1-1-2008

Mentoring novice elementary teachers in science teaching

Mary Sowder
University of Nevada, Las Vegas

MENTORING NOVICE ELEMENTARY TEACHERS IN SCIENCE TEACHING

by

Mary Sowder

Bachelor of Arts
Chapman University
1974

Master of Science
NOVA Southeastern University
1989

A dissertation submitted in partial fulfillment
of the requirements for the

Doctor of Philosophy Degree in Teacher Education
Department of Curriculum and Instruction
College of Education

Graduate College
University of Nevada, Las Vegas
December 2008

UNLV
UNIVERSITY OF NEVADA LAS VEGAS

Dissertation Approval
The Graduate College
University of Nevada, Las Vegas

November 17, 2008

The Dissertation prepared by

Mary Sowder

Entitled

Mentoring Novice Elementary Teachers in Science Teaching

is approved in partial fulfillment of the requirements for the degree of

Ph.D.

Examination Committee Co-Chair

Examination Committee Chair

Dean of the Graduate College

Examination Committee Member

Examination Committee Member

Graduate College Faculty Representative

1017-52

ABSTRACT

Mentoring Novice Elementary Teachers in Science Teaching

by

Mary Sowder

Dr. Sandra Odell, Examination Committee Co-Chair
Professor of Education
University of Nevada, Las Vegas

Dr. Jian Wang, Examination Committee Co-Chair
Associate Professor of Education
University of Nevada, Las Vegas

This dissertation explored how novice elementary teachers learn to teach science, how their preparation for teaching affects their classroom practice and their students' learning, and how they may be mentored toward more reform-based science practice. The instructional practices of four novice elementary teachers, two from traditional and two from alternative preparation programs, were studied as they worked with mentor teachers toward building pedagogical content knowledge for reform-based instruction in science. Data collected from interviews of novice and mentor teachers, from classroom observations of science lessons, from observations of mentor-novice conferences, and from student work were analyzed to discover patterns of information that may lead to understandings about effective practices for mentored learning to teach in science.

TABLE OF CONTENTS

LIST OF TABLES

ACKNOWLEDGEMENTS

I wish to first and foremost thank my husband, David, whose steadfast faith in my abilities never wavered. He gave me space to grow and a soft place to fall. His patience sustained me on this long journey, and his love made all things possible.

I would also like to express my deepest gratitude to Dr. Sandra Odell, a true mentor and one of the co-chairs of committee. Her cheerful enthusiasm has never lagged, and her support has been invaluable. Heartfelt thanks also go to the other co-chair of my committee, Dr. Jian Wang, who continued to guide and advise me even through the darkest moments of his own life.

To the other members of my committee, Dr. Emily Lin and Dr. LeAnn Putney, I offer my warmest thanks for their forbearance in reading my work time and again and giving me invaluable feedback.

Finally, I would like to dedicate his work to my parents who were models of perseverance and courage. Their selfless support and unconditional love gave me the heart to achieve my goals, and they would have been proud to see me finish.

God bless us, every one.

CHAPTER 1

INTRODUCTION

Genesis of the Research

"These two groups of students are really different," I muttered to myself. I was teaching an elementary science methods course to two different cohorts of university students. One was a cohort of undergraduate students who were learning about teaching in a professional development school program, and the other was a group of Teach for America recruits who were in their first weeks of teaching school and just beginning their Master's program in education. One assignment common to both groups was a written summary and oral presentation of contemporary, peer-reviewed research in education around a topic of their choosing. The assignment specifically required the incorporation of active learning strategies in the presentations.

Presentations for this assignment in both groups reflected choices of research articles and books that were timely, pertinent to classroom issues and challenges, and were published by reliable sources. Topics ranged from strategies to help guide learning in science with English Language Learners, to studies supporting inquiry-based instruction, to current discourse surrounding the teaching of evolution, etc. Here the similarities between the responses of the two groups ended.

Teach for America Presentations

With one exception the graduate students from the Teach for America (TFA) program presented their papers in lecture format (supported by index card notes) with accompanying PowerPoint presentations. Although active class involvement was required for each presentation and was included on the class' evaluative rubric, most presenters asked other class members to respond superficially to their topic. Instead of planning activities that encouraged their classmates to build or confront their own understandings of the topic, many of the presentations asked class members to answer pre-prepared surveys or view materials (e.g. videos or websites) that were related to their topic in order to fulfill the active learning requirement for the assignment. Most of these activities did not also require the class members to discuss and reflect on those materials in order to come to a better understanding of the topic at hand.

The written papers that accompanied these presentations from the graduate students were, for the most part, very well done. The writing was fluid and the grammar was correct. The papers were written in correct APA format, and citations and references were appropriate and numerous.

Professional Development School Presentations

None of the students involved in the professional development school cohort (PDSC) chose to use Power Point presentations as part of their reports to the class. With one exception, every team used active learning strategies to help their classmates access the material from their research. Teams used small and whole group discussions, role-playing, concrete materials, visual representations, and concept organizers to make explicit connections between the students' own ideas and experiences and the content of the material being presented. They incorporated activities that required their classmates to access, confront, and possibly transform their prior understandings through interactions with materials, text, natural phenomena, and other learners.

The written papers that accompanied these presentations from these students were not as sophisticated in form or substance as those from the graduate students. The writing was not always fluid, but the grammar was generally correct. The papers used APA format inconsistently, and citations and references were used sparingly.

How did two groups of students with the same instructor in the same course respond in such different ways to the same assignment? It seemed to me that there were elements of the students' preparation for the classroom that contributed to their understanding of "active learning" strategies, and that each group's collective apprenticeship of experience in education may have influenced their beliefs about the nature of teaching.

I began to wonder how the differences in pedagogical understanding (as demonstrated in the presentations of these two groups) might indicate what each group of students was learning from my course, and what, if any, influence their participation in this class would have on their classroom practice. I was curious about what might be additional, and perhaps more influential, sources of students' ideas about effective instruction in science. I wondered about how the nature of these sources might be affecting the practice of novice teachers in teaching elementary science and consequently, their students' learning.

Because I was also functioning as a school-based elementary science mentor to novice teachers at this point, I began to look at how my practice as a mentor might be influenced by novice teachers' preparation for the classroom as well. I wondered whether I was using accurate ideas about novice teachers' prior understandings about science and science teaching to inform my practice as a mentor. I wondered how, or if, my mentoring was actually helping new teachers' connect and transform their prior ideas about science teaching to more reform-based conceptions of instruction for classroom practice.

My personal teaching and mentoring experiences caused me to reflect on the how the synthesis of novices' prior experiences, their preparation for the classroom, their coursework in science pedagogy, and the understandings generated from a mentoring relationship might be influencing their classroom practice and affecting their students' learning in science.

Importance and Context of the Study

This study is important because it is focused on elementary science instruction, an area that, while underrepresented in the classroom and in the literature, is filled with opportunities for learning about the world, about teaching, and about learning. Unfortunately, the knowledge base for discussing challenges in preparing teachers to teach science at the elementary level has been mainly concerned with addressing the apparent lack of science content knowledge (e.g. Lederman, 1998) and the corresponding lack of self confidence (e.g. Schoon & Boone, 1998) among elementary teachers, rather than addressing the development of teachers' pedagogical content knowledge and efficacy as an ongoing process constructed in the context of classroom experience. Nor does the literature consider the possible effect of alternative teacher preparation programs on novices' ability to teach reform-based science at the elementary level (see Luft, 2007).

Little of the mentoring literature addresses issues specifically associated with elementary teachers' professional development in science content or reform-based pedagogy (e.g. Magnusson, Krajcik & Borko, 1999; Zembal-Saul, Starr & Krajcik, 1999). Like much of the general mentoring literature, these studies often look at the *practice* of mentors (e.g. Jarvis, 2001; Hudson, 2003, 2004, 2005), rather than the *effect of that practice* on novice teachers' instruction or on student learning.

The ways in which preservice elementary teachers are prepared to teach science, and the ways in which novice teachers from various programs of recruitment and/or preparation may be mentored to develop pedagogical content knowledge (PCK) for elementary science instruction are elements of this dissertation that add to the current knowledge base. This research also addresses gaps in the literature as it studies situated, content-specific mentored learning to teach and its effect on both novice classroom practice and student learning in science.

The next section describes the importance of science in the elementary curriculum and the importance of implementing reform-based practices in the elementary context. The following sections describe the influence of educational policies on elementary science instruction and the effects that these may have on the preparation of teachers for implementing reform-based practices.

Science in the Elementary Context

Elementary science education offers teachers and students the opportunity to learn *how to learn* about the world. It offers an educational context in which students can apply understandings from skill-based areas of the curriculum to meaningful investigation into natural phenomena. It offers opportunities for students to develop and practice learning strategies that may be generalized across the curriculum. In classrooms that are increasingly required to institute lessons designed to help students acquire discrete bits of testable knowledge, it offers the hope of authentic learning.

Harlen (2001) makes a case for the importance of teaching primary science as a way for children to learn to link their experiences together and to learn ways of collecting and organizing information and of applying and testing ideas.

> This learning...prepares them to deal more effectively with wider decision making and problem solving in their lives. For this reason learning science is as basic a part of education as is developing numeracy and literacy. It daily becomes more important as the complexity of technology increases and touches every part of our lives. (p.1)

The literature on elementary science education reform (American Association for the Advancement of Science [AAAS] 1989, 1993a, 1993b; NRC, 1996; Millar & Osborne, 1998; Harlen, 2001; Eady, 2008) also argue for an expanded role for elementary science education not only in developing conceptual understanding of content, but in preparing scientifically literate citizens. Reform documents call for elementary science instruction that will begin to educate students to locate, interpret and evaluate evidence, and construct arguments of their own so that, as the future citizens of the world, they will be able to make informed choices about issues in society (Eady, 2008).

The issues of the importance and substance of elementary science instruction are addressed in the research questions for this dissertation because they are focused on the particular forms of science instruction identified with the documents of reform (e.g. AAAS, 1989, 1993a, 1993b; NRC, 1996). Each research question of this study seeks to identify sources of teacher learning and the mentored development of PCK in relation to reform-based classroom practice for teaching science.

Elementary Science Teaching Reform

While schools and universities give lip service to instructional reform efforts towards the kind of instruction that emphasizes the skills and strategies in Harlen's (2001) description, current national mandates for accountability in education have resulted in an increased focus in the schools, and consequently in teacher education, on narrowly situated skill-based programs, professional development classes, and methods courses that target student achievement in reading and mathematics (Southerland, Smith, L., Sowell & Kittleson, 2007). The present emphasis on instruction for decontextualized reading and mathematics skills tends to take the form of a curricular content narrowing to tested subjects, to the detriment or exclusion of non-tested subjects (Amaral, Garrison & Klentschy, 2002; Smith, M., 1991). Science teaching has recently become an even more tangential part of the elementary curriculum because "what gets taught in a classroom is largely determined by what gets tested" (Lee & Luykx, 2006, p. 28). Some elementary administrators are so eager to provide evidence of acceptable annual yearly progress in math and literacy that science has been completely removed from their school's curriculum (Saka, 2007). A report from the Center on Education Policy (CEP) found that, of those schools who increased instructional time for math and reading since 2002, more than half (53%) cut time by at least 75 minutes per week in science (Center on Education Policy, 2008). Despite ongoing calls for reform, science education at the elementary level has been, and continues to be, a neglected and undervalued area of the curriculum (Marx, R. & Harris, C., 2006; Spillane, Diamond, Walker, Halverson, & Jita, 2001).

Beginning in the 2007-2008 school year, however, schools must also administer annual tests in science achievement at least once in grades 3 to 5, 6 to 9, and 10 to 12. Although the results of student testing in science will not be figured in to reports of annual yearly progress (AYP), some science educators hope that these assessments will encourage instruction based on standards for content knowledge (Hovey, Hazelwood, & Svedkauskaire, 2005). Others have a more cautious and skeptical appraisal of the influence of standardized testing on science instruction, suggesting it could stall any progress toward reform in science teaching by forcing schools to adopt a more didactic, transmittive approach that facilitates the acquisition of unconnected bits of content knowledge that will be tested (Cavanagh, 2004; Southerland, et al., 2007).

> The structures within NCLB policy encourage schools to do more of what they have traditionally been doing: more rigor (in terms of scope of content, not depth of thought) as a route to greater student achievement. Quick fixes … become far more imperative than exploring what is called for within science education research-based reform. (Southerland, et al., 2007, p. 61)

Whether or not the addition of science to the list of tested subjects will affect the practice of teachers at the elementary level remains to be seen. The effect that this addition will have on the preparation of novice elementary teachers and/or the development of their systems of PCK for reform-based science teaching is an area of concern related to the influence of public policy on teacher preparation. However, because research on the influence of testing on beginning teachers learning to teach science at the elementary level are limited, this dissertation is designed explore how contextual factors may affect the development of novice teachers' PCK for reform-based science teaching.

Elementary Teacher Preparation for Science Instruction

Underlying all classroom practice, methods of teacher preparation, and strategies for professional development are assumptions about what is important for teachers to learn, how teachers learn to teach, and what factors may influence the substance of teacher knowledge and the process of learning to teach (e.g. Shulman, 1987; Carter, 1990; Grossman, 1990; Cochran-Smith & Lytle, 1996). The curricular narrowing in response to high stakes testing has served to deemphasize preparation for science instruction in teacher education field experiences despite persistent and increasingly alarmist calls for better trained science teachers at all levels (National Commission on Mathematics and Science Teaching, 2000).

Even in the wake of new requirements for testing science at the elementary level, the limited format of standardized test documents in science may be measuring reading comprehension skills for expository text and word knowledge rather than any understanding of scientific content or processes (Cavanagh, 2004; Southerland, et al., 2007). Teacher candidates are often unable to observe models of reform-based science teaching during their preservice field experiences (McDevitt, Heikkinen, Alcorn, Ambrosio, & Gardner, 1993). As educational policy assigns the teaching of authentic science a low priority in the elementary curriculum (Abell & Roth, 1992), the preparation and professional development of teachers for science instruction may be consequently limited.

Traditional teacher education programs generally refer to a university-based, four to six year course of study towards a bachelor or master's degree that includes both academic coursework and one or more field experiences, among them student teaching. In most traditional teacher education programs, formal, academic coursework for propositional knowledge for teaching is regarded as the province of the university, while the practical knowledge developed from its implementation is relegated to the domain of the schools and teachers (Wideen, Smith & Moon, 1998). Even though the structural elements may appear similar in these programs, they are inconsistent across institutions and their substance may vary widely (Kennedy, 1999; Zeichner, 1987).

Current research into teaching and learning "has had very little influence on policymaking about teacher education both in the U.S. and elsewhere...[and] fails to address the character and quality of what students experience in ... science courses" (Zeichner, 1999, p. 12). In many teacher preparation programs (as in the programs for the traditionally prepared novice participants in this doctoral research), content preparation for teachers is minimal (Ball & McDiarmid, 1990) and is often taught in a way that does not reflect reform-based practices (Roth, 1991). Incoherent and often inadequate preparation in science content knowledge affects elementary teachers' beliefs about the nature and substance of science instruction as well as their confidence and competence in science teaching (Smith, D. C., & Neale, 1989; Czerniak & Lumpe, 1993; Magnusson, Krajcik, & Borko, 1999).

The lack of adequate pre-service elementary teacher preparation for teaching science has created a need for ongoing, situated professional development during teachers' induction years, as well as a need for research on the effectiveness of various structures and practices associated with content-specific teacher training in science. Science mentors are increasingly being touted as one solution for addressing the preparation gap (Luft, 2007), a chasm that may be especially wide for elementary teachers who come to the classroom from alternative certification programs with little pedagogical training in any curricular area.

Alternative certification programs "vary greatly in their content duration and rigor" (Roehrig & Luft, 2006), in most states an initial, provisional teaching license is granted when an undergraduate degree (which may or may not be in a field appropriate to the applicant's eventual placement) is paired with some kind of introductory training program. These teachers are placed in classrooms while they finish any other work needed to qualify for a full credential.

The particular form of alternative certification pertinent to this dissertation study is the Teach for America (TFA) program. Based on a conception of teacher education as situated learning, initial experiences in the TFA program consists of short, intensive training modules composed of mastering a number of predictable, standardized, and simple routines that allow teachers to "implement externally designed and prescribed curriculum" (Darling-Hammond, 1995, p. 21).

(Of note here are restrictions imposed by the Teach for America foundation on access to information about their program. Requests to the organization to observe training sessions and gather evidence from them as background for this research were denied, although some artifacts from these activities and descriptions of these training sessions were provided by sympathetic TFA teachers. Other information was gathered from public documents on the TFA web site (TFA, nd), and from literature in the public domain.)

Underlying assumptions about teaching and learning and their influence on alternative and traditional approaches to teacher preparation (Carter, 1990; Cochran-Smith, 1991, 2005; Feiman-Nemser, 1990; Kagan, 1992; Zeichner & Conklin, 2005) have implications for considering how novice teachers develop the pedagogical content knowledge needed to implement reform-based science instruction in the elementary classroom, and how the development of this knowledge may be assisted.

In particular, this dissertation explores the contributions of mentored learning to teach as it attempts to create a link between educational theory, prior understandings about teaching and learning, teaching experience, context, and classroom practice in the development of novice teachers to teach science in ways consistent with national standards for reform (e.g. AAAS, 1989, 1993a, 1993b; NRC, 1996).

Mentored Learning to Teach

The practice of situated, content-specific mentoring reflects constructivist methods of teaching and learning outlined in the *National Science Education Standards* ([NSES] NRC, 1996), in which communities of learners negotiate meaning from their individual and shared experiences through active reflection, and with support and guidance from other learners, teachers, and scholarship move toward reform-based instruction as described in the NSES (NRC, 1996).

> The term "active process" implies physical and mental activity. Hands-on activities are not enough--students also must have "minds-on" experiences. Science teaching must involve students in inquiry-oriented investigations in

> which they interact with their teachers and peers. Students establish connections between their current knowledge of science and the scientific knowledge found in many sources; they apply science content to new questions; they engage in problem solving, planning, decision making, and group discussions; and they experience assessments that are consistent with an active approach to learning. Emphasizing active science learning means shifting emphasis away from teachers presenting information and covering science topics. The perceived need to include all the topics, vocabulary, and information in textbooks is in direct conflict with the central goal of having students learn scientific knowledge with understanding. (NRC, p.20).

The body of current literature on mentoring is more concerned with identifying general mentoring strategies, perspectives, and program structure than with attempting to determine the effect of those elements on teacher practice and student learning (e.g. Odell & Huling, 2000; Feiman-Nemser, 2001; Huling, 2001; Wang & Odell, 2002). Even the slim collection on mentoring in elementary science instruction is limited to studies of rubrics or outlines for effective mentoring practices that are more concerned with mentors working with teacher candidates than with in-service teachers (e.g. Jarvis, et. al, 2001; Hudson, 2003, 2004, 2005).

This research addresses gaps in the literature as it studies mentored learning to teach as ongoing, situated, post-preparation professional development, and in the way it attempts to trace connections between teacher preparation for teaching elementary science, mentoring as professional development, novice teachers' classroom practices, and student learning. The importance of mentored learning to teach lies in the way it may create a bridge between inconsistent teacher preparation for teaching science at the elementary level and classroom practice, and facilitate the development of teachers' knowledge of science content and reform-based pedagogy in the context of the elementary classroom.

