75	2.5
13	3	3	3
14	2.75	2.75	2.75
15	4.75	4.75	5
16	2.25	2.25	2.75
17	4	3.75	3.75
18	5	5	5
19	5	5	5
20	5	4.75	5
21	5	5	5
22	4.8	4.8	4.8
23	4.8	4.8	4.8

24	4.4	4.4	4.8
25	4.6	4.6	4.6
26	3.6	3.4	3.8
27	4.8	5	4.8
28	4.2	4	4.4
29	5	5	5
30	5	5	5
31	4.4	4.4	4.4
32	4.6	4.6	4.8
33	5	5	5
34	4.75	5	5
35	4.8	4.6	4.8
36	4.6	4.6	4.8
37	4	3.6	4.2
38	4.75	5	5
39	4.8	4.6	4.8

40	4.6	4.4	4.4
41	4.6	4.6	4.8
42	4	3.6	4.2

Expert Review of Earth Science Assessment

Four middle school teachers deemed middle school earth science "experts" were asked to review the earth science pre/post content assessment given at the beginning and end of the life science endorsement class. Demographic data of the experts was collected in the survey. Their average teaching experience is 15.5 years and they have taught middle school earth science an average of 7.75 years. Two of those surveyed has earned a Bachelor's in education, one has earned a Specialist in education and one has earned a Ph.D. in education. Three of the four experts reported they had delivered professional development to science teachers and presented at local and state science conferences. One of the experts has taught the science endorsement.

The experts were asked to review each assessment item and given the directions, "Using a Likert Scale of 1 - 5 with 5 being the highest, please indicate to what degree do the following assessment items represent:"

1. Represent what is taught to students at this grade level?
2. Represent the content taught on the job with students?
3. Reflect what kids need to learn in this subject area at this grade level?

Q #	1	2	3
1	4.5	4.5	4
2	4.25	4	4
3	4	4	4.25
4	5	5	4.75
5	4.5	4	4.5

6	5	4.75	4.75
7	5	5	4.75
8	4	4.25	4
9	4.5	4.75	5
10	3.5	3.25	3.5
11	5	5	5
12	5	5	4.75
13	5	5	5
14	4.75	4.5	5
15	5	5	5
16	4.5	4.25	4.25
17	4.5	4.5	4.25
18	4.75	4.75	4.5
19	4.25	4.5	4.25

20	5	5	5
21	3.75	3.5	3.5
22	5	5	5
23	5	5	5
24	5	5	5
25	4.75	4.75	4.75
26	5	5	5
27	4.75	4.75	4
28	4.75	4.75	4.75
29	5	5	5
30	3.75	3.75	3.5
31	4.75	4.75	4.25
32	5	5	5
33	4	3.75	4

34	5	5	5
35	5	4.75	4.5
36	4.5	4.5	4.5
37	5	5	5
38	5	5	4.75

Expert Review of Physical Science Assessment

Five middle school teachers deemed middle school physical science "experts" were asked to review the life science pre/post content assessment given at the beginning and end of the physical science endorsement class. Demographic data of the experts was collected in the survey. Their average teaching experience is 12.8 years and they have taught middle school physical science an average of 7 years. One of those surveyed has earned a Master's in education, two have earned a Specialist in education and two have earned a doctorate in education. All of the experts reported they had delivered professional development to science teachers and presented at local and state science conferences. One of the experts has taught the science endorsement.

The experts were asked to review each assessment item and given the directions, "Using a Likert Scale of 1 - 5 with 5 being the highest, please indicate to what degree do the following assessment items represent:"

1. Represent what is taught to students at this grade level?
2. Represent the content taught on the job with students?
3. Reflect what kids need to learn in this subject area at this grade level?

Q #	1	2	3
1	4.6	4.8	4.8
2	5	5	5
3	3.4	3.2	3.2

4	3.8	4	4.6
5	4.4	4.4	4.6
6	4.4	4.4	5
7	4.6	4.6	5
8	4.4	4.4	5
9	4.4	4	4.2
10	4.8	4.6	4.8
11	4	3.6	3.8
12	4	3.4	4.2
13	5	4.6	5
14	5	4.6	5
15	2	2	2.4
16	5	5	4.8
17	5	5	4.6

18	5	5	5
19	4.8	4.6	4.8
20	5	5	5
21	4.2	4.2	4.8
22	4.2	4.2	4.8
23	4.6	4.4	4.8
24	4.6	4	4.8
25	4	4	4.5
26	4.6	4.4	4.6
27	3.8	3.6	3.8
28	5	4.8	4.8
29	5	4.8	5
30	5	5	5
31	4.8	4.8	4.8

32	4.6	4.6	4.8
33	4	3.8	4.6
34	3	3.2	3.6
35	4.8	4.6	4.8
36	4.8	4.8	4.8
37	4.8	4.8	4.6
38	4.8	4.6	4.8
39	5	5	4.6

APPENDIX B

K-5 SCIENCE ENDORSEMENT TEACHER & SELF-EFFICACY QUESTIONNAIRE

1. Do you consent to participate in the following survey about you and your beliefs in your capabilities related to teaching and do you consent that your content pre/post test taken during the endorsement may be used in this study? If returned by mail, please initial your consent in one of the two choices below:

_______I consent to participate in this study
_______I do not consent to participate in this study

2. Would you like to be entered into a drawing for a $25 gift card? You do not have to participate in the study in order to be entered into the drawing.

____yes
____no

If you are opting not to participate in the study, please enter your name below then scroll to the end of the survey and click submit.

Part 1 Demographic Survey

3. First Name ___________________________________
4. Last Name ___________________________________
5. Current grade(s) and subject(s) teaching ___________________________________
6. Number of Years teaching ___________________________________
7. Number of Years teaching science ___________________________________
8. Number of Years science was taught at each grade level:
   Kindergarten ___________________________________
   1st grade ___________________________________
   2nd grade ___________________________________
   3rd grade ___________________________________
   4th grade ___________________________________
   5th grade ___________________________________

9. Are you currently teaching science
   - Yes _____
   - No _____
   - If not, please indicate why____

10. If yes, how much time do you spend teaching science – choose from the models below based on how your school includes science in the academic schedule:
    - *Daily - if you teach science every day, indicate the number of minutes taught each day______________*

- *Weekly - if you teach science a few days per week (indicate the total minutes per week)* _______________
- *6 or 9 weeks periods - if you alternate teaching science with another subject (indicate how many weeks per year and the number minutes per day)* _______________
- *Other, please explain*____

11. Current teaching assignment:
    - _____Regular Education
    - _____Special Education
    - _____Gifted Education
    - _____ English Language Learners (ELL)
    - _____ Science Specialist or Science Coach
    - _____K-5 Science "specials" or lab teacher
    - _____Other, please explain____

12. Percentage of the academic day you are teaching science
    - _____0%
    - _____25%
    - _____ 50%
    - _____75%
    - _____ 100%
    - Other, please explain____

Highest Degree:

_____Bachelor's
_____Master's of Education
_____Specialist
_____Doctorate

Part 2: Self-efficacy Survey

Please read the statements below and indicate the strength of your personal belief in your capabilities BEFORE and AFTER your participation in the K-5 science endorsement. Response scale:

1. Weak beliefs in my capabilities
2. Moderate beliefs in my capabilities
3. Strong beliefs in my capabilities
4. Very strong beliefs in my capabilities

When considering a typical science class you teach, please identify the strength of your personal belief in your capabilities to:

	BEFORE completing the K-5 science endorsement				**AFTER completing the K-5 science endorsement**			
	1	**2**	**3**	**4**	**1**	**2**	**3**	**4**
1. Implement inquiry based instructional strategies for the								

purpose of designing investigations, collecting evidence and making claims								
2. Involve students in discussions in which students communicate claims and evidence from investigations								
3. Implement strategies that provide students with opportunities to explore science concepts before they are explained								
4. Actively engage involve students in critical analysis and/or problem solving								
5. Implement teaching methods at an appropriate pace to accommodate differences among my students								
6. Effectively plan engaging science lessons that develop student understanding								
7. Provide opportunities for students to learn science through exploring ideas or problems								
8. Communicate to students ways that the content is relevant to their lives								
9. Communicate to students the purpose and/or importance of learning tasks								
10. Communicate to students the specific outcomes of the lesson								
11. Communicate to students content knowledge that is accurate and logical								
12. Provide opportunities for students to learn at more than one cognitive level								
13. Understand concepts well enough to be effective in teaching elementary science								
14. Motivate students to perform at their fullest potential in science								
15. Clarify student misunderstandings or difficulties in learning science concepts								
16. Adjust teaching and learning activities as needed in order to develop student understanding								