Summary

"How one frames the learning-to-teach question depends a great deal on how one conceives of what is to be learned and how that learning might take place" (Carter, 1990). The following sections provide a rational for the importance of examining novice teachers' sources of pedagogical content knowledge (PCK) for reform-based science teaching, the possible influence of their various preparatory experiences on their classroom practice, and the effect that situated mentoring practices may have on the development of novice teachers' systems of PCK for teaching elementary science and on their students' learning. The investigation of these questions may help educational researchers and policy-makers to better understand how novice teachers may be better prepared and supported to implement science teaching in the elementary classroom that enhances student learning.

Research Direction

This study examines how novice elementary teachers may develop the pedagogical content knowledge to teach reform-based science, and contributes to global understandings about teacher learning presented in the literature. In order to address gaps in the literature covering how novice teachers come to understand how to teach elementary science, it also examines how the mentored development of novice elementary teachers' pedagogical content knowledge for reform-based science teaching may have been affected by their preparation for the classroom, as evidenced in their classroom practice and their students' learning. Little of the current literature addresses adequately teacher learning about reform-based science instruction in the context of the elementary classroom (e.g. Magnusson, Krajcik, & Borko, 1999; Smith, D.C., 1999), and those studies that do rarely attempt to link teacher preparation to its observed effect on novices' classroom practice. Even fewer studies (e.g. Amaral, Garrison & Klentschy, 2002) have attempted to look for evidence of the influence of teachers' evolving systems of pedagogical content knowledge for science teaching on student learning.

The following research questions were formed to frame the investigation.

- How do novice elementary teachers develop the pedagogical content knowledge needed to implement reform-based science teaching?
- How might the nature of elementary teachers' general pre-service pedagogical training and their preparation in science content and pedagogy affect the mentored development of pedagogical content knowledge for reform-based science teaching?
- How is the mentored development of novice teachers' pedagogical content knowledge for reform-based science instruction reflected in classroom practice and student learning?

CHAPTER 2

REVIEW OF RELATED LITERATURE

This review outlines the methods used to discover and select the scholarship for review, then presents an in-depth look at the research selected as it pertains to each of this dissertation's research questions about mentored learning to teach reform-based science at the elementary level.

Finally, the review will integrate the material presented to identify gaps in the body of current scholarship and to address how the design of the dissertation's empirical study helps fill the holes and inform the literature.

Method and Limitations of Review

This study is informed by aspects of previous work in the fields of teacher preparation, mentored learning to teach, and the development of pedagogical content knowledge in science teaching. Three searches of ERIC using the keywords of mentoring, teacher education, science education, pedagogical content knowledge, and alternative certification resulted in about 200 titles consisting of research studies, literature reviews, and position papers written between 1980 and 2007. This review also includes selections from books and journal articles on science teaching, teacher preparation, and mentored learning to teach that were selected from a personal collection of resources. Articles from this and other searches were eliminated if they did not address issues pertinent to my research questions (e.g. online mentoring practices) or if they did not contain relevant data on characteristics of teacher preparation, mentoring practices, and pedagogical content knowledge for science teaching at the elementary level.

Not included in this review are studies about the role of *conceptual change* (Strike & Posner, 1982; Tobin, 1993) in PCK for science teaching. While this dissertation is framed by constructivist and transformative (Piaget, 1929; Vygotsky, 1978) approaches to learning that are also represented in models for conceptual change, the inclusion of conceptual change literature would be redundant in the discussion of constructivist methods in mentored learning to teach. Furthermore, "the view of misconceptions as interfering agents that must be removed and replaced ignores the constructivist basis of learning" (Magnusson, Krajcik, and Borko, 1999, p.106).

Constructing Pedagogical Content Knowledge: A Systems Approach

- How do novice elementary teachers develop the pedagogical content knowledge needed to implement reform-based science teaching?

This section begins with a description of pedagogical content knowledge (PCK) as it has been formed and reformed in the literature. Following this general introduction, further examination of PCK is framed by its definition as a system of interacting parts in order to inform analysis (see Chapter 4) of how components of that system act to influence the function of the whole. This framework is then used to look at the literature on PCK in the context of science instruction, and to examine the role that individual components (knowledge of content, pedagogy, and context) interact in its development. Finally, the conceptual definition of individual PCK for science instruction is expanded to consider how it may become part of a larger, nested system of PCK for instruction in the discipline of science.

The integral nature of pedagogical context knowledge required that discussion of its development in mentored learning to teach required be woven into the review. The ways in which mentoring practices may be used to help build knowledge of content, pedagogy, and context are directly related to the nature of PCK described in the literature reviewed.

Descriptions of Pedagogical Content Knowledge

In refining and clarifying Shulman's (1986) original conception of pedagogical content knowledge, Grossman (1990) identified the central components of PCK as: a) knowledge and beliefs about the purposes for teaching a subject at different grade levels, b) knowledge of students' understandings, including common misconceptions, about particular topics in a content area, c) knowledge of curriculum materials and knowledge about the scope of curricula within a subject, d) knowledge of topic-specific instructional strategies and representations, and e) knowledge of contextual influences on classroom practice.

Social and critical constructivists would argue either for the inclusion of context in the definition of PCK (Cochran-Smith & Lytle, 1999; Gess-Newsome, 1999), or for the elimination of any consideration of codified teacher knowledge. The role of context in creating knowledge of teaching outlined by Gess-Newsome (1999) suggested a continuum of views of PCK as either *integrative* or *transformative* models of teacher knowledge.

> At one extreme, PCK does not exist…Teaching is the act of integrating knowledge across these three domains [context, pedagogy, and content]…At the other extreme, PCK is the synthesis of all knowledge needed in order to be an effective teacher…PCK is the transformation of subject matter, pedagogical and contextual knowledge into a unique form…(p. 10).

Whether PCK exists independent of context, whether it is a mixture of contextual materials, or whether it is a compound created by the addition or release of energy to create a new substance (Gess-Newsome, 1999), research on the influence of contextual knowledge in developing proficient levels of PCK for elementary science instruction is largely unexplored. The role of context is especially important to this dissertation study as it looks at novices' development of PCK for science teaching in the context of the elementary classroom, and in the context of teaching second language learners.

PCK as a System

While much of the literature looked at PCK as an assemblage of parts forming a complex or unitary whole, less attention was paid to the way in which these parts are balanced as they function together in teaching. "While it is useful to understand the particular components of pedagogical knowledge, it is also important to understand how they interact and how their interaction influences teaching" (Magnusson, Krajcik, and Borko, 1999, p. 115). Revisions to the definition of PCK have added more detailed descriptions of elements of content and pedagogical knowledge in attempt to capture its integrative nature.

The problem with looking at PCK as an amalgam is that it is either there or it is not there – there is no way to consider the effect of a variety of combinations that can result from intermediate appearances of various elements of knowledge of content, pedagogy, or context. In contrast to this conception, this review considers how the essentials of PCK identified by Grossman (1990) work as parts of a system in classroom performance (see Magnusson, Krajcik, and Borko, 1999). A systems approach allows for a description of how PCK functions at different levels, according to the way these elements are understood by the teacher. Just as an automobile may be able to function at some level even when all of its system components are not performing at optimum capacity, the work of novice teachers may exhibit some sputtering progress toward a proficient level of PCK, even though their practice may not hum with the smooth and powerful roar produced when expert knowledge of content, pedagogy, and context operate together to create effective teaching.

PCK for Reform-Based Science Instruction

The ways in which pre-service and novice teachers build knowledge of science-specific content and pedagogies is critical to implementing reform in science instruction (Hudson, Skamp, & Brooks, 2005). Lee, et al. (2007) described seven categories of PCK for reform-based science teaching developed from analysis of data from observations of experienced science teachers: a) knowledge of science (including science processes, the nature of science, and connections between disciplines), b) knowledge of goals (aligned with standards), c) knowledge of students, d) knowledge of science curriculum, e) knowledge of assessment strategies, f) knowledge of teaching strategies, and g) knowledge of resources. This definition again presented PCK as a more complex system formed from a variety of crucial components, rather than an amorphous substance created from more general descriptions of the mixture of content, pedagogy, and context.

In their review of the literature, Magnusson, Krajcik, and Borko (1999) proposed that PCK for teaching science requires not only topic-specific content knowledge (within the larger subject matter content), but that PCK operates as system and that a lack of coherence between components can affect the development and utilization of PCK as whole. The authors defined five components of PCK for science teaching that are closely aligned with Grossman's (1990) model. The first component, teachers' orientations toward science teaching, affects and is affected by, teachers' knowledge and beliefs about the other four components: science curriculum; students' understanding of science topics; assessment in science; and instructional strategies for teaching science. These authors pointed out that it is not

> the use of a particular strategy but the *purpose* of employing it that distinguishes a teacher's orientation to teaching science...teachers with a discovery, conceptual change, or guided inquiry orientation might each choose to have students investigate series and parallel circuits, but their planning and enactment of teaching relative to that goal would differ (p. 97).

These descriptions of PCK as a system of interacting elements that reflect teachers' orientations to teaching science is central to the analysis and discussion of data in this dissertation on the influence of teacher experience and preparation on mentored learning to teach. As Magnusson, Krajcik, and Borko (1999) pointed out, not only do the elements of PCK interact, they are used according to personal and contextual influences.

Orientations and Self Confidence: Components of PCK

Because teachers' orientations toward science teaching interact with their knowledge about the science curriculum, science content, assessment in science, and instructional strategies (Magnusson, Krajcik, and Borko, 1999), they must be considered as part of the system of PCK for science teaching. The influence of these elements on learning to teach science is well represented in the literature, especially in the literature on elementary teachers learning to teach reform-based science. Some representative studies from this are included in this review for this reason.

A study by Bryan (2003) examined the development of a prospective elementary teacher from a traditional preparation program about the value and nature of science and science teaching. The novice teacher in this study held two conflicting "nests" of beliefs. Her beliefs about learning as transmission were based on her own experiences and guided her fledgling practice in teaching science, even as she built a more hands-on vision of instruction in the context of reflective science teacher education. Her progress in learning to teach reform-based science was constrained by her beliefs about the goal of science education as an accumulation of facts and by her concerns with classroom management of active learning. Bryan's (2003) findings echoed the concerns raised by both Kagan (1992) and Grossman (1989, 1990) about how novice teachers build conceptual understanding discrepant to their beliefs about science in the midst of acquiring procedural knowledge for classroom management, and raised questions about methods to effectively address the persistent beliefs about science and science learning that may affect novice teachers' development a system of PCK for reform-based practice. As situated mentors work with novices to develop all components of PCK in the context of their classroom, they may offer the support and challenge (Daloz, 1986) necessary to encourage the use of instructional strategies and management techniques that are consistent with reform goals.

A case study by King, Shumow, and Lietz (2001) described how four teacher-participants in an urban elementary school (from traditional teacher education programs) were poorly prepared to teach science in terms of science content knowledge and instructional skills, and in terms of general classroom pedagogical and management skills, even though they had received further professional development in science at the school site. The authors described the inconsistency between how the four teachers perceived their teaching and how investigators described their classroom practice. While the teachers described what they did, or what they were trying to do, in the classroom as facilitating "hands-on," or "inquiry-based" instruction, data collected by the investigators revealed their practice to be textbook driven and "expository in nature, with little higher-level interaction of significance" (p. 89). In this case, the teachers' expressed beliefs in reform-based science teaching did not tally with the traditional, tacit dispositions they actually used to guide their instructional practice.

The work by King, Shumow, and Leitz (2001) showed that, while there was evidence from teacher interviews that the teacher participants involved in the study *believed* they were implementing inquiry in their science instruction and were able to use the vernacular of educational reform to *talk* about reform-based instruction, they were much less prepared to effectively *implement* classroom practice that reflected the paradigm shifts for science teaching outlined in the NSES. The authors concluded that the kind of professional development for science teaching these participants had received was effective only in equipping them with the proper jargon for educational reform, while failing to influence their tacit beliefs about the nature of science instruction or to add to their understanding of science content.

In a related study by Eady (2008), data collected over a year from a British regional survey and from four case-study primary schools revealed that elementary classroom teachers and science coordinators were unclear as to the purpose of scientific investigation. The result was an approach to reform-based instruction reflecting a trivial constructivist approach (Tobin, 1993) to teaching that was expressed in experiential terms, rather than as a way of developing conceptual understanding.

> There was far greater reference…to planning and conducting investigations that developed process skills such as planning, predicting, observing and fair testing. Few class teachers emphasized the importance of pupils seeking patterns, interpreting results or developing explanation based on evidence…Several class teachers stated that the main priority was for children to experience investigations and that the 'knowledge bit' was added afterwards by writing it on the board for them to copy down into their books…There seemed to be the assumption that as long as children engaged in practical activity in science they would somehow learn something" (p. 11).

Unfortunately, the science coordinator (mentor) in Eady's (2008) study had a naïve orientation toward reform-based instruction that reinforced rather than challenged the beliefs of the teachers. This finding pointed to the need to look at mentor as well as novice orientations to science content and pedagogy in studying how PCK for reform-based instruction is built.

Eady (2008) also described the way that elementary teachers learn to teach science can be affected by policies for standardized testing in science. Her findings suggested that teachers responded to these policies by revising their beliefs and practices for teaching science content as an activity separate from investigation, in which they should elicit and correct students' naïve conceptions about content, turning them into a form that can be tested. Teachers began to see students' ideas about science that were generated from their own experiences as separate from what they learned about formal, codified science content, a tension "heightened by the representation of long-settled knowledge as 'laws'…[that were] experienced by students as having far greater authority than their personal experience" (Wallace & Louden, 2002, p.22).

These findings appeared to confirm the role of educational policy in forming PCK for reform-based instruction. While site-based mentors may try to mitigate the effects of educational mandates on reform-based instruction, an emphasis on standardized test scores may become increasingly important to the context of teachers' understandings of the relationship of content and pedagogy. The coherence between components of PCK may become unbalanced, leaning more toward only those aspects of content knowledge that can be measure by standardized testing.

The Function of Content Knowledge in PCK

In contrast to the integrative, balanced concept of PCK, some studies (Hashweh, 1987; von Driel, Verloop & de Vos, 1998; Gess-Newsome, 1999) suggested that improving science content knowledge is the most important component for advancing

PCK for science teaching in beginning teachers. Hashweh, (1987) used the results of a three-part questionnaire completed by 35 science teachers with different science backgrounds and teaching at different educational levels to find that teachers who teach unfamiliar subjects have difficulty selecting appropriate representations for their lessons because they are unable to anticipate students' problems with the content and are unaware of their possible preconceptions. Furthermore, teachers unfamiliar with content may also harbor their own misconceptions of the subject matter (Hashweh, 1987), they talk more, and they ask lower level questions (von Driel, Verloop, & de Vos, 1998; Carlsen, 1999). A study of the effects of an inservice workshop for ten elementary teachers by Smith and Neale (1989) concluded that while this program had been successful in terms of promoting teachers' knowledge of a specific topic, these teachers had not acquired the "deeply principled conceptual knowledge of the content" (Smith, D. & Neale, 1989, p. 17) necessary for the construction of PCK.

The emphasis in the literature on content knowledge (often defined as factual knowledge separate from knowledge of science as inquiry) as central to the development of PCK, especially for elementary school teachers, failed to take into account the importance of the interaction of content knowledge with understandings of context and pedagogy. Other findings (Sanders, Borko, & Lockard, 1993; von Driel, Verloop, & de Vos, 1998; Gess-Newsome & Lederman, 1999; Luft & Roehrig, 2007) indicated that an emphasis in teacher preparation on content knowledge in isolation from other elements of pedagogical and contextual knowledge does not facilitate the development of an effective of system of PCK.

The Function of Context and Pedagogical Knowledge in PCK

Another crucial factor in the development of PCK represented in the literature is teaching experience (Hashweh, 1987; Smith & Neale, 1991; Sanders, Borko, & Lockard, 1993; von Driel, Verloop, & de Vos, 1998; Gess-Newsome, 1999). Gess-Newsome and Lederman's (1993) study of ten preservice science teachers suggested a situative component to the development of PCK. They found that the transformation of content knowledge from university coursework to PCK may not be able to be achieved until teachers have gained enough classroom experience.

In their review of the literature, Van Driel, Beijaard, and Verloop (2001) identified teaching experience as the most important factor in the development of PCK. A study by Clermont, Borko, and Krajcik (1994) that found that science teachers' PCK differed considerably, even when their subject matter knowledge and teaching assignments were similar. Clermont and colleagues (1994) identified experienced and novice chemical demonstrators through a questionnaire. Participants were asked to view and respond to view two videotapes of a chemical demonstration. The experienced chemistry teachers in this study demonstrated a larger and richer collection of representations and strategies for a particular topic than did novice teachers, and they were more successful in connecting these demonstrations to students' learning difficulties. The authors contended that a lack of teaching experience explains why prospective or novice science teachers usually evidence little to no PCK despite their background in content (Lederman, Gess-Newsome, & Latz, 1994; Lee, E., Brown, M., Luft & Roehrig, 2007).

The influence of pedagogical knowledge built from experience in the development of PCK was illustrated in the work of Sanders, Borko, & Lockard (1993). These researchers found that effective classroom practice of experienced secondary science teachers teaching outside their area of certification was maintained by their general pedagogical knowledge, and that those teachers quickly learned the new content and its related instructional strategies.

PCK as Nested Systems

Most of the studies reviewed here looked at the development of PCK as an individual process, skirting the issues involved in the development of *knowledge of teaching* (Cochran-Smith & Lytle, 1993) in larger contexts of learning communities. Loughran, Mulhall, & Berry (2004) concluded that "portraying science teachers' PCK requires working at both an individual and collective level as, in many ways, PCK resides in the body of science teacher as a whole while still carrying important individual diversity and idiosyncratic specialized teaching and learning practices" (p.174). This "nested" conception of PCK (the individual teacher < small, specialized learning communities < larger learning communities) has important implications for the discussion of how various teacher education programs conceive of the relative importance of context and research in their frameworks for teacher development.

The communal creation of knowledge of teaching reflects a social constructivist approach to teacher learning (Cochran-Smith & Lytle, 1999, Vygotsky, 1978), and suggests altered structures for learning to science at the elementary level. As Penick (1994) asserted,

> Why not come out and advocate a real program, one with cohorts of students who stay together for years, long enough to really form a cohort? Within those cohorts, weave modeling of desired instruction, science and education, all within a research-based rationale and framework. Rather than merely praising reflective teaching, why not discuss theory and goal-driven reflections. We rarely see what we are not looking for... Without specific understanding and awareness, our teachers will see little when they look at their own teaching (p.662).

While personal knowledge in teaching (Cochran-Smith & Lytle, 1999) may contribute to pedagogical content knowledge, it may more closely resemble *teacher lore* (Schubert, 1992). "Because it is constructed from "the bottom up" and is independent of educational research, teacher lore is often atheoretical...Indeed, it can sometimes include vigorously anti-intellectual maxims" (Barnett & Hodson, 2001, p. 434). Teacher lore is important to the consideration of novice teachers' development of PCK because it is often the principal means by which teachers, especially from alternative certification, construct, reconstruct, and share their professional knowledge (Schubert and Ayer, 1992). In the absence of input from a more knowledgeable other (as in mentored learning to teach), novice teachers may form knowledge in teaching (Cochran-Smith & Lytle, 1999) built from their classroom experiences (and influenced by their personal orientations) that does not reflect reform-based practice for elementary science instruction.

Pedagogical Context Knowledge

Because personal experience is crucial to the development of PCK (Clermont, Borko, & Krajcik, 1994; Lederman, Gess-Newsome, & Latz, 1994; Lee, E., et al., 2007;

Sanders, Borko, & Lockard, 1993;Van Driel, Beijaard, and Verloop, 2001), mentored learning to teach allows novice teachers to connect their prior learning and situated experiences to research on science content and pedagogy and to other teachers' experiences. Barnett and Hodson (2001) proposed a synthesis of models for teacher learning they called *pedagogical context knowledge.* Grounded in experiential and situated (Kagan, 1992) approaches to teacher learning, pedagogical context knowledge grows from and is stimulated by teachers' formal and informal interaction with other teachers. These authors identified four overlapping and interacting elements of pedagogical context knowledge: academic and research knowledge, pedagogical content knowledge, professional knowledge, and classroom knowledge.

For Barnett & Hodson (2001), teaching is a matter of developing a framework of personal professional understanding through reflection in- or on- action (Schön, 1983). Their description of pedagogical *context* knowledge was echoed in Loughran, Mulhall and Berry's (2004) nested conception of teacher knowledge, in the way it looks at teaching as a:

> complex and subtle activity which requires many forms of knowledge – situated, on the one hand within one classroom on one day with one class of students, yet, at the same time, situated within the broadest expanses of the teacher's knowledge landscape" (p.448).

Barnett and Hodson suggested that their definition implied a different structure for teacher education and professional development that includes teacher knowledge built from personal and shared experiences within a particular context. In much the same way, this dissertation examines how mentor teachers attempt to help novice teachers create and navigate their own knowledge landscapes in situated structures for mentored learning to teach reform-based elementary science instruction. Framed by the definition of PCK proposed first by Shulman (1986), extended by Grossman (1990), and later modified by Magnusson, Krajcik, and Borko (1999) and Barnett & Hodson (2004), the collaboration of mentors and novice teachers with various levels of pre-service preparation for the classroom in building systems of pedagogical content knowledge for teaching elementary science forms the focus of the research for this dissertation.

Elementary Teachers' Preparation to Teach Reform-Based Science

- How might the nature of elementary teachers' pre-service pedagogical training and their preparation in science content and pedagogy in traditional and alternative certification programs affect the mentored development of pedagogical content knowledge for reform-based science teaching?

The debate about what teachers should know about teaching and learning (e.g. Carter, 1990; Darling-Hammond & Bransford, 2005; Dewey, 1938; Fenstermacher, 1994; Holmes Group, 1986; National Board for Professional Teaching Standards, 1991) has given rise to teacher education programs from various orientations towards learning to teach. Because the data for this study were collected from participants from two different university-based teacher education programs and from participants in the Teach for America program, this review includes a succinct review of the discourse in the literature representing competing conceptual orientations to teacher (Grossman, 1989, 1990, 1992; Kagan 1992), the challenges involved in trying to distinguish or define various teacher preparation programs (Darling-Hammond, 1990; Feiman-Nemser, 1990; Zeichner & Conklin, 2005), and the Teach for America alternative certification program.

Following this discussion is a brief review of studies about the influence of elementary teacher candidates' beliefs and attitudes on learning to teach science in the construction of systems of PCK, and a description of investigations into how methods of teacher education support reform-based practice in elementary science instruction.

Conceptual Orientations for Learning to Teach

A continuing concern in teacher education has been the issue the relative importance of theoretical and practical knowledge for teaching, and the ways in which to effectively integrate the two forms of knowledge in the preparation of teachers (Grossman, 1989, 1990, 1992; Kagan, 1992; Korthagen, et al., 2001). The influences of pragmatic and procedural orientations for teacher development are often evident in current alternate routes to certification, while more traditional programs continue to emphasize the application of theoretical and conceptual understandings of classroom practice.

On the basis of her review of the research on learning to teach, Kagan (1992) concluded that traditional teacher education programs failed to provide novices with "a realistic view of teaching in its full classroom/school context" (p. 162), and advocated a movement in teacher preparation away from providing novices with theoretical background about teaching and learning towards encouraging the acquisition of practical and procedural knowledge for the classroom unencumbered by any consideration of complex moral and ethical dilemmas of practice. This conceptual orientation allowed that it is acceptable, even desirable, for novice teachers to focus on acquiring fluency with generic strategies for establishing and maintaining discipline rather than trying to reconceptualize this challenge as an instructional or ecological concern while they are working to gain control of the classroom (Morine-Dershimer & Kent, 1999; Wideen, et al., 1998). Furthermore, according to Kagan (1992), the development of knowledge about students' abilities, interests, and problems essential to novices' professional growth can only be drawn from extended classroom experience.

Critics of Kagan's (1992) conclusions pointed to methodological inconsistencies in her work (see Dunkin, 1996), and questioned the characterization of classroom management as a set of morally and ethically neutral routines that can be separated from the larger context of teaching and learning. Grossman (1992) challenged Kagan's (1992) developmental, or "stage" model of learning to teach that will lead to further development of conceptual understanding through experience only. "There is no evidence that having developed classroom routines that work, teachers will necessarily begin to question those routines" (Grossman, 1992, p. 174). In fact, some studies suggested that when novice teachers do manage to master classroom routines, they can become satisfied with the level of their classroom practice and "may learn to manage pupils and clasrooms without learning to teach" (Feiman-Nemser & Buchmann, 1989, p. 367), and that issues related to reform-based approaches to teaching and learning are not automatically addressed by the accumulation of procedureal knowledge or experience alone (e.g. Ball & Cohen, 1999; Cochran-Smith & Lytle, 1999; Feiman-Nemser & Buchmann, 1989).

In contrast to Kagan's (1992) procedural and experiential framework for teacher preparation, Grosssman's (1989, 1990) concept of teacher preparation - based on a review of the literature and her empirical study of teachers with different levels of preparation prior to entering the classroom – made a case for teacher preparation that included coursework that presented and modeled a vision of reform-based instructional strategies and included induction support. Analyses of the practice of novice teachers from traditional and alternative teacher preparation programs led Grossman (1989) to caution against relying on classroom experience to produce instructional expertise, especially for teaching that is anything more than the attempted replication of teaching practice created from novices' "apprenticeship of observation" (Lortie, 1975).

> We learn that without formal systems for induction into teaching, learning to teach is left largely to chance. Although much pedagogical knowledge has been characterized as common-sense, knowledge is not hanging, ripe and fully formed, in the classroom, waiting to be plucked by inexperienced teachers. Learning from experience requires that teachers first interpret classroom experience in some way that makes sense to them. How teachers without professional education interpret experience may become problematic. (Grossman, 1989, p.320).

While alternative programs (e.g. Teach for America) are generally associated with the more procedural approach to teacher preparation outlined in Kagan (1992) and traditional teacher education is linked to Grossman's (1989, 1990) conceptual orientation, the inconsistent nature of teacher preparation within these divisions and the problems encountered in attempting to sort programs into definable categories makes these associations tenuous.

Teacher Preparation Programs

The following review of literature attempts to define, conceptually or structurally, traditional and alternative forms of teacher training.The few studies reviewed in this section were selected to represent how the literature has attempted to describe various approaches to teacher preparation in order to provide a backdrop for subsequent descriptions of how different approaches prepare or do not prepare elementary teachers to teach science.

Traditional Approaches to Teacher Education

Feiman-Nemser (1990) describes different structures for teacher education programs, and surveys five program categories and their characteristics based on their conceptual orientations: academic, practical, technological, personal, and critical/social. These categories are useful in examining the underlying assumptions of different approaches to teacher learning, although, as the author points out, they may account for a "single component or an entire professional sequence, and apply to undergraduate as well as graduate-level programs. Nor are the conceptual orientations mutually exclusive. By design or default, they can and indeed do exist side by side in the same program" (Feiman-Nemser, 1990).

Zeichner and Conklin's (2005) review of the literature for teacher education programs identifies five different types of programs categorized by structure. Yet these authors also devote some effort to explaining how and why the programs within each of their divisions vary – "generally, there is so much variety within each type of teacher education program (e.g., graduate, alternative, and traditional) that it does not make sense to compare general types without discussing the substantive characteristics and policy contexts of these programs" (p. 648).

Alternative Certification Programs

Zeichner and Conklin (2005) identify the *naming problem* in scholarship comparing teacher preparation programs that developed in attempting to categorize a certain program on the basis of its structural characteristics alone. One aspect of this problem is illustrated the way the term *alternative certification program* has come to be a catch-all identifier for a myriad of programs with widely diverse structures and substance. Darling-Hammond (1990) distinguished different types of alternative programs as *alternate route* (AR), programs that change the route to certification, but not the standards, or *alternative certification* (AC), programs that change the rules by which certification is granted. Preparation for alternative certification provides less pedagogical or subject matter coursework and more limited field experiences than alternate routes, and the "focus in these programs is on generic skills rather than subject-specific pedagogy; on singular specific teaching techniques rather than a range of methods; and on specific immediate advice rather than research or theory" (p. 138). Program elements may often vary even within specific national programs, as in some elements of the Teach for America program.

Teach for America

The enlistment requirements for the Teach for America (TFA) program (Zeichner & Shulte, 2001) as well as the structure of its five week summer pre-service training remain fairly constant across the country. Reflecting an experiential and procedural approach to teacher learning, TFA relies heavily on its recruits' apprenticeship of learning in highly competitive Ivy League Universities to inform their instruction. The program's pre-service summer institutes held in urban centers around the United States are designed to give cohort members some short-term opportunities for the practice, observation, coaching, study, and reflection needed to develop the "foundational knowledge, skills, and mindsets needed to be highly effective beginning teachers" (TFA, n.d., a, ¶ 2.).

Participants in the summer institutes spend approximately one hour a day for three weeks tutoring small groups of students in math and literacy and about one hour a day leading a full class lesson. During this limited field experience they are occasionally observed and given feedback from Teach for America instructors. (Typically, these instructors are former participants in the TFA program.) Cohort members also work with a Teach for America instructor in small groups to discuss, plan, and rehearse their lessons, and to engage in structured reflection on student achievement data (TFA, nd.). Part of the summer institute time is also spent in institute seminars that cover teaching as leadership, instructional planning, classroom management, diversity, learning theory, and literacy (TFA, nd).

However, there is great variation in the support and pedagogical education provided the participants once they have assumed responsibility for a classroom (Zeichner & Conklin, 2005). Some areas of the country require that these teachers take university coursework as a condition of their provisional credential within a set period of time, but some areas do not. The focus and nature of ongoing training sessions and support from TFA mentors during the novices' induction experiences also vary greatly from location to location (Zeichner & Conklin, 2005).

Discourse Around Teach for America. Because the intent of this dissertation is to look behind statistics and beyond testimonials to examine how elements of program design and orientation may affect novice teachers' development of pedagogical content knowledge for teaching science at the elementary level, this review includes only a few relevant studies from the myriad of studies, articles, editorials, etc. from the discourse in the literature about the merits/demerits of various teacher preparation programs (e.g. Ballou, & Podgursky, 1997, 1998; Darling-Hammond 2000a, 2000b, 1995, 2005; Darling-Hammond, Chung, and Frelow, 2002; Darling-Hammond & Bransford, 2005). This discussion is intended to raise questions and point to some important insights about specific elements of teacher training for teaching elementary science in order to identify effective mentoring practices for novice teachers who come to the classroom with various levels and forms of preparation. However, in order to facilitate further discussion of the issues associated with this program, this review will include relevant studies in the literature surrounding the TFA program.

Founded 1989, TFA quickly became the focus of controversy among educational policy makers, teacher education researchers, and practitioners (Cochran-Smith, 2005a). Although TFA is identified by Zeichner and Conklin (2005) as a teacher recuitment and initial training (not an alternative certification) program, research on its effects on student achievement have ignited spirited public debate about the effects of teacher education. Raymond, Fletcher, and Luque (2001) studied TFA teachers for the Center for Research on Education Outcomes (CREDO), compared new TFA teachers hired in Houston with other new teachers hired there. The authors concluded that TFAteachers were at least as good as other teachers in terms of pupils' test scores and better than other new teachers in raising pupils' math test scores.

The CREDO study (2001) did not compare TFA teachers to traditionally prepared and certified teachers, and this omission is important in considering how the study's finding might be generalized to other contexts. TFA teachers in Houston were compared to a control group of teachers in which about half of of the novice teachers, and about a third of all teachers, were uncertified. Furthermore, a third of the novice teachers did not have a bachelor's degree. The goal of the TFA program is to place teachers in schools with high percentages of at-risk students, sites that out of necessity hire many novice teachers who are under-qualified and uncertified. The study's controls for teacher experience and student characteristics drew comparisons of TFA teachers to other novice teachers who lacked the education and/or certification that might be found in beginning teachers in other contexts (Darling-Hammond, et al., 2004).

In a replication of the CREDO study (Raymond, Fletcher, and Luque, 2001), Darling-Hammond, Holtzman,Gatlin, and Heilig (2004) examined information from a large set of student data from Houston that linked student characteristics and achievement with data about their teachers' certification status, experience, and degree levels. The authors tried to determine if certified teachers were generally more effective than those who were not fully certified, and if Teach for America teachers were as effective as certified teachers with similar inservice classroom experience. This study (Darling-Hammond, Holtzman,Gatlin & Heilig, 2004) analyzed 4th and 5th grade student achievement gains on six different reading and mathematics tests over a six-year period.

The authors found that

> certified teachers consistently produced stronger student achievement gains than do uncertified teachers... Controlling for teacher experience, degrees, and student characteristics, uncertified TFA recruits are less effective than certified teachers, and perform about as well as other uncertified teachers...Teachers' effectiveness appears strongly related to the preparation they have received for teaching (Darling-Hammond, et al., 2004, p.1).

The study also noted that TFA recruits who became certified after two or three years did about as well as other certified teachers in supporting student achievement gains.

A major national study released by Mathematica (Decker, Mayer, & Glazerman, 2004) looked at the impact of TFA teachers on pupils' achievement as indicated by test scores. This study compared test score gains of students who were randomly assigned to either TFA teachers or "non-TFA" teachers, a group that included traditionally certified, alternately certified, and uncertified teachers. Two major analyses were conducted. The first compared student test scores between TFA and non-TFAteachers and the second compared student scores of novice TFA teachers and novice non-TFA teachers. In math, the gains of TFA students were significantly higher than those of non-TFA students, but in reading, the growth rates of students in both groups were equivalent. In comparing the students of novice TFA with novice non-TFA teachers, the study found that effect on students' test scores was the same as or greater than in overall comparison.

The Mathematica (Decker, et al., 2004) study linked teacher preparation with pupils' learning, and it was the first to use an experimental design to assess the impact of TFA recruitment and training on pupils' test gains with a large nationwide sample (Zeichner & Conklin, 2005). The research sample included 17 schools, 100 classrooms, and nearly 2,000 students in urban, at-risk elementary schools across the country. Decker et al. (2004) did not intend to compare the effectiveness of university-based teacher preparation with that of alternative certification programs, but to shed "light on who teaches in the schools where TFA places teachers, and on the impact TFA teachers have on student outcomes" (p. xii). The study describes the mixed experiences and educational background of teachers included in the control group, noting that even though the TFA teachers had less preservice classroom experiences than many of the contol teachers, they acutally had had more than over helf of the novice teachers in that group. Neverthless, these researchers concluded that "the success of TFA teachers is not dependent on their having extensive exposure to teacher practice or training" (Decker et al., 2004, p. xvi).

A critique of the Mathematica study by the Southeast Center for Teaching Quality (SECTQ, 2004), challenged this interpretation, pointing out that the TFA teachers in the Mathematica study had more background in teacher education than the novices in the control group, which was filled with emergency, temporary, and alternatively licensed teachers. Most of the TFA teachers had earned a regular or initial teacher certification by the end of the study year, and more TFA teachers were actually certified than the novice control teachers. About 40 percent of TFA teachers had earned a master's degree, mostly in education, by the end of their second year of teaching. Decker, et al. (2002) suggested this might account for the much greater impact they had on student achievement as compared to the first-year TFA teachers, and SECTQ (2004) argued that "if TFA is producing slightly higher student achievement gains, perhaps it is because they are more likely to be prepared to teach than the woefully under-prepared control group of teachers" (SECTQ, 2004, ¶ 5).

Another study by Laczko-Kerr and Berliner (2002) conducted in five urban Arizona school districts with high percentages of students living in poverty found that only half of the districts' teachers were fully certified. The rest were "undercertified" - either they were teaching on emergency or provisional licenses, or they had entered the classroom through Teach For America. These researchers compared the standardized test scores of primary students taught by unlicensed teachers with those taught by certified teachers at the same grade level, in the same district, and with similar years of teaching experience. The study found that students with certified teachers performed about 20 percent better on the tests than students with noncertified teachers. These findings were just as true for the students of Teach For America recruits as they were for the students of the entire group of unlicensed teachers.

One flawed assumption underlying studies that attempt to quantify the effects of various approches to teacher preparation is that traditional teacher education and alternative certification (TFA) programs are composed of well-defined and uniformly implemented sets of practices (Zeichner and Conklin, 2005). The uncontrollable nature of teacher preparation even within a particular program makes many of the findings dubious, even assuming it is desireable to equate teacher quality with students' standardized test scores alone. What might be more meaningful to the improvement of teacher preparation and classroom practice is to examine how specific structures or practices affect teacher performance and student learning.

> We need research and debate that identify and explain—with empirical evidence— what the active ingredients are in any programs, approaches, or routes where teachers have a positive impact as well as the conditions and contexts in which these ingredients are most likely to be present (Cochran-Smith, 2005a, p.5-6).

This call for research fits nicely with the purpose of this study as it looks at site-based mentored learning to teach as an "active ingredient" in promoting the development of novice teachers' PCK for teaching elementary science, and how this development may be affected by various forms of pre-service preparation for the classroom. One component of PCK that is an area of conern in mentoring novice teachers towards reform-based science instruction is elementary teachers' content preparation in science.

Content Area Preparation

The studies reviewed above discussed how contrasting views of the role of content preparation may influence the design and substance of teacher preparation programs, but apart from Grossman's work, they did not specifically consider the sources of teachers' subject matter learning. Prospective teachers from both alternative and traditional programs "take most of their [content] courses, not in much-maligned colleges of education, but in liberal arts departments. The professional training they receive in colleges of education is also not centrally concerned with their subject-matter knowledge" (Ball & McDiarmid, 1990, p. 439).

This is especially true for prospective elementary teachers, who may take more than half of their courses in the liberal arts, enrolling in a range of introductory courses across a variety of disciplines. In their commentary on the subject-matter preparation of teachers, Ball and McDiarmid (1990) propose that, in fact, "a major portion of teachers' subject-matter learning occurs prior to college…Not only is the precollege phase of subject-matter study longer than the college period, but also the content studied in elementary and high school classes is often closer to that that prospective teachers actually teach" (p. 440, 441). The kind of subject-specific preparation they receive at the college level, especially in science, fosters problems arising from the discreet nature of university coursework in science. Teachers who take classes in biology, for example, may not be exposed to content in physical science and may continue to harbor naïve conceptions in areas outside of their discipline (Hasweh, 1987). This problem is especially pertinent to issues of prospective elementary teachers' content preparation because not only are they expected to teach all scientific disciplines, but all other subject areas as well.

Ball and McDiarmid (1990) also noted another important issue concerning the subject-matter preparation of teachers – the hidden curriculum about methods of teaching and ideas about learning. Teachers spend thousands of hours in as students (Lortie, 1975), developing ideas for teaching content by watching their own teachers for those particular subjects. Beliefs about teaching and learning are well established by the time prospective teachers enter their preparation programs (Kagan, 1992; Pajares, 1992; Richardson, 1996a), and these beliefs affect teachers' practice. The importance of mentored learning to teach in challenging, or at least tempering novice elementary teachers' beliefs and attitudes about teaching and learning science in order to facilitate the development of reform-based classroom practice is examined in the following research.