17. Present ideas that challenge students' thinking about science								
18. Ask a variety of questions throughout the lesson to engage students in higher order thinking								
19. Provide students with specific feedback about their learning								
20. Provide students with suggestions for improving learning								
21. Use formative assessments to find out more about student ideas about science								
22. Use assessments to inform planning and instructional decisions								
23. Use a variety of types of assessments (journals, student presentations, lab reports)								
24. Integrate science with other subjects								
25. Use knowledge of the vertical alignment of the curriculum to make connections to content taught at other grade levels								
26. Implementing standards based instruction								
27. Adjust teaching and learning activities as needed								
28. Maintain a classroom environment in which students work cooperatively								
29. Effectively manage routines and procedures for learning tasks								
30. Monitor students' involvement during learning tasks								

Part 3: Personal Opinions

Listed below are a number of statements concerning personal attitudes and traits. Read each item and indicate how strongly you agree or disagree with the statements.

	Strongly disagree	**Disagree**	**Agree**	**Strongly agree**
5. On a few occasions, I have given up doing something because I thought too little of my ability.				
6. When I don't know something I don't at all mind admitting it.				

7. I am sometimes irritated by people who ask favors of me.				
8. No matter who I'm talking to, I'm always a good listener.				

APPENDIX C

DEVELOPING EVELOPING THE PCK SELF EFFICACY SURVEY & EXPERT REVIEW

Part I: Developing the Survey

The five components of PCK (Magnusson et al., 1999), the revised teaching orientations depicting degrees of student centeredness (Friedrichsen & Abell, 2011), and the PCK Learning Progressions (Schneider & Plasman) were used to develop a Self-Efficacy survey for participants that had completed the endorsement. Questions were generated from the Learning Progression chart and modified from the TEBS-Self (Dellinger, Bobbett, Olivier & Ellett, 2008).

1. *Knowledge of students' understanding of science* include how student learn science, the misconceptions they may hold, and learning difficulties they may experience
2. *Knowledge of instructional strategies* includes the toolbox of teacher strategies such as inquiry learning, teaching for conceptual understanding, using models, analogies and multiple representations, and includes subject and topic specific strategies
3. *Knowledge of curriculum* includes knowledge of standards and curricular programs; vertical and horizontal alignment of the curriculum, knowledge of curriculum reform and standards have been added to the original Magnusson et al. model
4. *Knowledge of assessment* includes knowledge of current assessment methods such as formative and summative assessment
5. *Orientations to teaching science* includes the goals and purposes for teaching and is organized into nine orientations that include both teacher centered and student centered orientations and considered to play a key role in PCK decision making; Friedrichsen, Van Driel & Abell (2011) synthesized the science teacher orientation research and organized the nine orientations identified by Magnusson et al. (1999) which included didactic, academic rigor, process, discovery, activity, inquiry, guided inquiry, problem based, and conceptual understanding into two categories: teacher centered and student centered/reformed oriented. Teacher centered orientations included didactic (lecture driven) and academic rigor (verifying challenging problems) while student centered/reformed oriented included current reforms such as inquiry, guided inquiry, problem based learning and conceptual understanding.