Teacher Preparation for Reform-Based Teaching

The literature in this section is sorted into two general approaches to research on how to prepare teachers for reform-based science instruction. One approach is procedural and developmental in nature and reflects Kagan's (1992) framework for emphasizing the mastery of practical and technical aspects of teaching, using knowledge gained from individual teachers' classroom experiences to construct more abstract understandings of pedagogy. The other approach stresses conceptual understanding of content and pedgagogy in teacher learning as outlined in Grossman (1989, 1990). The research reviewed here includes studies from both perspectives, beginning with those studies that advocate for procedural changes for science teaching reform.

Procedural Preparation for Teaching Science

A study by Schwarz, et al. (2008) contended that because novice teachers and other teachers inexperienced in teaching science rely heavily on curriculum materials to guide their practice (Grossman & Thompson, 2004), teacher educators should incorporate a major focus on training preservice teachers how to use curriculum materials for effective teaching. The authors studied the work, responses, and interactions of teacher candidates participating in three elementary methods classes in which the instrutors empahsized curriculum analysis and modification based on criteria outlined in Project 2061 (AAAS, 1989, 1993a, 1993 b). The results of this study indicated that the teacher candidates would accurately use a subset of these criteria to evaluate curriculum materials that most closely matched their own understandings and goals or that were specifially addressed in their methods section. However, many of these methods students did not find the criteria provided helpful or realistic for selecting identifying effective materials, and they based their curricular decisisons on their own practical and affective criteria that did not generally overlap with the Project 2061 list, and "reflected their strongly held desires of making science fun and relevant to everyday life" (p.366). Because most of the teacher candidates did not see evidence of their cooperating teachers engaging in curriculum analysis and planning, they regarded the practice as inauthentic and irrelevant.

These findings highlighted the importance of context in establishing pedagogical content knowledge for teaching reform-based science. The science teacher educators in this study would have done well to consider the literature on the effect of teacher candidates' beliefs and attutudes about science instruction on their pedgaogical development (see Shumow & Lietz, 2001; Howes, 2002; King, McGinnis, et al., 2002; Bryan, 2003; Eady, 2008, reviewed above) prior to designing their coursework. The challenges faced by these instructors highlight a critical dilemma in preparing teachers for reform-based classroom practice. As the "more knowledgeable others" in this context (Vygotsky, 1978), teacher educators committed to reform in science education have a certain responsibility to guide the socially constructed learning of the class. However, it is equally important to consider the students' existing beliefs and their zone of proximal development (Vygotsky, 1978) for pedagogical understanding in designing instructional practice. The practice of scaffolding for student understanding of the content of pedagogy becomes a critical consideration of teacher education (Grossman & Thompson, 2004).

Another procedural element of reform-based science instruction covered in the literature is the use of a framework for lesson planning. A study by Settlage (2000) looked at how elementary education students learn to use the *learning cycle*, a tool for designing guided inquiry lessons, as part of their repertoire of teaching strategies. Developed at the University of California, Berkeley as part of the Science Curriculum Improvement Study (SCIS) materials of the 1960s (see Karplus, 1964), the learning cycle begins with the active engagement of students in investigating selected phenomena. As the students explore, the teacher acts as a facilitator, asking questions and guiding students as they work. Following the exploration, teacher and students share their observations with classmates, and the teacher helps students connect their experiences to the target science concept and introduces scientific vocabulary. Students then engage in additional activities in which they apply their recently formed understandings to new situations. Because the author found significant correlations between preservice teachers' understandings of the learning cycle and posttest measures of their self-efficacy, he suggested a focus on this instructional tool in science methods courses could serve as a mechanism for advancing the science teaching efficacy of future teachers.

Settlage's (2000) conclusions and recommendations seemed somewhat ambitious and require, as the author suggested, extended research to establish such a connection. Although the learning cycle lesson design is generally aligned with the NSES, the underlying assumption of this study, that the internalization and implementation of this particular instrument will automatically foster improved elementary science teaching, again reflects Kagan's (1992) procedural and propositional view of instructional practice. If the ultimate goal of teacher education is to develop conceptual understanding of content and pedagogy, then an instructional emphasis on the procedural implementation of a single tool in preparing elementary teachers to teach science seems limiting.

Conceptual Preparation for Teaching Science

Gess-Newsome (2002) approached learning about teaching elementary science from a more conceptual orientation. Her study proposed that because teachers' understanding of the nature of science (NOS) and science inquiry (SI) can be linked to the use of the teaching methods advocated by the current science education reforms (Lederman, 1992, 1998), elementary science methods courses should be designed in which the NOS and SI are embedded and explicitly taught. Her study with 35 pre-service teachers showed that as a result of participating in such a course, the teacher candidates' incoming conceptions of science as primarily a body of knowledge changed to a more appropriate, blended view of science as a body of knowledge generated through the active application of scientific inquiry.

As with many of the other studies about learning to teach elementary science reviewed here, Gess-Newsome's (2002) research did not attempt to determine whether or not teachers with a blended or process-based conception of science teach differently than those who persist in holding product-based views, or how these differing instructional orientations influence student learning. The paucity of longitudinal data connecting the substance and structure of teacher education in elementary science to its influence on classroom practice and, ultimately, student learning leaves a gaping hole in the literature. Still, studies addressing the "elementary problem" in science education continue to focus on the effect of teacher education on prospective teachers rather than on their prospective students. This dissertation attempts to address this oversight as it strives to look at evidence of any connections between how teachers learn to teach science, how they are mentored towards building PCK for reform-based instruction, and how their classroom practices are evidenced in student work.

Another approach is described by Rosebery and Puttick's (1998) study of how one novice elementary classroom teacher learned to teach science. In this study the case is drawn from the personal practices of the participating teacher. This teacher participated in a four-year educational research project as she continued her classroom practice. The project "engaged teachers in learning and viewing science as a socially and historically constituted sense-making practice, and in viewing and practicing science teaching itself as a form of sense-making" (p. 649). The results of the study suggest that this teacher's learning about science content and pedagogy with a community of other teachers even as she brought her newly formed understandings to bear on her classroom practice, helped her form an understanding of scientific ideas and practices and of how knowledge is constructed in science.

The teacher-researchers in this study attended a professional development seminar twice a month for two hours during the school year and for two weeks during the summer during each year of the four-year project. The content of these meetings was divided equally between inquiry in science and inquiry in teaching and learning. As learners of science, participants conducted investigations that were typically driven by their own questions about a phenomenon and were conducted in small groups that were stable across time. As part of their inquiry into science teaching, these teachers viewed video tapes of classroom lessons and kept records of what they and their students said and did so they could reflect and make sense of them. "From this perspective, teaching, like learning in science, can be viewed as a form of situated sense-making" (Rosebery and Puttick, 1998, p.673).

Unlike Kagan's (1992) description of the acquisition of craft-level classroom practice in situated learning to teach, this study illustrated how a situated perspective can be used to develop both procedural and conceptual understandings of science teaching. The teacher in this case demonstrated significant growth in her understanding of science content and pedagogy over time, in a program that reflected Grossman's (1989, 1990) recommendations for teacher preparation that presents and models a vision of reform-based instructional strategies and includes induction support. Rosebery and Puttick (1998) concluded that in preparing elementary teachers to teach science, it is important for teachers to have opportunities to learn about complex scientific content and practices in a socio-cultural context over an extended period of time.

The authors also suggested that teachers need access to tools (e.g. videotapes or audiotapes) that allow them to collect data and think about their practice, they need to have opportunities to talk about their teaching dilemmas with colleagues, and they need access to intellectual resources (e.g. articles and texts on classroom discourse, history of science, new forms of pedagogy) to help them build their theories of learning and teaching. Finally, this case study suggested that teachers need to engage in teaching science and learning about science concurrently so that their experiences and "their explorations of their students' learning mutually shape one another. …From this point of view, the question of what students are understanding and learning about scientific phenomena becomes inseparable from the question of what teachers are understanding about their students and about the scientific phenomena in question" (p. 674).

A similar, year-long case study with preservice teachers by Zembal-Saul, Blumenfeld & Krajick (2000) examined changes in the science content representations of two elementary teacher candidates. These students were participants in a program that modeled cycles of guided instructional practice in science: planning, teaching, and structured reflection. Their findings indicated that at the accuracy, sequencing, and connectedness of these representations improved over the length of the course, as did the teacher candidates' attention to the needs of the learners.

Both of the final two studies included in this review (Rosebery & Puttick, 1998; Zembal-Saul, Blumenfeld & Krajick, 2000) are significantly different in approach from other research in this area in two critical areas. Both of these studies attempted to make connections between novice and preservice teachers' content learning in the context of instruction that modeled reform-based science teaching and the teachers' own classroom practices. Even though the focus in each of these studies was on the evolving practice of teachers, both also included a consideration of how these changes were addressing the needs of the teachers' students.

The role of reflection in teacher learning was also an explicit element of each of the programs studied. While Zembal-Saul, Blumenfeld & Krajick's (2000) approach to encouraging teacher reflection appeared to be more instructor-directed, the interactive, collaborative reflection on practice described by Rosebery & Puttick (1998) resembles Cochran-Smith and Lytle's (1999) definition of communities of inquiry focused on building knowledge of teaching. "It is this entire process of reflection in action that is central to the art by which practitioners sometimes deal well with situation of uncertainty, instability, uniqueness, and value conflict" (Schön, 2002, p.50) It is this process of reflection that is intrinsic to the practice of mentored learning to teach.

Mentored Learning to Teach: Goals and Roles

While the scholarship on specific issues of general mentoring practice is plentiful, this review pulls from the literature works on both general and context specific mentoring that could be used to create a foundation for the examination of the mentoring practices observed for this dissertation, including the few pieces that specifically address mentoring in the context of elementary science instruction. Studies specific to the inspection of elementary science instruction in general (Borko, 1993; Czerniak & Lumpe, 1993; Hudson, 2003; Koch & Appleton, 2007; Smith, D.C., 1999), while they may not explicitly include aspects of mentoring, were added to this review in order to inform the analysis of data collected from interviews, observations, and student work in science.

Literature on the movement toward the use of mentor teachers in induction experiences as described by Feiman-Nemser & Parker (1993) reflected an ongoing concern that mentor teachers are inclined to focus on either on replicating current practices in teaching (Cochran-Smith, 1991) or on supporting novice teachers' emotional well-being at the expense of challenging them to develop pedagogical content knowledge for reform-based teaching (Wang & Odell, 2002). Research on which approaches to mentoring serve to replicate existing school culture and practices or to encourage educational reform, especially in elementary teacher education, is an area of scholarship that is less than robust.

Except for studies of teacher retention (e.g. Odell & Ferraro, 1992), the number of empirical inquiries into the effects of various mentoring policies and practices is still small, especially as to the effects of mentoring practice on student learning. Much of the mentoring scholarship is "descriptive or declarative" (Hawkey, 1997), focusing either on the history, development, and practical implementation of mentor-mentee relationships (Clawson, 1980; McIntyre, Hagger & Burn, 1994; Wilkin, 1994), on presenting or evaluating models for mentor programs and strategies (Feiman-Nemser, 1990; Odell and Huling, 2000), or on describing the nature of mentoring interactions (Abell et. al., 1995; Brooks, 1996; Daloz, 1986; Elliott, 1995). Few reviews of the mentoring literature contain analyses of theoretical frameworks for mentored learning to teach (see Little, 1990; Wideen, Mayer-Smith, & Moon, 1992; Wang & Odell, 2002).

The uneasy relationship between pragmatic mentoring designed to support novices' entry into the world of the classroom and mentoring designed to challenge novices to build PCK for reform-based teaching. In addition to examining the way the literature describes *how* novice teachers are mentored, this review will comment on how the literature presents evidence (or not) for how those practices facilitate the development of novices' pedagogical content knowledge for reform-based instruction. The ways in which the roles and goals of mentored learning to teach are deconstructed, described, and categorized in the literature are evaluated to the extent they offer insightful illustrations, observations and/or grounded theory for mentoring practices and program structures that address various perspectives on mentoring.

The following review analyses the literature according to two critical elements of mentoring practice. First, a few selected studies covering general practices, challenges, and assumptions associated with mentored learning to teach will be reviewed in order to establish a reference for considering aspects of content specific mentoring practices, and because this literature raises issues that can also be applied to content-area mentoring. A more comprehensive review of research on mentoring science teaching will follow, focusing especially on those studies concerned with mentoring reform-based science instruction at the elementary level.

All-Purpose Mentoring

In spite of concerns about the nature of mentoring practices, there is general agreement that the close and consistent interaction between mentors and mentees can be very influential in the development of novice teachers (Huling-Austin, 1990; Koerner, 1992; Smithey & Evertson, 1995). A number of studies have shown that mentor teachers even play a more important part in the learning process of teacher candidates than university-based teacher educators (Emans, 1983; Watts, 1987;Calderhead, 1988), a situation that may lead some to leery of the perceived conservative practice of mentor teachers (Zeichner & Tabachnick, 1981; Lanier & Little, 1986). Teacher candidates' and novice teachers' concerns about matching their mentors' teaching style, of being judged, and of performing well can lead to ill-considered replication of the mentor's practice (Calderhead, 1988; Kagan, 1992; Hawkey, 1996). The literature reviewed in this section looks at how the perspectives on mentoring influence mentoring strategies and purposes.

Daloz's (1986) model of mentoring claimed that novice teachers need both *support* and *challenge* for their professional development. *Support* affirms mentee's experiences and ideas, while *challenge* questions novice assumptions and introduces conflicting ideas. This cognitive dissonance "creates tension in the student, calling for closure" (p. 213), and is instrumental in transforming knowledge acquired during teacher preparation programs to long-term, conceptual understanding of teaching and learning

(Kagan, 1992). Daloz (1986) proposes that various ratios of support to challenge affect learning within a mentoring relationship. If support is high but challenge is low, the learner will feel affirmed but will not be compelled to develop any deeper understandings of teaching and learning. If support is low but challenge is high, the learner will withdraw and will cease to develop further. If support and challenge are both low, the lack of direction will allow the learner to flounder. Only when support and challenge are both high will the learner begin to progress. Daloz's (1986) conceptualization is useful for looking at mentor roles and actions and how they may influence novices' development of reform-based instructional practices; however, it fails to clearly identify the goal of mentored learning to teach. Supporting and challenging novice teachers may enhance their professional development, but towards what end? It is not only the efficacy of the mentoring practice, but its *direction* that is critical to an examination of teacher learning in a mentoring context (Kagan, 1992; Little, 1990; Wang & Odell, 2002).

In contrast to Daloz's (1986) call for multi-dimensional mentoring practices, a study by Ben-Peretz & Rumney (1991) concluded that mentor-novice conversations emphasized superficial aspects of teaching performance and content issues rather than asking the novice teachers to reflect on more challenging issues and principles of content or pedagogy in their demonstrated practices. The mentor teachers in this study were more concerned with teacher performance than with teacher development, and were not particularly interested in either affirming or challenging the mentees' experiences and ideas. Although the effect of this narrow mentoring context on novice development was not specifically addressed in this study, the combination of low support and low challenge mentoring would, according to Daloz's (1986) model, lead to undeveloped practices of instruction.

What is not clear in the preceding study is how the larger mentoring context (e.g. educational policy) influenced the mentors' focus, however its findings illustrate the importance of the element of context to mentoring practice and to developing a system of PCK. "Different forms of mentoring emerge in different contexts. Formal expectations, working conditions, selection, and preparation all create a set of constraints and opportunities that shape how mentors define and enact their role" (Feiman-Nemser & Parker, 1993, p. 716). The importance of school culture and community to the enactment of mentor roles is demonstrated by Wildman *et al.* (1992), who concluded that the mentor teachers observed in their study offered more than just emotional support. They focused on developing novice teacher competence by using reflection, modeling, and collaborative problem solving. In contrast to the study by Ben-Peretz & Rumney (1991), this approach to mentoring presents a practice of challenge *with* support which, according to Daloz (1986), would function to promote novices' professional development. What is once again missing from this consideration of mentoring practices is an investigation into the direction of that development. It is not clear how the reflective practice modeled by these mentors was directed toward any particular vision of reform-based teaching.

Little's (1990) review of the mentor phenomenon identifies three functions of formal mentor roles in education: occupational induction, teacher retention and recognition, and professional or programmatic development. This review concludes that while elements of school culture (reflected in problems associated with the identification, selection, and training of expert mentor teachers, the emphasis on the acquisition of procedural skills, and the restrictions of time and resources) affect each of these functions, the "marked conservatism" of formal mentoring structures helps to preserve traditional norms of culture and practice and discourage mentoring to challenge engrained cultural and educational expectations.

> The relations between mentors and teachers, on the whole, stress matters of comfort over issues of competence. They provide socioemotional support but appear to exert little influence on teachers' thinking or performance. Teachers are more likely to credit mentors with providing moral support or enlarging a pool of material resources than with exerting direct influence on their curriculum priorities or instructional methods (Little, 1990, p. 342).

According to Little's (1990) evaluation, mentors ascribe to a model of high support, low challenge approach, resulting in little challenge to novice teachers understanding of instructional practice. Although many of the issues listed in Little's (1990) review may persist, more recent scholarship has begun to examine mentoring goals for influencing both the instructional and personal development of novice teachers.

Feiman-Nemser & Parker (1993) specified two goals of mentoring related to mentor roles. First, mentor teachers should function to help develop effective teachers. Second, they should provide support for the entry of novice teachers into the profession. The first goal emphasized teaching performance, and the second stressed the assistance needed for novices to function effectively in the culture of the classroom. Similar roles of the mentor teacher, the *reflective coach* and the *effective facilitator*, were identified by Tomlinson (1995). The reflective coach facilitates the development of the mentee's teaching and reflection skills, and the effective facilitator stimulates the mentee's motivation and commitment through counseling.

Elliott & Calderhead (1994) found that mentor teachers had various perceptions of their roles. Some felt the role of the mentor teacher was to be a guide or leader. Some stressed the importance of being a good listener or a friend. Other mentors saw their roles as organizers of experiences for the novice to build practical knowledge for teaching. "On balance, the mentors appeared to perceive the mentoring role more in terms of nurturing or supporting the novices so that they can learn 'by whatever works' in their school or their classroom" (p. 176).

Maynard & Furlong (1994) distinguished three models of mentoring: the *apprenticeship model*, the *competency model* and the *reflective model*. They suggested that these models were correlated to novice teachers' stages of development, and argued for their successive application in teacher education. At the start of practice teaching, teacher candidates can learn from observing their mentor teachers, who fulfill the role of interpreters and models. Following this apprenticeship of observation (Lortie, 1975), novices develop classroom skills through systematic training with the mentor teachers as instructors until they gradually begin to reflect on their teaching experiences along with their mentor teachers.

Martin (1996) found that mentor teachers often chose the role of supporter because they thought the role of assessor was incompatible with the practices of mentoring support. This discrepancy between identified models of mentoring and the results of Martin's (1996) empirical study lead to the consideration of how personal and contextual influences shape mentor teachers' perception of their roles.

Several studies have revealed some common features of mentor teachers' roles. Franke & Dahlgren (1996) distinguished a *traditional* and a *reflective* approach to mentoring in their study of mentor and teacher candidates. The traditional approach identified mentoring as a replicative function in which mentor teachers' professional knowledge and practice were mimicked by teacher candidates. The novices' teaching experiences and the related mentor-novice conversations were regarded as opportunities for practicing the methods and strategies used by the mentor. These conversations were mainly episode-oriented, rarely referencing classroom events and culture to general pedagogical principles and theories. In the reflective approach the emphasis shifted from the teacher candidates' replicative teaching performance to their learning about educational theory and practice. Mentor-novice conversations were used as opportunities for reflection designed to develop professional knowledge and competence. These conversations were principle-oriented and went beyond the actual teaching episode to connect theory and practice.

Just as teachers systems of PCK are influenced by their orientations toward content, pedagogy and context, so are mentors' practices influenced by their perspectives on mentoring. The ways in which the mentors in this dissertation study approached their work with novice teachers did not present a singular perspective, but varied according to the needs of the novice teachers and/or the situation at hand. However, the overarching goal for each of the mentors in this study was to help novices develop PCK for reform-based science instruction.

Humanistic, Situated Apprentice and Critical Constructivist Perspectives on Mentoring

Wang and Odell's (2002) review of the mentoring literature identifies three perspectives underlying various mentoring programs and discusses each of these approaches in terms of its potential to affect standards-based teaching reform. The *humanistic* perspective looks at solutions to issues of teacher development as being grounded in novice teachers' self-esteem and emotional well-being. The function of mentoring relationships from a *situated apprentice* perspective is to create contextualized knowledge about practice generated from the teaching context. The goal of the *critical constructivist perspective* for mentoring is not only to create and integrate contextualized knowledge for teaching, but to analyze and transform existing school structures and cultures as they relate to reform-minded practice and issues of social justice.

While a humanistic perspective may help novice teachers transition into existing school cultures and aid them in accessing opportunities for developing reform-minded teaching by reducing stress, it "does not focus on the content and process of reform-minded teaching" (Wang and Odell, 2002, p.476). However, the literature on learning to teach science (see Wenner, 1993, 1995; Schoon & Boone, 1998; Shumow & Lietz, 2001; Howes, 2002; King, McGinnis, et al., 2002; Bryan, 2003; Eady, 2008, reviewed above) reminds us that the absence of the humanistic element from discussions of mentoring relationships may limit the appreciation of the role of the affective domain in cognition and teacher learning about reform-minded practice. Research on the specific influence of humanistic perspectives of mentoring on successful implementation of reform-minded teaching is absent from the current literature.

The function of mentoring relationships from a *situated apprentice* perspective (Wang & Odell, 2002) is to create contextualized knowledge about practice generated from the teaching context, and may support reform-minded teaching if that is the vision and practice of the situated teaching community (Cochran-Smith, 1991; Cochran-Smith & Lytle, 1999; Wang & Odell, 2002). Mentoring as *cognitive apprenticeship,* a relationship that features "authentic activity, social interaction, collaborative learning, and a teacher/coach who makes his or her knowledge and thinking visible to the learner(s)" (Feiman-Nemser & Remillard, 1996, p. 82), illustrated the way that situative mentoring reflects Vygotsky's (1987) theory of *assisted performance* as applied to learning to teach. "Assistance from and cooperative activity with a teacher, expert, or more capable peer enables the learner to perform at levels beyond his or her level of independent performance" (Feiman-Nemser & Remillard, 1996, p. 82). Less has been written *how* mentor teachers make their knowledge base of learning and teaching available to mentees in order to facilitate this assistance (e.g. Feiman-Nemser, 2001; Wang & Paine, 2001), an essential part of the mentor teacher's role (Zantig et al, 1998).

The situated perspective on mentoring runs the risk of emphasizing replicative teaching behaviors and procedures (Cochran-Smith, 1991), as mentees strive to imitate the practice of their mentor teachers. *Educative mentoring* (Feiman-Nemser, 2001) expands this perspective beyond "situational adjustment, technical advice, and emotional support" (p.17). In this concept of teacher learning, educative mentors interact with mentees in ways that foster inquiry into teaching and learning by helping mentees cultivate skills that enable them to learn from their own teaching (Feiman-Nemser, 2001).

Still missing from this approach is a connection between fostering inquiry into personal practice and using that inquiry to create standards-based practice.

Mentoring programs based on national standards for reform (e.g., NRC, 1996, 2000) are built on a very different conceptual framework than programs looking only to guide novice teachers toward efficient classroom practice, and from programs focused exclusively on situated teacher learning. Based on codified sets of content, teaching strategies, and approaches to learning, these programs require mentor teachers with a vision of and commitment to reform-based teaching and the ability to work with novices as agents of change (Cochran-Smith, 1991; Feiman-Nemser & Parker, 1992; Wang & Odell, 2002). Because mentor teachers in these kinds of programs must help novices bridge the gap between theoretical and context-general knowledge for teaching and learning and situated, practical knowledge of teaching built from personal experience, they must have a deep understanding of subject matter and of the relationship between teaching scholarship, national standards for content and teaching methods, and the context of the classroom developed through reflection and inquiry (Carter, 1990; Feiman-Nemser & Parker, 1992; Kennedy, 1991, Wang & Odell, 2002). However, studies that present successful case studies of standards-based mentoring, or studies that identify and define specific mentoring strategies that facilitate the forging of connections between these elements (e.g. Feiman-Nemser & Parker, 1992; Hawkey, 1998) are few.

The goal of the *critical constructivist perspective* (Wang & Odell, 2002) for mentoring is not only to create and integrate contextualized knowledge for teaching, but to analyze and transform existing school structures and cultures as they relate to reform-minded practice and issues of social justice (Cochran-Smith & Lytle, 1999; Ladson-

Billings, 1999; Wang & Odell, 2007). Underlying this approach are goals for constructivist learning for empowerment that encourage both novice and experienced teachers to work as part of a learning community examine and deconstruct existing knowledge and practices in education and to use inquiry into their own practice in order to build new constructs for teaching and learning (Cochran-Smith & Lytle, 1999; Wang & Odell, 2007; von Glasersfeld, 1995).

Mentoring as Collaborative Inquiry

The role of critical constructivist practice in forming knowledge about teaching is examined in Cochran-Smith and Lytle's (1999) description of *inquiry as stance*, the creation of teacher knowledge "generated in inquiry communities" (p. 288). The authors describe alternative conceptions of the processes for teacher learning that lie at various points along the transformative, constructivist continuum: knowledge *for* practice, knowledge *in* practice, and knowledge *of* practice. Knowledge *for* practice is the formal knowledge and theory created by university-based researchers *for* teachers to use in improving instruction, and corresponds to behaviorist and cognitivist views of the value of epistemic knowledge and the additive nature of learning.

Knowledge *in* practice is practical knowledge "embedded in practice and in teachers' reflections on practice" (Cochran-Smith & Lytle, 1999, p.251) and reflects the situated perspective on teacher learning promoted by many alternative certification programs. While knowledge in practice promotes reflective practice, this reflection is informed only by the individual's own perceptions and interpretations of classroom events.

The third conception, knowledge *of* practice, is based on an expanded view of teachers' practical knowledge as generated from personal inquiry, in which teachers conduct investigations into effective instruction, in light of the knowledge and theory produced by others. *Inquiry as stance* takes a social constructivist approach to teacher education as it calls for teachers' inquiry learning in communities to produce knowledge related to practice. Located on the constructivist continuum at the point where a contextual, transformative approach to learning is linked to a view of knowledge as discovery of external forces, *knowledge of practice* also calls for reflection in action to examine the ways in which the phronetic understandings of teachers are affected by the myriad of external social, cultural, ideological, and political influences on that learning (Cochran-Smith, 2005b).

Some of the same concerns attached to the situated perspective of mentoring also may apply to collaborative inquiry to construct knowledge of teaching described by Cochran-Smith and Lytle (1999). An emphasis in building knowledge of teaching as the product of circumstantial inquiry may serve to reinforce the notion of effective teaching practice as idiosyncratic, based only on discrete collections of teacher learning dependent on individual or group personalities and situations, and makes the formation of a set of standard practices for effective instruction drawn from a more inclusive body of research problematical.

This dilemma is particularly pertinent to the study the role of subject matter knowledge in mentored learning to teach in science. The ongoing tug-of-war between approaches to teacher education built around world views of knowledge (especially in regard to generally accepted scientific canon) as external and enduring, existing independently of individuals and the contexts in which they operate (e.g. conceptual change models or models for standards-based reform), and those approaches that view knowledge as an infinite number of internally constructed private universes (e.g. radical constructivist models) reflects the delicate balance between transformative and integrative approaches to science teaching and science mentoring (Gess-Newsome, 1999).

Mentoring Elementary Science Teaching

While education students may be introduced to inquiry-based learning in science as part of their university experience in content and/or pedagogy coursework, this is often unconnected to the context of science teaching in the elementary classroom. Many elementary teacher candidates may leave the university with an "incomplete understanding of science concepts" (Jarvis et al, 2001, p. 6) and many require ongoing support in science teaching (e.g. mentoring) during their induction in order to apply theory to practice (Putnam & Borko, 2000; Koch & Appleton, 2007).

The research on mentoring towards reform-based science instruction at the elementary level reflects an approach to teacher learning supported by professional development literature. Haney and Lumpe (1995) identified three phases of effective professional development: planning, training, and follow-up, and this implies that ongoing professional development that incorporates all three phases may be more effective than participation in a single methods courses and/or intermittent professional workshops. Long-term programs that include experiences for teacher content learning along with provisions for groups of teachers' sharing experiences and building knowledge for reform-based science teaching practices have had some success (e.g.

Rosebery & Pittuck, 1998). However, these require that teachers spend extra hours attending workshops after school and on weekends, a commitment that not all teachers are able or willing to make. One alternative to ineffective or time-intensive models of professional development is personal, on-site mentoring of elementary teachers in science (Koch & Appleton, 2007).

Research into science mentoring practices during elementary preservice field experiences is limited (e.g. Hudson, 2003, 2004, 2005; Hudson & Skamp, 2003; Hudson, Skamp & Brooks, 2005), but literature on the effect of mentoring as induction support in elementary science teaching is even rarer (e.g. Jarvis et al.2001; Koch &Appleton, 2007). An evaluation of an induction program for secondary science teachers by Luft and Patterson (1999) found that 93% of the induction teachers surveyed attributed to their induction program positive changes in their attitudes toward science, classroom instruction, and instructional ideology.

The disconnect between tertiary and elementary instructional practice in science is especially pertinent for novice teachers who enter the elementary classroom from alternate routes to licensure. With a vision of classroom practice generated from their own most recent apprenticeship of observation in university science coursework that remains unaffected by preservice pedagogical training, they may not be equipped to effectively teach reform-based science at the elementary level.

In a study of science-focused induction experiences of *secondary* teachers from different teacher preparation programs Roehrig & Luft (2006) found induction experiences primarily met the needs of the elementary-certified teachers teaching science in middle schools and alternatively-certified high school teachers, by providing science-specific pedagogical approaches to reform-based teaching that were missing from their preservice programs. This study is the sole representative of qualitative research investigating the effect of science-focused induction programs on teachers with various levels of preparation for the classroom at the secondary level. Research on mentored learning to teach science with novice teachers from alternative and traditional certification at the elementary level appears to be non-existent at this point.

The studies on mentored learning to teach in science reviewed below are presented in two sections. First are studies that look at strategies for mentoring elementary science that essentially apply all-purpose mentoring practices to mentoring in the context of elementary science teaching. Following these reviews will be a discussion of studies that look specifically at the contextual factors that are unique to mentoring science instruction at the elementary level.

Hudson and Skamp (2003) used a survey of Australian preservice elementary teachers at the end of their final practicum teaching experiences that included 35 items derived from a review of the literature on generic mentoring practices. These teacher candidates to rate their mentor teachers' use of mentoring practices, and the results of the survey were used to identify five key factors for effective mentoring in the area of science, including: 1) personal attributes, 2) system requirements, 3) pedagogical knowledge, 4) modeling, and 5) feedback.

Findings from this study revealed that the teacher candidates perceived that their mentored learning to teach in science lacked elements from several of these categories. For example, in the category of "personal attributes," less than half the mentors in this study were perceived as displaying science content knowledge related to primary science teaching, and less than a quarter of respondents indicated that their mentors outlined or discussed the aims, policies, and procedures for teaching science with them. Another interesting, and somewhat inconsistent finding showed that three quarters of the mentees indicated that they did not see their mentor model the teaching of science, yet over half of the mentor teachers were perceived as displaying enthusiasm for science teaching. Perhaps this finding points to the methodological difficulty in using an instrument to measure perceptions of personal attributes to characterize mentor practice.

The authors conclude that, "despite the positive signs of providing feedback to mentees, there were few mentors who seemed to take a proactive role in exemplifying *specific* science teaching strategies" (p.19). These specific strategies are not defined in the study, and it is unclear how they may differ from general instructional strategies for such as lesson planning or classroom management, except that these activities would occur in the context of science instruction. Further studies by these authors using the data collected from this research and additional input continued to try to indentify "science-specific" mentoring practices.

Hudson (2003, 2004, 2005) used data generated from this study and two follow-up studies that used a very similar survey of preservice teachers to identify elements of general mentoring practice that are essential to mentoring science instruction: personal attributes, system requirements, pedagogical knowledge, modeling, and feedback. While the findings of the later studies are generally the same as the initial research in terms about the perceived lack of mentor modeling for science instruction and the lack of mentoring conversations about science teaching, Hudson (2003, 2004, 2005) uses the responses to make a case for modeling as the primary tool for effective mentoring in elementary science. “A key component for teaching science is having pedagogical knowledge, and mentoring in science requires modelling [sic] of practice to assist the mentee’s pedagogical understandings” (Hudson, 2003, p.23).

Furthermore, the author used data generated from the surveys to define specific strategies or attributes that are central to mentoring science instruction at the elementary level: displaying enthusiasm for science teaching, modeling effective science instruction, demonstrating rapport with students in science lessons, demonstrating well-designed science lessons, demonstrating hands-on science lessons, modeling effective class management in science teaching, and using science content-specific vocabulary. From these, Hudson (2004, 2005) and Hudson, Brooks and Skamp (2005) created a “five factor model” for science mentoring (personal attributes, system requirements, pedagogical knowledge, modeling, and feedback) that should form the core of programs to prepare experienced teachers to mentor others in science teaching.

In a related study, Hudson and McRobbie (2003), again used data from the same survey tool to compare the perceptions of mentor teachers’ practice in teaching science between a control group (n=60) and an intervention group (n=12) after a four-week field experience program in which the intervention group was involved in a mentoring program that focused on developing primary science teaching practices. The perceptions of each group for the five factors (personal attributes, system requirements, pedagogical knowledge, modeling, and feedback) identified earlier (Hudson & Skamp, 2003). Results indicated that those in the intervention group perceived that they had received more mentoring experiences on each of the five factors. Based on this finding, the authors argued that mentoring designed for “developing specific aspects of primary science teaching has the potential to enhance the degree and quality of teaching experiences within a preservice teacher's professional experiences" (p.1).

While each of these studies (Hudson & Skamp, 2003; Hudson & McRobbie, 2003; Hudson, 2003, 2004, 2005; Hudson, Brooks & Skamp, 2005) presented a descriptive summary of the statistical analyses that led to the development of the five factor model for mentoring elementary science instruction, the premise underlying the instrument used in each of these studies is questionable. Deriving a set of core strategies for mentoring practices in elementary science distilled from preservice teachers' perceptions of their mentors' practices seems a little like recreating a complex recipe by asking diners what they thought about the cook. The analyses of the survey results may accurately reflect the mentees' perceptions, but novice practitioners may not have the experience necessary to accurately identify elements of practice. A more reliable method of discovering elements of effective mentoring practice might be to gather data from observations of mentor practice made by more experienced and knowledgeable individuals.

Another concern with this study was the authors' assertions that the strategies identified in the study are "specific" to science mentoring at the elementary level. A careful reading of related literature tells us that these elements are specific neither to content area nor grade level. Re-examining the list of the core elements identified in the first study (Hudson & Skamp, 2003) from which these authors developed their model for mentoring science instruction reveals an interesting trait. By deleting the word "science" from each of the entries this list of "specific" mentoring practices for science teacher looks very like a list of generic elements of mentoring practice: displaying enthusiasm for

~~science~~ teaching, modeling effective ~~science~~ instruction, demonstrating rapport with students in ~~science~~ lessons, demonstrating well-designed ~~science~~ lessons, demonstrating hands-on ~~science~~ lessons, modeling effective class management in ~~science~~ teaching, and using ~~science~~ content-specific vocabulary . Of course these are all important elements of mentoring practice defined in the literature (e.g. Feiman-Nemser & Parker, 1992; Feiman-Nemser, 2001), but they are strategies that are crucial to mentoring every part of the elementary curriculum.

Not included in these studies' recommendations for science mentoring were strategies appropriate to building mentors' or mentees' science content knowledge and/or conceptual understanding of reform-based science instruction. Hudson's "five factor mentoring model" (2003, p. 4) emphasized mentor modeling, a practice that, depending on the expertise of the mentor teacher, may serve to replicate rather than reform instructional practice in elementary science instruction.

In contrast to the studies reviewed above that look at generic practices in the context of mentoring elementary science teaching are those that look at issues that are uniquely relevant to this content area. Elementary teachers face challenges and advantages associated with teaching science that are specific to the nature of their practice, including limited subject matter knowledge (Anderson & Mitchener, 1994), capacity to engage in standards-based science instruction (Smith & Gess-Newsome, 2004), consistent opportunities for cross-curricular instruction (Amaral, Garrison, & Klentschy, 2002; Klentschy, & Molina-DeLaTorre, 2004), and a lack of curricular resources necessary to support reform-minded science teaching practice (Appleton &

Kindt, 2002). The way in which these particular issues may be addressed by mentoring practices are examined by the literature reviewed below.

Science-Specific Mentoring

Jarvis, et al, (2001), pointed to several challenges specific to mentoring primary science teaching. The lack of subject matter knowledge for both mentor and mentee teachers was identified as the critical barrier to effective mentoring practice. Because their own content understandings in science may be incomplete, mentor teachers were reluctant to challenge and develop their mentees' ideas about science facts and processes. This difficulty with content knowledge affected mentor teachers' ability to model how to identify misconceptions and accurately assess student learning in order to inform instruction. The authors developed a checklist of factors derived from the mentoring and science education literature that were important to effective science instruction. This list was used by the mentor participants to guide their observations of mentees' science lessons, and to facilitate their mentoring conversations about science teaching. Results of the study showed that the use of this checklist in planning and debriefing sessions facilitated a greater discussion about subject matter.

While many of the items on this list (see Jarvis et al., 2001, pp. 21-23) were also generic in nature, the difference between this list and the one created by Hudson et al. (see the studies reviewed above) lies in the way it also contains guiding questions aimed at specific practices for teaching reform-based science. While the Hudson form (2003) focused on mentor modeling of generic instructional strategies, the Jarvis model (2001) focused on the practice of the novice teacher in teaching science. For example, Jarvis et al. (2001) addressed how mentee lessons involved students in using science process skills (observing, recording, comparing, making a fair test, etc.), it asked about how the lessons helped students develop productive questions for investigation, and it addressed how the lessons asked students to evaluate, interpret, and share their findings – all science-specific strategies for reform-based instruction.

This study also adhered to Kagan's (1992) framework for establishing procedural knowledge through practiced routines in learning to teach. In this case, the primary importance of developing procedural understanding was the underlying assumption about learning to mentor science teaching. The corollary assumption, that implementation of set procedures will eventually lead to a more internalized, conceptual understanding about science and science teaching is not addressed here. Jarvis, et al. (2001) seemed less concerned with helping mentor and mentees build long-term, conceptual understandings of science content and pedagogy than with providing a tool for mentor teachers to use that would facilitate discussion of important aspects of reform-based classroom activities. Not addressed by this study are any after effects on science mentoring and teaching of using a practical instrument without also developing an understanding about how or why it is important to use.