Part 2: Source of Self-Efficacy Items & Interview Questions

PCK Component	Self-efficacy survey	Question Source	Interview Questions
Instructional Strategies (5)	Implement inquiry based instructional strategies for the purpose of students posing questions, designing investigations, collecting	PCK Learning Progressions Instructional Strategies, Science	• Did the endorsement influence your lesson planning practices? If so, in what ways?

	evidence and making claims	Frameworks: Practices	• Did the endorsement influence your knowledge of science instructional strategies? If so, in what ways? • Did your knowledge of the of the 5 E learning cycle model have an impact on your instructional decisions for the unit observed?
	Involve students in discussions in which students communicate claims and evidence from investigations	PCK Learning Progressions Instructional Strategies, Science Frameworks: Practices	
	Implement strategies that provide students with opportunities to explore science concepts before they are explained	5E Learning Cycle Research	
	Actively engage involve students in critical analysis and/or problem solving	TEBS-Self, 21	
	Implement teaching methods at an appropriate pace to accommodate differences among my students	TEBS-Self, 12	
Orientations (5)	Plan engaging science lessons that develop student understanding		• Tell me about a typical day in your science class. • What do you consider your goals and purposes for teaching science? • Which lesson or unit that you developed for the endorsement best exemplify your goals as a science teacher? Tell me more about that unit and why you chose it? • Tell me about how the lessons in the unit provide insight to your goals of teaching science.
	Provide opportunities for students to learn science through exploring ideas or problems	PCK Learning Progressions Rubric	
	Communicate to students ways that the content is relevant to their lives	PCK Learning Progressions Rubric: Purposes	
	Communicate to students the purpose and/or importance of learning tasks	TEBS-Self, 10	
	Communicate to students the specific outcomes of the lesson	TEBS-Self, 10	
Subject Matter Knowledge (3)	Communicate to students content knowledge that is accurate and logical	TEBS-Self, 15	• Did the endorsement influence your science content knowledge? If so, in what ways? (Pre Obs) • Did new content that you learned during the endorsement impact the instructional decisions you made for the lessons within the unit tat were observed?
	Providing opportunities for students to learn at more than one cognitive level	TEBS-Self, 14	
	Understand concepts well enough to be effective in teaching elementary science.	STEBI-A	
Understanding of Students	Motivate students to perform at their fullest potential in science	TEBS-Self, 26	• Tell me about the lessons you

Conceptions of Science (5)	Clarify student misunderstandings or difficulties in learning science concepts	TEBS-Self, 16	taught and how you think they went. How did you develop student understanding during the unit? • Tell me about your students and how your understanding of your students influenced the instructional decisions you made for the unit? • Follow Up: Did the endorsement influence your knowledge or conceptions of your students?
	Adjust teaching and learning activities as needed in order to develop student understanding	TEBS-Self, 23 PCK Learning Progressions	
	Present ideas that challenge students' thinking about science	PCK Learning Progressions	
	Ask a variety of questions throughout the lesson to engage students in higher order thinking	PCK Learning Progressions TEBS-Self, 20	
Assessment (5)	Provide students with specific feedback about their learning	TEBS-Self, 17	• Did the endorsement influence your knowledge of assessment?
	Providing students with suggestions for improving learning	TEBS-Self	
	Use formative assessments to find out more about student ideas about science.	Emphasized in endorsement	
	Use assessments to inform planning and instructional decisions	PCK Learning Progressions	
	Using a variety of types of assessments (journals, student presentations, lab reports)	PCK Learning Progressions	
Curriculum (4)	Integrating science with other subjects	PCK Learning Progressions	• Did the endorsement influence your capacity to integrate science with other subjects? • Did the endorsement influence your understanding of the K-12 science curriculum?
	Use knowledge of the vertical alignment of the curriculum to make connections to content taught at other grade levels	Emphasized in endorsement	
	Implementing standards based instruction	PCK Learning Progressions	
	Adjust teaching and learning activities as needed	TEBS-Self, 23	
Pedagogy (3)	Maintain a classroom environment in which students work cooperatively	TEBS-Self, 30	• Are there challenges you face that inhibit you from teaching science in a way you think is ideal? If so, what are those and did the endorsement better prepare you to deal
	Effectively manage routines and procedures for learning tasks	TEBS-Self, 4	

	Monitor students' involvement during learning tasks	TEBS-Self, 22	with those?

The survey was sent to 23 individuals with professional development expertise. The individuals were considered experts in delivering professional development. They represented the diverse fields of university teaching, PhD students, professional developments in various subject areas and district science coordinators. Ten individuals responded to the survey and three individual provided personal feedback on the survey. The ten respondents had an average of 13.5 years experience in professional development with teachers.