A study by Koch and Appleton (2007) described a model for ongoing professional development in science teaching in which university science education professors mentored elementary teachers. The results of this study's data collection revealed that one-to-one mentoring had at least short-term implications for implementing constructivist science teaching practices. As the teachers in this case began to work with their mentors, the nature of their science lessons began to change from directed activities to investigations that responded to students' ideas and questions. The teachers also attended one all-day workshop with these mentors in which they were introduced to science content using reform-based instructional strategies. Based on the teachers' reflections on this experience, the authors suggested that mentoring models in elementary science should include components that also facilitate the understanding of science content. Their experiences in mentoring these teachers led the authors to surmise that effective mentoring towards reform-based elementary science instruction must work from the predispositions of the teachers.

When Feiman-Nemser and Parker (1990) examined the conversations that took place between mentors and novices, they found that subject matter was rarely discussed directly; it was usually discussed in relationship to students' thinking or classroom management. The authors suggested that mentors should guide discussions with their mentees to address "content-related issues in content-specific terms" (p. 42). While this point seems especially important to the study of specific mentoring practices for learning about elementary science teaching, it appears that the literature, with only a few exceptions, does not address content-, and context-specific mentoring practices.

The available studies about mentoring elementary science (Jarvis et al., 2001; Hudson, 2003, 2004, 2005; Hudson & Skamp, 2003; Hudson & McRobbie, 2003; Hudson, Skamp & Brooks, 2005; Roehrig & Luft, 2006; Koch & Appleton, 2007) did not provide any evidence of mentoring practices that are unique to the context of elementary science instruction. They ignored the role of context in developing systems of PCK for reform-based science instruction, assuming a stance based on supplying knowledge of teaching and mentoring from a secondary or tertiary perspective. On the whole, these studies also supported a more procedural approach to developing pedagogical content knowledge for teaching science, emphasizing the effective implementation of management strategies for guided inquiry almost to the exclusion of building conceptual understanding for reform-based science instruction.

As Hudson and McRobbie (2003) point out, while their study "demonstrated increased perceptions of mentoring practices because of a specific intervention, it *does not examine the improvement of primary science teaching practices as a result of this intervention*" (p. 19, emphasis added). The critical links between intervention, teaching practice, and student learning are assumed, but not tested in these studies.

Mentored Learning to Teach and PCK

- How is the mentored development of novice teachers' pedagogical content knowledge for reform-based science instruction reflected in classroom practice and student learning?

Research in this area is extremely limited for elementary science teaching. While several of the studies reviewed above pointed to the need for research that made connections between mentoring practice and novices' classroom practices, few studies actually used classroom observations to look for evidence of changed teaching practices, and none of the studies looked for evidence of student learning. Apart from the work by Rosebery and Puttick (1998), King, Shumow and Leitz (2001), Bryan (2003), and Koch and Appleton (2007), connections between approaches to preparing teachers to teach reform-based science were not traced to the effect of that preparation on teacher practice.

The research in this dissertation addresses these gaps in the literature. The elementary mentoring programs that form the context for this study were examined not only in the way they addressed the needs of novice teachers with varying levels of preparation for the classroom in developing systems of PCK for teaching reform-based science. This research also looked for evidence of the effect of novices' preparation and PCK for teaching science by observing their classroom practice and by examining the work of their students.

Summary

The questions framing this dissertation are addressed in the literature in different ways, however this study seeks to address some of the gaps in the literature related to mentored learning to teach reform-based science at the elementary level. First, the literature on pedagogical content knowledge for elementary science instruction does not address the role of mentored learning to teach in facilitating the construction of systems of PCK. While some of the literature on mentoring in the context of elementary science instruction addresses components of PCK (e.g. Jarvis, et al., 2001; Hudson, 2003, 2003, 2005), none of these studies sought to identify elements of mentoring program structures that help novice teachers build PCK. This dissertation addresses both of these gaps as it looks at how site-based mentors help novices' build systems of PCK for teaching reform-based science in the context of different mentoring programs.

Studies concerned with the preparation of elementary teachers to teach reform-based elementary science often emphasize the importance of one component of PCK (usually content knowledge) without considering its interaction with other components within the system. The discussions of site-based mentored learning to teach in this dissertation illustrate the interactions between components of PCK, and the nature of personal experiences and mentoring practices that may affect the construction of those components.

Few of the studies reviewed here investigated connections between teacher preparation and the nature of their classroom practices in teaching science. None of the studies looked for evidence of the effect of teacher preparation for science teaching (including mentored learning to teach) on student learning. This dissertation examined the relationships between the novice teachers' preparation in science content and pedagogy, the kind of reform-based practices encouraged by the mentors, and the way these practices were enacted in the classroom. Student work was examined for evidence of the effect of teacher preparation on student learning.

The focus of this dissertation on connecting the development of components of pedagogical content knowledge to ways in which teachers and mentors are prepared to teach science at the elementary level is novel to this study. The consideration of site-based mentored learning to teach as a continuation of teacher preparation for teaching reform-based science instruction is reflected in a few studies, but none of these studies made attempt to make explicit connections between mentoring structure and practices, novices' classroom practices, and student learning.

If the purpose of education is student learning, then the purpose of educational research should be the same. Studies of educational theory and instructional practices that do not attempt to investigate possibilities for connections miss the opportunity to add to knowledge for teaching.

CHAPTER 3

RESEARCH METHODOLOGY

Introduction

This dissertation uses a case study approach to look at mentoring in elementary science instruction in order to explore the potential for mentored learning to teach as a tool for encouraging reform-based science teaching. Data were gathered from three mentor teacher educators and four novice teachers with different preparatory experiences for the classroom in an effort to inform the following questions for this research.

- How do novice elementary teachers develop the pedagogical content knowledge needed to implement reform-based science teaching?
- How might the nature of elementary teachers' general pre-service pedagogical training and their preparation in science content and pedagogy in traditional and alternative certification programs affect the mentored development of pedagogical content knowledge for reform-based science teaching?
- How is the mentored development of novice teachers' pedagogical content knowledge for reform-based science instruction reflected in classroom practice and student learning?

The first section of this chapter describes the participants and context for investigation. The following sections describe data collection and analysis in relation to the research questions, followed by a description of procedures used to ensure trustworthiness. The final section discusses assumptions of the study.

Participants

Novice Teachers

The participants for this study were drawn from the faculties of two different elementary school sites. The design of this dissertation examines four cases of novice elementary school teachers (with from 1-3 years of prior classroom experience) as they began to teach science at the fifth grade level with the guidance of a mentor teacher. The novice teachers ranged in age from 23-35; three were male and one was female. They came to the classroom from two different approaches to teacher education: 1) traditional - a university-based four-year teacher education program, or 2) alternative – a teacher preparation program focusing on recruitment, specifically the Teach for America [TFA] program. They had diverse backgrounds in science content, but they all worked with the same set of content modules from a state-approved science program, the *Full Option Science System* [FOSS]. For a summary of participant characteristics, see the following table.

Table 1: Teacher Participants

Teacher	School	Mentor	Level	Preparation program	Licensure	Prior Yrs in the classroom
Ted	Joy ES	Lois, Kate	5	TFA	alternative	1
Don	Joy ES	Lois, Kate	5	University (Canada)	elementary	2
Mark	Love ES	Helen	5	TFA	alternative	1
Lia	Love ES	Helen	5	University	elementary	1

Participants Ted and Don were males teaching fifth grade at Joy Elementary School. Ted and Don worked with mentors Lori and Kate in a program that focused on science instruction as well as general teaching strategies. The teachers at Love Elementary School, Matt and Lia, also taught at the fifth grade level. Both of the Love teachers worked with Helen as their science mentor to complete one unit of study with her in the school's science lab.

Ted. Ted was recruited by the *Teach for America* (TFA) program, and was in his second year in the classroom during this study. Ted's undergraduate degree in international studies was granted from a well-known university in the eastern United States. He completed his initial TFA training during the summer before he began teaching, and was finishing his Masters of Education program during the course of this research. Ted had decided that he would leave the classroom at the end of his second year of teaching, although, at the time of this study he was still uncertain of his future plans.

Don. Don was in his third year of teaching, and he came to his teaching program in Canada from a career in business. Don opted for a teacher education program with an international orientation. A fluent speaker of Spanish, Don's initial fieldwork (e.g. practicum) was completed in Mexico. The remainder of his coursework and field experiences took place in Canada. Don earned an undergraduate degree in education.

Mark. Mark was also from the *Teach for America* program, and was in his second year in the classroom. With an undergraduate degree in political science from a university in the southeastern United States, Mark was placed at Love ES upon completion of the TFA Summer Institute. Mark was also in the process of finishing his Masters program in education, and was planning to spend one more year in the classroom.

Lia. Lia was prepared in a traditional university-based teacher education program at a university in the same southwestern city in which she began teaching, and where this research took place. She completed her student teaching at Love ES two years ago, was hired by the site administrator for a teaching position, and was now in her second year of teaching. Lia's undergraduate degree was in elementary education.

These participants were selected because they were novice teachers with zero to three years of previous classroom experience. They taught students of the same age in schools with very similar demographics, and they taught science using the same district-approved curriculum. These novice teachers represented a variety of teacher preparation programs, and they taught at schools that have dedicated mentor teachers (teachers who were not also teaching in their own regular classroom). These teachers were working at elementary schools that employed science-specific mentors. These schools not only allowed teachers to engage in science instruction, they were encouraged, even required to do so. Finally, these teachers were selected because they volunteered to participate.

Mentors

The three mentors for these novice teachers (two at Joy ES and one at Love ES) also differed in the nature of their science content knowledge, their years of experience in the classroom and as a mentor teacher, and in their own preparation for teaching and their preparation for mentoring.

Table 2:Mentor Participants

Mentor	**School**	**Mentor training**	**Licensure**	**Prior years in classroom**	**Prior years as mentor**
Lois	Joy ES	0 (1 semester in a university mentoring course)	Elementary	6 (+ 8 as a district-level teacher, providing professional development in math and science)	1
Kate	Joy ES	3 yrs	Elementary	30	3
Helen	Love ES	0	Alternative	2	0

The first two mentor participants (Lois and Kate) were assigned to Joy Elementary School. They were both prepared for teaching in traditional university programs. Kate was assigned to Joy ES as part of a mentoring initiative in one region of the local school district, while Lois' position was funded with school monies. Both Kate and Lois played an integral part in teacher development in inquiry-based instruction at Joy, and have both been involved in long-term teacher leader training in mathematics and science at the district level.

Lois. Lois had little mentor training, but she worked regularly with classroom teachers as a professional developer and curriculum specialist in math and science for the local school district for eight years prior to accepting the position at Joy. Lois co-authored a book and several articles on the use of science notebooks at the elementary level, she regularly presented at regional and national science conferences, and she consults with schools at the local, state, and national levels on developing effective programs of elementary science instruction. While Lois' undergraduate and graduate degrees were in elementary education, she minored in biology and she has been involved as a learner in many university courses and district professional development classes in science content. Lois is currently pursuing a doctoral degree in teacher education. Lois worked with the novice teachers in this study specifically in the areas of content and pedagogy related to science teaching, concentrating on using pilot assessment tools created by the Lawrence Hall of Science (University of California at Berkeley) for the FOSS curriculum.

Kate. Kate came to the district's mentoring program with 30 years of classroom experience at the elementary level. She spent the past three years mentoring novice teachers and participating in regular and ongoing mentor training at the district level. Kate has also initiated an additional component to novice teacher education at Joy ES as part of the school district's efforts to train and retain novice teachers in urban schools. Kate's Bachelor's and Master's degrees were in education, but she received additional training and coursework in mathematics and science as a teacher leader in a local systemic grant funded by the National Science Foundation. Kate concentrated on mentoring the novice teachers on general teaching strategies that were also important in science instruction (e.g. management of collaborative groups, lesson plan design, vocabulary instruction, etc.).

Helen. Helen was in her first year as a science mentor, and only in her third year of teaching. She also was recruited by the Teach for America program, and taught third grade for two years prior to assuming responsibility for the mentor role. Helen's undergraduate degree was in environmental science, with an emphasis in zoology. As part of her studies, she worked in the field in Central and South America, and learned to speak Spanish fluently. In compliance with state licensing requirements, she completed courses in pedagogy at the local university as part of her Master's program in education. Helen worked collaboratively with novice teachers in the context of a dedicated science lab, incorporating general teaching strategies and science-specific strategies into her mentoring practice.

Research Context

Schools

The research sites for this research were located in the same section of a large urban school district in the southwestern United States, and had very similar student population profiles. Joy Elementary School had 63.3%, of students with Limited English Proficiency (LEP); Love Elementary School had 62.7%. All of the students at each school qualified to receive Free/Reduced Lunch (FRL) from federal Title1 funding. There was a student transiency rate of 45.5% at Joy ES, and 39.6% at Love ES. The majority of the students at both schools were Hispanic, 86.9% at Joy ES and 85.1% at Love ES.

The demographics of the personnel were also similar between the two schools. Joy ES had 53 certified staff members of which 34% were within their first 3 years of teaching. Love ES had 62 certified staff members of which 18% were within their first 3 years of teaching. Of those certified staff members, Joy ES had 5 teachers and Love ES had 12 teachers who had come to teaching through an alternative route to licensure program.

In both schools chosen for this study the administration was committed to the implementation of standards-based teaching and has hired mentors in math, science, and literacy to help teachers as part of this effort. The selection of participants from these sites was directly related to this particular quality of the two schools. Most elementary schools in the large urban school district that is the larger context of this study, especially those (like the schools in this study) that are identified as "at-risk" in terms of the socioeconomic status of their student populations, are discouraged from implementing a science curriculum in favor of an extended focus on developing skills in mathematics and literacy that form the bulk of state standardized tests. Despite administrative pressure, Joy ES and Love ES chose to include science instruction as a required element of weekly classroom planning and instruction, and both allocated funding toward supplying science materials, staff development in science instruction, and mentoring in science teaching for faculty members.

Contexts of Mentored Learning to Teach

The two sites and three mentor teachers participating in this research differed in their approach to mentoring novice teachers in science instruction. One traditionally prepared teacher and one teacher with alternative certification participated at each site (see Table 1, p.101). All of the teachers used lessons and materials from the Full Option Science System (FOSS), a program that meets the criteria for exemplary science curricula developed by the National Science Foundation (National Science Resources Center, 1997). The FOSS program is designed to engage students in actively constructing scientific concepts through multi-sensory, hands-on, minds-on lessons (FOSS, n.d.).

The teachers at each school site were using different modules from the FOSS science curriculum during the time that data for this dissertation were collected. The two novice teachers at Joy ES were using the FOSS Environments module, a series of investigations designed to introduce students to basic concepts in environmental biology. The two novice teachers at Love ES were using the FOSS Landforms module to study change and interaction in earth science and to learn about some of the tools and techniques used to depict landforms. Both of these modules were aligned with the content standards for grade five in the National Science Education Standards (NRC, 1996).

Joy ES employed two mentors (Kate and Lois) in an unstructured program that enabled them to respond to teachers' as needed. Each novice teacher taught science by themselves in their own classrooms, with the mentors occasionally joining them to observe and conference afterward. Joy's dual mentors divided the task of mentoring the participants in this study: one mentor (Kate) focused on general teaching strategies; one (Lois) attended to on science-specific areas of classroom practice.

In addition to science-specific mentoring, Kate was responsible for implementing a learning group for novice teachers at Joy ES that was sponsored by the school district. The Urban Teaching Learning Community met on site after school twice a week for three hours. The agendas for these meetings were composed at weekly meetings of mentor teachers, and were made up of items that came partly from needs identified by participating teachers at each site, and partly from materials supplied by a school district facilitator for addressing common concerns for beginning teachers. The sessions looked at curriculum, lesson planning, teaching strategies, grade level planning for long-term goals, uses of technology, etc., and pulled in literature about more formal educational research to inform the group's discussion. The novice teachers would meet to discuss on any new or reconsidered instructional ideas, then they would try to implement and/or observe how these ideas worked in the classroom. During the following group session these teachers would share their experiences and reflect on what those results meant in terms of knowledge for teaching (Cochran-Smith & Lytle, 1999). Both of the novice teacher participants in this research participated in this learning community. Don had attended the meetings for two years, but Trevor stopped attending the sessions after one year.

Lois also sometimes met with Ted and Don by themselves or along with a few other teachers as part of Assessing Science Knowledge (ASK) from the Lawrence Hall of Science (LHS), University of California at Berkeley (FOSS, n.d.). This was a four-year project designed to define, field test, and validate assessment tools and techniques meant to help elementary teachers assess, guide, and confirm student learning in science for curricula developed by FOSS. Often meeting on Saturday mornings, this group discussed how evidence from examples of student work on pilot assessments demonstrated levels of understanding. Lois worked with these teachers to develop a protocol for assessing student work and to learn how to use the assessments and their accompanying rubrics. Much of the discussion during her mentoring conferences with Ted and Don at Joy ES sprang from the use of these assessments with their students, and the implications of the assessment results for planning instruction.

The Love ES mentoring model used a structured, collaborative mentor-novice teaching model, in which the mentor co-planned, co-taught, and co-assessed the novices' students in the context of a dedicated science classroom. The mentor/novice collaboration continued in this context for one unit of study in science (approximately four to six weeks). During this period, the mentor teacher initially assumed major responsibility for coordinating the instruction, gradually transferring it to the novice teacher as it was appropriate to their development. At the end of this intensive, structured phase of the mentoring program, the novice teacher assumed full responsibility for teaching science in his/her classroom, and the mentor's role shifted to a responder model. Because only one mentor (Helen) was involved in mentoring science teaching at this site, much of what she addressed with the novice teachers also applied to general teaching strategies.

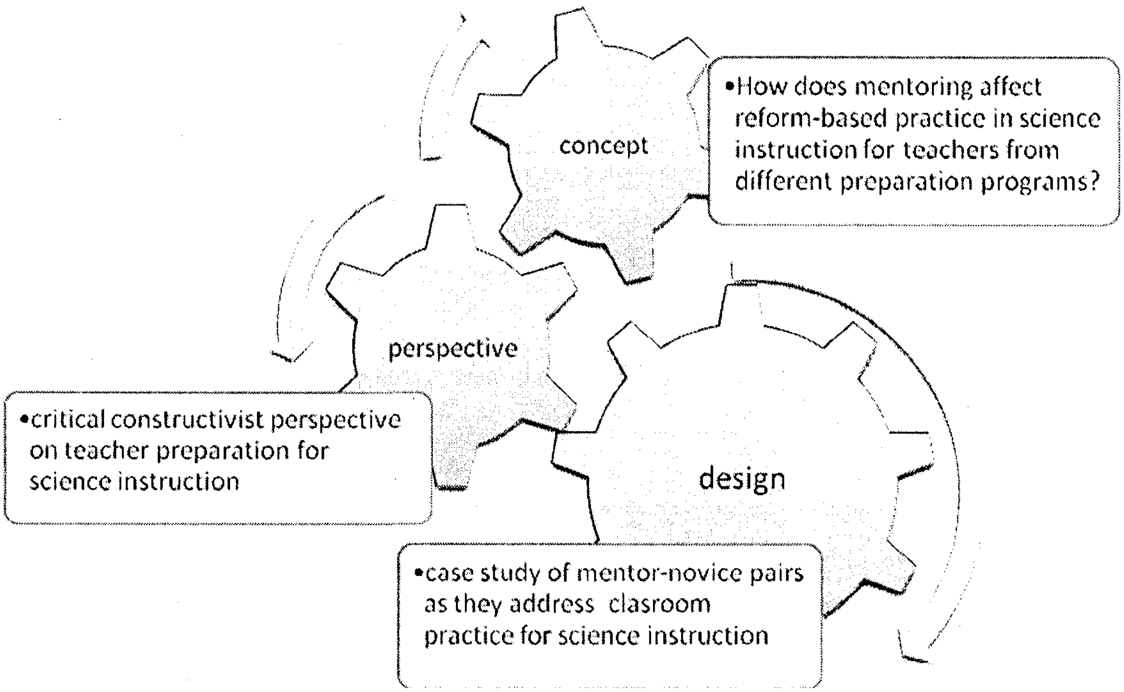
Despite difficulties in controlling for participants' age, gender, and mentors, and allowing for inconsistencies in standardizing lesson content and mentoring structures, this case study approach was able to examine participants and pairs of participants with reference to the particular context in which they work. Other uncontrollable variables included the background of individual teachers and mentors in science content and the extent of training and classroom experience for mentor teachers.

Perspectives on Research Design

A critical constructivist perspective was used by the researcher to examine the challenges associated with context, collaboration, culture, and orientation inherent in building knowledge *for, in, and of* practice (Cochran-Smith & Lytle, 1999, see further description in Chapter 2) for science instruction at the elementary level Knowledge *for* practice, the formal knowledge and theory created by university-based researchers *for* teachers to use in improving instruction may function as one component of mentors' pedagogical content knowledge for mentored learning to teach. Knowledge *in* practice, the practical knowledge "embedded in practice and in teachers' reflections on practice" (Cochran-Smith & Lytle, 1999, p.251), may also contribute to the study in way in which novice teachers develop situated components of PCK for teaching science in the context of site-based mentoring. Teacher knowledge "generated in inquiry communities" (Cochran-Smith & Lytle, 1999, p. 288) is reflected in the ways mentors and novices work together to create knowledge *of* practice from collaborative inquiry that may be informed by mentors' knowledge of the literature as well as the shared experiences of mentors and novices. This critical constructivist framework was particularly applicable to a qualitative case study designed to build understandings about mentoring practices from "*the meaning people have constructed*, that is, how they make sense of their world and the experiences they have in the world (Merriam, 1998, p.6).

The reciprocal nature of learning in mentoring relationships as collaborative inquiry for reform-minded practice in science instruction also influenced analysis and discussion of the data. The relationship between these elements of research design is illustrated in Figure 1.

FIGURE 1: Components of Research Design



Conducted from an etic perspective of an observer with an emic understanding of the general culture of the elementary classroom, this dissertation study is particularistic in the way that if focuses on the particular practices associated with mentoring science instruction at the elementary level. It is descriptive in nature in order to illuminate challenges and promises for mentoring as avenue to aid novice teachers understandings about how to teach science developed from cross-case analysis. Data were collected and examined to build an understanding of mentored learning to teach, interpreting those findings as they apply to practical considerations for helping novice teachers develop PCK for standards-based practices in science instruction. The themes and patterns generated from the analysis of the data collected within and across cases, though not generalizable to populations, found some connections to generalizable theoretical propositions in the literature (Yin, 2003).

Data Collection

Data collection included interviews of mentor and novice teachers, observations of mentor-novice meetings, observations of novices' classroom lessons, and analysis of students' written responses during those lessons (as applicable). Following an overview of how each of these tools for documentation was used to inform the research questions is a more detailed description of the nature of these particular tools and how they were chosen to gather data pertinent to this investigation.

Interviews

Each participant was asked to complete three structured interviews (see Appendices A and D) with the researcher on their preparatory experiences and beliefs about teaching, about their background in science content and pedagogy, and about their experiences as a classroom teacher. Mentor teachers were interviewed about their perception of the needs of their mentee(s) in relation to these areas, and about what they were doing to meet these needs. The interviews were audio-recorded and transcribed for analysis, and digital pictures were taken to record responses to sorting activities. Audio recordings and still photography were chosen as methods to record the data from these interviews because they were the least intrusive instruments that could accurately record the data.

The formation of the interview questions (see Appendix A) was guided by examples from scholarship that looked at the practice of novice teachers from different preparation experiences (Grossman, 1988, 1990; Roehrig and Luft, 2006) and from the literature on identifying pedagogical content knowledge in science teaching (Baxter & Lederman, 1999; Carlsen, 1999; Zembal-Saul, Starr, & Krajcik, 1999; Loughran, Mullhall & Berry, 2004). The interviews were structured to elicit information on the pedagogical content knowledge of the mentor and novice teachers and to gain insight as to the source of participants' knowledge about teaching and learning. In order to capture better the elusive and continually transforming nature of the participants' knowledge, the inteviews used questions that approached this information in different ways. Some questions were straightforward queries about beliefs and knowledge about science teaching (e.g. "What science courses did you take as part of your undergraduate (and/or graduate) level studies? Did you specialize in any one discipline? Can you describe a typical science lesson in your undergraduate (or graduate) studies?" Some questions or tasks illustrated participants' pedagogical content knowledge (e.g. creating a visual representation of the major disciplines in science and the connections between them in interview one). Mentor and novice teachers' responses and their accompanying rationales served as sources of data about participants' background in science learning and served as indicators of their tacit and explicit beliefs and knowledge about science content and pedagogy.

The following chart illustrates how the design of the interview questions addressed the research questions for this dissertation.

Table 3:Research Questions and Interview Design

Research Question	Connection to Design of Interviews
1	Questions were designed to identify sources of participants' systems of PCK for teaching elementary science (see especially Interview 2). Amendments to these questions were intended to uncover what the mentors understood about novice teachers' systems of PCK.
2	Interview questions were designed to gather data about the nature of teachers' pre-service preparation (see especially Interview 1) and to shed light on any effect that preparation might have had on the development of PCK for teaching elementary science (see Interviews 2 and 3). Amendments to these questions were added to determine the relationship between mentoring practices, novices' systems of PCK, and novices' preparation for teaching science.
3	Data for this question were intended to be drawn from only from mentors' responses to questions about their mentees' classroom practice (e.g. Interview 1, question 7; Interview 2, question 1; Interview 3, question 4).

Subsequent sections will provide a detailed explanation for the inclusion of each question of every interview.

Interview #1: Content Background and Conceptions of Science Pedagogy

1. Would you tell me about your background in science?

This question was designed to identify learning experiences that may have influenced teachers' knowledge of content and/or their understanding of pedagogy as it was built from their own apprenticeships of observation.

2. What do you think is meant by the term "science literacy" means? What makes someone literate in science?

3. Would you talk about the major disciplines in science? How are these areas related to each other? (Would you create a visual representation of these areas and their relationships?)

Responses to these two questions were designed to get a preliminary sense of participants' content knowledge and their understanding of the nature of science. The visual representations were included to demonstrate participants' understanding of the relationships between scientific disciplines, an aspect related to understanding the nature of science. This knowledge forms an integral component of pedagogical content knowledge (PCK) for science instruction because it influences teachers' perceptions of what is important to teach and how it is important to teach it.

4. What made you decide to become an elementary teacher?

This question was included to uncover previously unexpressed orientations to teaching and learning that may affect the function of components of teachers' systems of PCK. Asking participants to outline factors affecting their decisions to teach at the elementary level was an attempt to uncover some of their assumptions about the function of content, pedagogy, and context in teaching science at the elementary level.

5. What, if any, coursework have you completed in methods for science instruction?

Mentor amendment: Will you be taking any such coursework in the near future?

6. What areas of science do you think are important for elementary students to learn (probe for both conceptions of content and process)?

These questions were included to provide data for participants' content area knowledge in science and to probe for mentors' perceptions of the role of science content knowledge in their systems of PCK for teaching and mentoring science instruction. They also were designed to uncover teachers' perceptions of the relative importance of content and process in elementary science instruction – orientations that might influence the development of their PCK.

7. What do you think makes science difficult for students? What areas do you think students might have problems with? What is easy for students? What do you think would make the study of science easier and more meaningful for students?

Mentor amendment: What do you think makes teaching science difficult? What areas do you think novice teachers might have problems with? What do you think would make the study of science easier and more meaningful for novice teachers?

Directly influenced by the literature on pedagogical content knowledge (e.g. Shulman, 1986; Grossman, 1990; Loughran, Mulhall & Berry, 2004), these questions were meant to assess participants' current systems of PCK for elementary science instruction. The mentor amendment was intended to do the same for mentors' current systems of PCK for mentoring novice teachers in teaching science at the elementary level.

Interview #2: Teacher Preparation Interview

1. I've written out the names of each of the courses you took in college in science content and science pedagogy. Would you first sort the cards according to how they influenced how you think about science? How did they influence your understanding of science concepts?
2. Now would you resort the cards according to how much you think they have influenced your ideas about how to teach science (probe for both positive and negative influences).

3. Are there any other experiences in your life that may have affected how you think about teaching science? Tell me about them.

These three questions were intended to elicit further information related to how teachers build PCK for teaching science. The card sorting activity was designed to illustrate the extent to which participants' formal and informal learning experiences were important to the development of their understandings of science content and pedagogy. These questions were also included to uncover any differences in preparation in science content between participants from traditional and alternative certification preparation programs, and between novice teachers and their mentors.

4. Tell me about the best teacher you have ever had (in any subject). What made him/her the best?

5. Tell me about the worst teacher you have ever had. What made him/her the worst?

6. Here are the titles of courses that you took during your teacher education program. Would you sort them into categories that are meaningful to you? How have you grouped them? Tell me about each pile. Are there other ways you might group them? Tell me about the different ways. Let's go through the titles one by one and talk about what you got out of each one (probe for both coursework and fieldwork).

Mentor amendment: Here are the titles of courses that *your mentee took* during their teacher education or undergraduate program. Would you sort them into categories that are meaningful to you in describing your mentee's understanding of science instruction? How have you grouped them? Tell me about each pile. Are there other ways you might group them? Tell me about the different ways.

7. What other experiences or resources do you see as important to helping you teach science?

Mentor amendment: Let's go through the titles one by one and talk about what you think your mentee got out of each one. What evidence do you see of any transfer from this coursework and/or fieldwork?

These questions were aimed at discovering participants' understandings about and orientations toward pedagogy. Because the research questions for this dissertation included some consideration of the effect of teacher preparation programs on novice teachers' PCK, these questions were also used to provide any indication of the role of fieldwork experiences (an element that was significantly different in the two programs represented in this study) in helping to develop pedagogical knowledge. The mentor amendment was included to gain insight into the mentors' perceptions of how novices' preparation for the classroom was influencing their development of systems of PCK.

Interview #3: Teaching a Science Unit

The participants responded to interviewer-supplied samples of student work in science completed in another teacher's classroom.

1. Would you talk a little bit about these papers?

    1.1. What kind of classroom experiences in science do you think generated this work? What do you think each of the students did prior to creating these pages?

Mentor amendment: What do you think the teacher did prior to asking the students to create these pages?

1.2. Tell me what you think each of the students represented by this work understand about science content and/or process. How do you know?

Mentor amendment: Tell me what you think the teaching practice represented by this work? What does the teacher understand about content and/or process? How do you know?

1.3. Do you see evidence of any naïve conceptions in the samples? Tell me about what you think these students may be misunderstanding.

1.4. What evidence do you see that students are making connections to the big ideas (unifying concepts) behind the unit?

Mentor amendment: What evidence do you see that the teacher is helping students make connections to the big ideas behind the unit?

2. If you were the teacher of these students, what kinds of follow-up questions would you like to ask, in order to determine their level of understanding about science concepts and/or process skills? How do these samples create, or fail to create, a picture of student learning?

3. If you were the teacher of these students, what do you think would be the next step in instruction that would address student needs?

4. What naïve conceptions about this science content have you observed in the students in your classroom? How did you address these ideas?

Mentor amendment: What naïve conceptions about science content have you observed in the students in your mentee's classroom? How did your mentee address these ideas?

The first four questions in this interview were used to help gauge teachers' understandings of content, context, and pedagogy as they may have been evidenced in student work. These prompts were designed to illustrate teachers' systems of PCK for teaching elementary science as they spoke about their perceptions of the teaching methods and content understandings used to elicit the student work samples provided. The questions also were intended to uncover participants' understanding of "big ideas" in science content underlying the instruction represented by these samples. Data illustrating participants' understanding of context and pedagogy was intended to be drawn from responses to questions about the relationship between assessment of student learning and instructional design.

The mentor amendments were designed to uncover their understandings of content, context, and pedagogy related to their systems of PCK for mentoring and to provide data from their perceptions of novice practice that could be used to triangulate information collected by the researcher during classroom observations and interviews.

5. What kinds of questions did students in your/ classroom generate about what they are studying? How does this reflect students' understanding of content and/or process?

Mentor amendment: What kinds of questions did students in your mentee's classroom generate about what they are studying? How does this reflect the mentee's understanding of content and/or process? What conversations have you had with the mentee about their classroom instruction in science?

Because teachers' recollection and interpretation of student questions may also provide an indication of how they are developing systems of PCK for teaching elementary science, these questions were designed to prompt them to talk again about elements of science content, context, and pedagogy in relation to student questions. The mentor amendment was designed to look again at mentors' perceptions of novice teachers' understanding of science content and process and to provide data for the kind of strategies mentors were using to address their mentees' development of PCK.

6. How would you respond to the following student question: Why do we have to draw and write about what we do in science?

7. How would you respond to student questions related to the science content?

Mentor amendment: How would you respond to mentee questions related to the science content?

These final questions were designed to further uncover teachers' understanding of the relationship of context and pedagogy in elementary science instruction. These questions were aimed at gathering data about teachers' development of PCK as they talked about the purposes behind instructional design (drawing and writing to reflect on learning). Participants' responses were intended to illustrate their understandings about content and pedagogy in the way they would respond to students' questions. Furthermore, the mentor amendments were designed to uncover strategies the mentors used to address the development of content area knowledge in novices' systems of PCK for science instruction.

Observations of Mentor-Novice Meetings

In addition to the interviews, I made audio recordings and/or took field notes of meetings between novice teachers and their mentors as they meet to plan for instruction or debrief following classroom observations. (For an example of field notes taken during one of these conferences, see Appendix C.) Specific connections between the research questions and the purpose for the gathering data from mentor-novice observations is outlined in the table below.

Table 4: Research Questions and Mentor-Novice Observation Design

Question	Connection to Design of Mentor-Novice Observations
1	Framework for observations included focus questions that were designed to uncover how the novice teachers were developing systems of PCK for teaching science from their mentoring relationship.
2	Observations were designed to gather data about how or if the mentors were adapting their practice according to the preparation of the novice teachers.
3	These observations were intended to provide data for strategies mentors were using to mentor novices toward developing PCK for reform-based science instruction.

Because some of these conversations took place in areas that were not conducive to the creation of clear audio records (e.g. in the teachers' lounge or at the back of the classroom), field notes were the most dependable and least intrusive method of recording data during these meetings. It was important that I observe these interactions as close as possible to the way that they naturally occur in order to capture teachers' authentic responses.

These observations were crucial in collecting data from first-hand observations of mentoring conversations that could then be compared to information gathered from interviews. In addition to my general notes, I also listened for and recorded data illustrating specific mentoring practices used to facilitate novices' development of knowledge of content and pedagogy for reform-based instruction in science (adapted from questions to identify PCK developed in Loughran, Mullhall & Berry; 2004). I looked for examples of how the mentors probed for the novices' content understanding in order to find out what they knew (or do not know) about science content or process in their lessons, and how they were identifying any difficulties or limitations (e.g. students' naïve conceptions) connected with teaching these lessons. I also looked for how the mentors guided the novice teachers to understand *what* they intended their students to learn about science content or process from their lesson(s), *how* they intended to teach it and assess student understanding, and *why* it was important for students to build an understanding of the selected content. I collected data about how the nature and substance of the mentoring conversation illustrated the mentor's conceptual orientation (humanistic, situated apprentice, or critical constructivist) perspective toward the mentoring relationship (Wang & Odell, 2007), and how the mentoring conversation illustrated the role of developing knowledge *for, in, and of* teaching in the novice teacher's practice (Cochran-Smith & Lytle, 1999).

Focusing on implicit and explicit understandings evidenced in these mentor-novice conversations will allow me to look for patterns of mentor prompts and novice responses that may illustrate differences that might be attributable to novice participants' different preparatory programs.

Classroom Observations

I took structured field notes for three classroom lessons over a period of eight weeks. The classroom lessons varied from 45 to 90 minutes in length, and were spaced two to three weeks apart. Data from these classroom observations were used to look at what the novice teachers were doing in the classroom, what they were discussing with their mentor teachers, and what they were saying in interviews with me. (See Appendix B for an example of field notes from a classroom observation.) Observing classroom lessons helped me triangulate data collected from other sources and gave evidence to support information offered in interviews and mentor-novice conversations. Specific connections from the research questions to elements of classroom observations are outlined in the table below.

Table 5:Research Questions and Classroom Observations

Research Question	**Connection to Design of Classroom Observations**
1	Classroom observations were designed to provide further evidence of the influence of different sources (including mentoring) for novice teachers' systems of PCK for science teaching at the elementary level, and to triangulate data from classroom interviews and mentor-novice conversations.
2	Observations of classroom lessons were included in the methods of data collection in order to provide data for how elements of novice teachers' preparation programs (e.g. science methods coursework) may be affecting novices' development of PCK .
3	Observations of classroom lessons were intended to provide data for how mentoring was affecting novices' development of PCK as evidenced in their observed classroom practice and student work.

I looked at ways in which novice teachers were implementing what was discussed with their mentor teachers, especially as they illustrated the development of pedagogical content knowledge (Baxter & Lederman, 1999; Borko, 1993; Gess-Newsome, 1999; Grossman, 1990; Loughran, Mulhall, & Berry, 2004; Magnusson, Krajcik, &Borko 1999; Van Driel, Beijaard, & Verloop, 2001; Zembal-Saul, Starr, & Krajcik, 1999).

In addition to notes responding to pivotal lesson events, I looked for evidence in the data of novice teachers PCK. I considered the teachers' practice in light of specific considerations drawn from the literature (Bodzin & Beerer, 2003; Jarvis, McKeon, Coates & Vause, 2001) about PCK for science instruction based on the NSES reform standards for content and pedagogy.

In general, I watched for evidence that the novice teachers were applying suggestions for practice drawn from interactions with the mentor teachers. Lesson activities were examined for how they encouraged students to use process skills (observing, sorting, comparing, classifying, predicting, doing a fair test, collecting, recording, and/or interpreting data, and communicating findings). I looked for examples of how the teachers used observation, questioning, and/or group discussion to informally assess student learning, and how they used informal assessment results to adjust the lesson(s). I looked for instances in which students were asked to reflect on their learning from their own prior experiences in science, to experiences in other content areas, and/or to real-world situations, and whether or not students were asked to make generalizations and predictions based on evidence from those experiences.

Other evidence of novice teachers' development of PCK for science instruction was gathered from the kinds of questions the teachers asked during their lessons. I looked at whether the questions allowed for a variety of responses, and if they required students to compare, organize, evaluate, or synthesize information. I also looked at number of opportunities for student to design procedures to investigate their own questions generated from their experiences. Data from class discussions were collected to show how the novices' lessons allowed students to share their science findings and to build or clarify their understanding of science content. Data from these discussions were also examined for evidence of the teachers' understanding of science content.