Part 3: Results of the Expert Review of the Self-efficacy Items Aligned to PCK Components

3. Please rate how the follow statements correspond to the definition of Knowledge of instructional strategies - includes the toolbox of teacher strategies such as inquiry learning, teaching for conceptual understanding, using models, analogies and multiple representations, and includes subject and topic specific strategies

Answer Options	Strongly agree	Agree	Disagree	Strongly Disagree	Response Count
Implement inquiry based instructional strategies for the purpose of students posing questions, designing investigations, collecting evidence and making claims	100%	0	0	0	10
Involve students in discussions in which students communicate claims and evidence from investigations	90%	10%	0	0	10
Implement strategies that provide students with opportunities to explore science concepts before they are explained	100%	0	0	0	10
Actively engage involve students in critical analysis and/or problem solving	80%	10%	10%	0	10
Implement teaching methods at an appropriate pace to accommodate differences among my students	80%	20%	0	0	10
Any comments?					10
				answered question	**10**
				skipped question	**2**

4. Please rate how the follow statements correspond to the definition of Knowledge of students' understanding of science - how student learn science, the misconceptions they may hold, and learning difficulties they may experience; Students' science ideas develop when teachers are responsive to their ideas and reasoning by adjusting instruction (sequence and integration)

Answer Options	Strongly agree	Agree	Disagree	Strongly Disagree	Response Count

Motivate students to perform at their fullest potential in science	50%	40%	10%	0	10
Clarify student misunderstandings or difficulties in learning science concepts	90%	10%	0	0	10
Adjust teaching and learning activities as needed in order to develop student understanding	100%	0	0	0	10
Present ideas that challenge students' thinking about science	80%	10%	10%	0	10
Ask a variety of questions throughout the lesson to engage students in higher order thinking	90%	0	0	0	9
Any comments?					8
				answered question	**10**
				skipped question	**2**

5. Please rate how the follow statements correspond to the definition of Knowledge of Curriculum - includes knowledge of standards and curricular programs; vertical and horizontal alignment of the curriculum; Teachers integrate science concepts and other subjects, are flexible in their thinking about sequencing, are familiar with and use standards, are familiar with available resources,

Answer Options	Strongly agree	Agree	Disagree	Strongly Disagree	Response Count
Integrating science with other subjects	70%	20%	0	0	9
Use knowledge of the vertical alignment of the curriculum to make connections to content taught at other grade levels	80%	20%	0	0	10
Implementing standards based instruction	70%	30%	0	0	10
Adjust teaching and learning activities as needed	70%	10%	10%	0	9
Any comments?					6
				answered question	**10**
				skipped question	**2**

6. Please rate how the follow statements correspond to the definition of Knowledge of Assessment - includes knowledge of current assessment methods such as formative and summative assessment; Assessments include a variety of strategies such as journal entries, portfolios, presentations (when taught and practiced); Assessments require planning such as developing criteria and should be matched with specific science ideas

Answer Options	Strongly agree	Agree	Disagree	Strongly Disagree	Response Count
Provide students with specific feedback about their learning	90%	0	10%	0	10
Providing students with suggestions for improving learning	90%	0	10%	0	10
Use formative assessments to find out more about student ideas	90%	0	10%	0	10

about science.					
Use assessments to inform planning and instructional decisions	90%	10%	0	0	10
Using a variety of types of assessments (journals, student presentations, lab reports)	90%	0	10%	0	10
Any comments?					6
				answered question	**10**
				skipped question	**2**

8. Please rate how the follow statements correspond to Content Knowledge - an understanding of science content at a level with enough depth to teach it at the assignment grade band (K-2, 3-5, 6-8) or within the domain (6-8, 9-12)

Answer Options	Strongly agree	Agree	Disagree	Strongly Disagree	Response Count
Communicate to students content knowledge that is accurate and logical	100%	0	0	0	10
Providing opportunities for students to learn at more than one cognitive level	100%	0	0	0	10
Understand concepts well enough to be effective in teaching elementary science.	90%	0	10%	0	10
Any comments?					5
				answered question	**10**
				skipped question	**2**

10. Please rate how the follow statements correspond to General Pedagogy- organizing and managing a classroom; engaging students in learning

Answer Options	Strongly agree	Agree	Disagree	Strongly Disagree	Response Count
Maintain a classroom environment in which students work cooperatively	100%	0	0	0	10
Effectively manage routines and procedures for learning tasks	100%	0	0	0	10
Monitor students' involvement during learning tasks	90%	0	0	0	9
Any comments?					5
				answered question	**10**
				skipped question	**2**

Survey Open-Ended Comments

Instructional Strategy Comments

- 5th instructional strategy listed under item 3: should include appropriate LEVEL not just pace?

- Practices 2 & 4 rated as agree: If the particular strategies associated with student involvement in communicating claims/evidence, critical analysis, and problem solving were included, then I would strongly agree with the statement. However, the generalization of knowing that you need to involve students in these practices without the specific strategy, left me unsure as to whether it would be included as part of a definition.
- Inquiry level- from open to guided Actively engage students in critical...
- I would say that these are all very important to the goals of current classroom instruction that I try to convey in PD and methods teaching.
- must be in the context of content-based learning experiences...as written, the descriptions could map onto PK, not PCK since there isn't any mention of content in them....
- These are very clear components. They also happen at different times during the instructional cycle & 5E model. It would be great to include these criteria when doing observations of my teachers.

Student conceptions

- I think the first statement, "motivate students to perform at their fullest potential." is too vague...maybe adding "by identifying and addressing student learning styles" is appropriate since this gets at how students learn science. Also, none of the statements capture actually identifying misconceptions/preconceptions...did you mean identify instead of clarify in the second statement?
- In statement 4, I think the word "present" has the danger of communicating lecture. How about Engage students with ideas that challenge their thinking about science...I don't think that gets to it either!
- Present ideas that challenge students' thinking about science [this gets at NOS, rather than PCK if 'science' is generalized to the practice of science] Ask a variety of questions throughout the lesson to engage students in higher order thinking [depends on what the questions are and how content-specific they are...]
- The clarification statement is causing me to pause. I've seen this reduced to the most basic (and not terribly effective) methods recently in class. Not sure how to make sure that the clarification is paired with best practice instruction
- I wonder if motivation goes with this definition or would be better with #8 Stem - In 1st line, "follow" should be "following" "student" should be plural; should students' understanding

Knowledge of Curriculum

- Maybe a statement about teachers' knowledge of available standards-based and interdisciplinary resources should be included?
- You can include science-literacy integration as an example of horizontal
- I'm not clear about the intent of the 4th as it relates to the Knowledge of the Curr... (My opinion: I do not see the integrating with other subjects as a key target...maybe just me.) :-)
- I am uncertain how the last statement fits in here. Maybe if it was reworded to include utilizing the standard to design instruction at the appropriate level.
- I wonder if adding "to align with standards" could be added to the 4th indicator. Do you want to be explicit that instruction aligns to the curriculum or is that a given? (It is a problem I see most often in observations of mathematics instruction.

Knowledge of Assessment

- GOOD!
- I always like the word descriptive with feedback...Provide students with descriptive feedback about their learning
- these are too general for me to think they map well onto the construct of PCK

- Suggestions for improving learning - do you mean Next Steps or how they could have done something better. I agree that it needs to be there, but not sure I understand fully what you are saying.

Orientations

- GOOD!
- I think it is also important for students to communicate the ways content is relevant and connect their learning to the purpose/outcomes.
- Do you consider cross-cutting concepts, explicit/implicit instructions, isolated, integrated, the 5Es... as orientation to teaching science?
- I'm not clear about 4th...purpose/importance of learning tasks...
- I see how clearly all of these statements align. Nicely done! I also think that this document would help teachers have a much better understanding of what we are looking for, when we come to observe their lessons. I would also like to have teachers use this to rate me when I deliver science professional development. It would certainly keep me on my does and help me maintain focus!
- I wonder if the motivation indicator from #4 would fit better here.

Content Knowledge

- GOOD!
- Understanding content and aligning to standard
- The last statement I believe is addressed by the first.

Pedagogy

- GOOD!
- You may include assessing students' learning
- Effectively manage comment is the one that really causes problems for teachers. I'm not sure that enough professional learning opportunities help teachers work on this. It is a real sleeper that has derailed many amazing lessons.