Student Work Samples

In order to support my observations, I collected samples of students' written work in addition to descriptions of student actions and responses during classroom lessons. I collected at least six samples of student notebooks from each of the novice teachers' classes. These samples were identified by the teachers as belonging to students with high, medium, or low achievement in science. But because some of the lessons observed produced no individual records of learning, some of the samples collected were created in the context of group investigations.

Because the lessons observed did not always include opportunities for students to record data, questions, and conclusions, etc., the consistency of this data varies. I examined these samples in order to gather evidence about what students may or may not understand about science content and process as a consequence of their teachers' developing PCK. Once again, I used a list of important elements for reform-based instruction identified in the literature (Baxter & Lederman, 1999; Carlsen, 1999; Zembal-Saul, Starr, & Krajcik, 1999) as a guide (but not a restriction) for my observations.

Specific connections between the research questions and the purposes for examining student work samples are outlined in the table below.

Table 6: Research Questions and Student Work Samples

Question	Connection to Student Work Samples
1	Student work was included to provide evidence of any effect of novice teachers' development of systems of PCK for teaching science on student learning.
2	Data from student work samples were gathered to clarify any differences in student learning that might be connected to their teacher's system of PCK for teaching science.
3	Data also were intended to provide evidence of the effect that components of PCK formed from other sources had on student learning.

I first looked at what was interesting or surprising in the work samples from lessons I had observed. I looked at student work for evidence of learning about intended or unintended lesson objectives as I examined the samples for information about students' understanding of science content and process. I looked also for examples of how the work reflected the teacher's classroom practice, content knowledge, understanding of context, and/or orientation to science instruction. I also examined student work from unobserved lessons and units of study in their science notebooks to find evidence of patterns in how they represented what they were doing or learning in class.

In summary, interview transcripts, field notes of classroom observations and mentor-mentee conferences, and student work samples were appropriate and valid research tools for this study for exploring the complex nature of mentored learning to teach. The various forms of data provided triangulation of data necessary for establishing trustworthiness in qualitative research (Creswell, 1988). The data included information that was self-reported as well as data that were recorded and interpreted by the investigator. Combining sources and methods of data collection help establish credibility (Yin, 2003).

Data Analysis

The information gathered from interviews, observations, and artifacts was examined and organized in three areas according to the research questions. Methods of analysis were informed by the literature on qualitative research (Stiles, 1993; Creswell 1998, 2003; Merriam, 1998; Glesne, 1999; Merrick, 1999; Yin, 2003).

This analysis was informed by the literature pertinent to the research questions as represented in the table below. Subsequent sections will further delineate the methods of analysis for each research question (See Table 7).

Table 7: Analysis for Research Questions and Findings in the Literature

Question	Pertinent Literature
1	PCK: Grossman, 1990; Magnusson, Krajcik & Borko, 1990; Barnett & Hodson, 2001; Lee, et al., 2007 Self confidence and PCK: Bandura, 1981, 1982; Crawley, 1991; Wenner, 1993, 1995; King, Shumow& Lietz, 2001 Teaching experience and PCK: Hashweh, 1987; Smith & Neale, 1991; Sanders, Borko, & Lockard, 1993; von Driel, Verloop, & de Vos, 1998; Gess-Newsome, 1999 Learning to teach science: Borko, 1993; Czerniak & Lumpe, 1993; Hudson, 2003; Koch & Appleton, 2007; Smith, D.C., 1999; Eady, 2008
2	Teacher education: Feiman-Nemser, 1990; Grossman, 1990; Kagan, 1992; Zeichner & Conklin, 2005 Teacher preparation for science teaching: Rosebery & Puttick, 1998; Zembal-Saul, Blumenfeld & Krajick, 2000; Gess-Newsome, 2002; Roehrig & Luft, 2006
3	Mentoring elementary science: Jarvis et al., 2001; Hudson & Skamp, 2003; Hudson & McRobbie, 2003; Hudson, 2003, 2004, 2005; Hudson, Brooks & Skamp, 2005; Koch & Appleton, 2007

Question 1: Examining Sources of Teachers' PCK

Questions about the ways novice elementary teachers develop the pedagogical content knowledge needed to implement reform-based science teaching and how mentoring practices contribute to this development, were examined using a constant comparative method. The critical events and descriptions from data collected from interviews, classroom observations, mentor-novice observations, and student work were coded and a domain analysis was completed within and across cases in order to identify sources of PCK for elementary science teaching. Categories of PCK elements were built from this analysis, and embedded categories of common sources for the construction of that PCK were also identified. These embedded categories were used as a framework for identifying how mentoring practices affected the development of novice teachers' systems in relation to research question two.

Question 2: Teacher Preparation and Mentored Learning to Teach

Data to show how the nature of elementary teachers' pre-service pedagogical training and their preparation in science content and pedagogy in traditional and alternative certification programs might affect the mentored development of pedagogical content knowledge for reform-based science teaching were again gathered from transcriptions of participant interviews and field notes of lesson observations and mentor-mentee conversations.

I used the systems model of PCK developed in the analysis for question one as a framework for searching for evidence of how mentoring practices affected the development of novice teachers' PCK. This area of analysis looked at the data gathered from the novice teachers without substantive teacher education prior to entering the classroom. A cross-case analysis looked for common patterns and themes between the cases. The same procedure was then used for the teachers with traditional teacher education backgrounds. The data from the two groups of teachers were analyzed to find patterns and themes related to components of teachers' pedagogical content knowledge and its sources.

Analysis of the data for this question was informed by the literature on generic mentoring and mentoring practices (Daloz, 1986; Little, 1990; Ben-Peretz & Rumney, 1991; Feiman-Nemser & Parker, 1993; Elliott & Calderhead, 1994; Wang & Odell, 2002) as well as the research on mentoring for reform-based science teaching (Haney & Lumpe, 1995; Rosebery & Pittuck, 1998; Jarvis et al.2001; Hudson, 2003, 2004, 2005; Hudson &

Skamp, 2003; Hudson, Skamp & Brooks, 2005; Koch &Appleton, 2007). This analysis also relied on the descriptions of collaborative inquiry into teaching in Cochran-Smith and Lytle (1999).

Question 3: Evidence of the Effects of Mentored Learning to Teach

Data for the research question about how the mentored development of novice teachers' pedagogical content knowledge for reform-based science instruction is reflected in classroom practice and student learning were gathered from transcriptions of participant interviews, field notes of lesson observations and mentor-mentee conversations, and samples of student work.

For this question, participants were regrouped according to the organization of the mentoring context (the school site) in which they participated. Data for each participant was coded as evidence of the influence of mentoring practice. A cross-case analysis for each group searched for evidence of the nature of the mentoring relationship and specific mentoring practices and their influence on novices' classroom practice. The data was then examined to contrast mentoring practices across the groups of novice teachers.

Data drawn from student work samples were examined for evidence of the possible effects of mentored development of novice teachers' PCK on student learning. As influences of mentoring structures and practices on classroom practice were suggested in the data, they were traced to any indication that these influences might be fournd to affect student learning in student work. Samples collected during the lessons observed for this research were examined for evidence of how the pedagogical practices of the lesson may have affected student learning, especially if those practices appeared to have been influenced by the mentoring process.

A section of a more detailed study for each individual participant was also included as part of each area of this analysis, chosen to illustrate a particular aspect of how teachers develop pedagogical content knowledge for teaching elementary science, and how their understanding about teaching may affect their students' learning.

Questions arising from the subjective nature of qualitative data gathering and analysis are considered in the following sections that present the steps taken in order to insure trustworthiness of the analysis.

Trustworthiness of the Analysis

This detailed description of the tools and methods of analysis used in this study is not intended for the purpose of replication, but is included in an attempt to provide evidence of my procedures of investigation.

> Given post-positivist acknoledgements that there is no one "truth" and that all knowledge is constructed, the aim (and even the possibility) of replication is thrown out. Qualitative researchers generally agree that a study cannot be repeated even by the same investigator, given the unique, highly changeable, and persoaal nature of the research endeavor. (Merrick, 1999, p.28)

In order to assure that the analysis and the findings it generates are *trustworthy,* the following section presents further evidence of my research practice. Stiles (1993) calls for five elements of qualitative research that should address the trustworthiness of analysis: a) disclosure of the researcher's orientation, b) persistent observation, c) intense and prolonged engagement with material, d) triangulation, and e) discussion of findings and observations with others.

Disclosure of Researcher's Orientation

Because I was the primary instrument for qualitative data collection and analysis, these data were mediated, intentionally or unintentionally, by the manner in which I responded to the context of the study to adapt techniques to the circumstances, to clarify questions and to explore anomalous responses (Merriam, 1998). The influence of my personal experiences as elementary teacher, mentor teacher, and university instructor for science methods classes could not be divorced from my perspective on teacher education and mentoring programs. These experiences have colored my thinking about effective science instruction, about the mentoring needed to address instruction towards national standards, and about the lack of preparation in science teaching found in many teacher preparation programs. My understandings may have affected my perceptions of events during this study and my interpretations of the data collected, a condition that was controlled through the use of thick description of the data, inter-rater confirmation, and member-checking of the data.

I took steps to increase the reader's exposure to the data by providing many detailed examples from the data to illustrate my findings (see Chapter 4). Because it was impossible to remove my personal orientation toward the data from my analysis, I have made it explicit and compensated through the use of thick descriptions of participants and events from the research in order to create a sense of shared experiences (Creswell 1998, 2003; Merriam, 1998; Glesne, 1999; Yin, 2003).

Multiple Observation/Intense and Prolonged Engagement with the Material

Over the course of my research I spent close to 25 hours observing classroom and mentoring practices. The requirements of this disseratation process have ensured an "intense and prolonged engagement" with the materials. Many more hours have been spent transcribing, coding, arranging and rearranging data in order to examine the research questions.

The comparative process was used to refine and clarify themes, to describe common characteristics across contexutalized mentoring practices, and to interpret preliminary findings towards an explanatory framework that addressed my research questions. Collecting and analyzing data concurrently forms a mutual interaction between what is known and what needs to be discovered. This iterative interaction between data and analysis is the essential to prolonged engagement for attaining trustworthiness.

Triangulation

In order to address its trustworthiness, data analysis in this account traingulate information from interviews, observations, and artifacts to build a coherent justification for themes. Information was drawn from first-hand observations of classroom practice, mentoring conversations, and the creation of student work. Data from interviews with each participant contributed information about their backgrounds, their preparation for teaching science, and their understanding of science and science teaching that could be traced to data from other sources.

Discussion Of Findings and Observations with Others

The work was evaluted in terms of its internal logical consistency and its findings were compared to other relevant educational research (Merriam, 1998). As presented above, each the analysis for each question was informed not only by my own research but from findings in related literature.

Member-checking was another measure used to determine the accuracy of the qualitative findings. I confirmed my classoom observations with participants' perceptions, and I checked with the novice participants about descriptions of identified themes. I planned to note any discrepant ideas (Creswell 1998, 2003; Glesne, 1999; Merriam, 1998; Yin, 2003), however none of the participants indicated any disagreement with either my transcription or my interpretation of the data.

My efforts to use inter-rater confirmation of my analysis had a curious, but informative result. I asked two experienced and knowledgeable educators to confirm my classification of the data. Given the bits of data from a matrix created in the coding of each participant's data, they were asked to resort the information according to how they felt in represented different aspects of pedagogical content knowledge. Each of these raters placements agreed with my own interpretation overall (98%). However, each of these raters *also* provided a justification for also how the information could be organized in other ways, depending on the context in which the data was collected. This thoughtful collaboration provided evidence for the importance of context in interpreting data collected in qualitative studies.

Limitations of the Study

There are several limitations to the data collection for this study. First, because classroom observations were recorded only with field notes (for reasons cited above), there was no opportunity to review and revisit verbatim accounts of events and conversations. There was also a limited number of observations (three for each participant)from which to draw conclusions about novices' teaching practices, over a limited length of time (three months). There were few participants in this research(four novice teachers and three mentors), and because this research was completed at the end of the school year, there was no way to do any follow-up interviews or classroom observations.

Summary

This analysis identified elements and sources of PCK for science teaching drawn from the data. It also defined structures and approaches to mentoring used in helping novice teachers with different preparation construct systems of content knowledge and/or pedagogical understandings needed for teaching science based on national standards. Patterns in recorded responses and behaviors were examined in relation to mentor strategies that were used to address the needs of novice teachers, especially as they were related to the teachers' particular form of pre-service training. The analysis looked at the ways in which novice teachers' development of PCK for teaching elementary science may have been evidence in classroom practice and student work. The results of this analysis that are presented in the following chapter look in depth about how the data collected shed light on my research questions and on extant literature, contributing to the knowledge base about mentoring in elementary science and how teachers develop pedagogical content knowledge for reform-based science instruction.

The data collected and analyzed in this study were used to create an in-depth description of how mentors and their mentees build knowledge *of* and *in* practice (Cochran-Smith & Lytle, 1999), and how that knowledge is related to knowledge *for* practice (see clarification under the section describing perspectives on research design, above) as described in the literature on the development of PCK for teachers with alternative certification (Grossman, 1990), on mentoring and teacher education (Little, 1990), on approaches to mentoring for standards-based instruction (Wang & Odell, 2002), on mentoring for science instruction (Loughran, Mulhall, & Berry, 2004), and on mentoring for science instruction at the elementary level (Hudson, 2005). A discussion of the dilemmas, challenges, and promise inherent in attempts at constructivist practice in teacher learning seeks to enhance understandings of ways in which novice teachers begin to develop PCK for standards-based practices in science instruction. The potential for mentoring as a tool for encouraging reform in science instruction in the classroom practice of novice teachers with different preparatory teaching experiences was evaluated in light of the results of this investigation.

CHAPTER 4

FINDINGS OF THE STUDY

While analysis of the data collected for this dissertation revealed only tentative findings about the effects of mentoring on learning to teach elementary science, this chapter attempts to explore possible connections of novice teachers' sources of knowledge about teaching science, including mentored learning to teach, to their development of PCK and to student performance. This section presents data specific to the novice teacher's: 1) knowledge of content, 2) knowledge of pedagogy, and 3) knowledge of context. Included with this discussion are illustrations of mentoring practices designed to move these novice teachers toward reform-based science teaching. The data also include evidence of student learning related to the influence of each participant's particular system of PCK on their classroom practice, and establish a base for subsequent discussions of findings for each research question. Exemplars of the analytic points were selected from among the data and placed in the Appendices.

The discussion will continue with findings related to each research question based on cross-case comparison. Discussion of the first research question will identify possible sources of teacher knowledge about content and process for science teaching, using examples that illustrate particular issues related to developing pedagogical content knowledge for teaching elementary science.

Discussion of the second question presents a cross-case analyses within and between two groups of novice teachers; one group without substantive teacher education prior to entering the classroom and one with more extended, traditional preparation for the classroom. Common patterns and themes between and across the cases are related to the teachers' pedagogical content knowledge and its sources.

Discussion of the third question describes evidence for categories that define the ways in which these mentoring contexts affected novices' classroom practices and may have influenced their students' learning.

Research Question One: Sources of PCK

A comparative analysis of the findings from this study informs my first research question: How do novice elementary teachers develop the pedagogical content knowledge needed to implement reform-based science teaching?

Categorization of Sources for PCK

Teachers' personal experiences as science students are connected in the analysis for this research to their ideas about science content and science teaching. Reflections on these *apprenticeships of observation* (Lortie, 1975) were the most common sources of teacher content knowledge about the nature of science for all participants, and the data drawn from these experiences illustrated how they affected novice and mentor teachers' views and dispositions toward both science content and pedagogy (Gess-Newsome, 2002).

Analysis of the data also indicated that other influential elements in teacher learning were *teacher education (including courses in science content), preservice preparation, and pedagogical coursework.* Although related to teachers' apprenticeship of observation, this narrower category is included because it is important in establishing a framework for comparing the impact of these experiences on teacher development in areas two and three of this analysis. This category includes classes in science content, formal teacher education courses taken either at the preservice or inservice levels, and other field service or leadership training components of preservice preparation programs.

The most commonly identified sources of teacher learning about specifically related to science pedagogy were teachers' personal *classroom experiences* and *mentoring as situated professional development*. Because these two elements were at times indistinguishable in the data (e.g. during observations of mentor-novice collaborative lessons), it was difficult to determine the exact order of occurrence. The category of personal classroom experiences refers to how the knowledge teachers build *in* practice (Cochran-Smith & Lytle, 1999) affects the development of their understandings about reform-based science pedagogy. Situated professional development in this analysis refers to how the mentor teachers participating in this research established an environment for helping novices develop PCK for teaching elementary science.

Finally, *contextual forces* refer to elements affecting novice teacher development that are beyond the scope of the previously defined categories. The forces identified in the data for this analysis include opportunities and constraints offered by particular elements of the contexts in which teachers operate: community, students, school culture, and educational policies.)

Subject Matter Preparation

Except for Ted, all of the novice teachers involved in this research had similar backgrounds in the amount of content coursework in science at the college level. None of the novice participants had an undergraduate or graduate degree in any of the science disciplines, and none of them had secured an endorsement on their full or provisional elementary certification required to teach science at the middle school level. Their college level content coursework was distributed among the disciplines of physics, chemistry, biology, anatomy/physiology, anthropology, geology, and sociology, along with related courses in statistics and engineering.

Table 8: Novices' Perceptions of Undergraduate Science Content Preparation

Ted	Mark	Don	Lia
anatomy/physiology/ exercise (combined in one course)	Anthropology Chemistry Sociology Statistics	Biology Chemistry Engineering Physics	Anthropology Biology (2 courses) Geology

These subjects were identified by the participants as science coursework. While there are those who assert that areas of social science (e.g. anthropology, sociology) and mathematics (statistics) do not qualify as "science," these subjects are included in the description of content areas for grades K-12 in the NSES (see pp. 121-207, NRC, 1996). There may have been differences in the substance and rigor of coursework at various institutions of higher learning, but except for Ted, the number of science courses completed (four) was the same for the other novice teachers.

All in all, the formal college level coursework in science content for these participants was, as might be anticipated, both diverse and limited compared to the content preparation in specific science disciplines for secondary teachers. A general approach to content preparation in science in teacher education programs is to include a few introductory level or general science classes as part of the program's required coursework. There is usually little restriction on which disciplines should be included in this coursework, or what diversity across disciplines must be included. But because elementary teachers are responsible for teaching all of the science disciplines (as well as several other subject areas), it is unrealistic to assume that they will take a significant number of credits in each area of science.

It is equally unrealistic to expect all novice teachers who come to the elementary classroom with alternative certification to have a solid background in science content across the disciplines. The two novice TFA teachers in this research (Ted and Mark) took classes that supported their undergraduate programs in political science and international studies rather than investing substantial time in science courses. Unlike their counterparts who enter secondary classrooms with provisional credentials, novice teachers from alternative certification programs who are placed in elementary schools are not required to present assurances of content knowledge beyond their undergraduate degrees. While a Bachelor's degree from a competetive university may imply a well-rounded exposure to subject matter, data from this research suggests it may not guarantee any greater expertise in science content knowledge than an undergraduate degree in education from a less prestigious institution of higher learning.

Novice participants from traditional and alternative teacher preparation programs recalled their experiences in science classes with mixed reactions. These teachers' most vivid memories of their own science learning came from biology labs and chemistry courses in college and high school. The study of biology was often connected to recollections of dissection labs, and chemistry was remembered (not always fondly) for requiring a good deal of memorization, for lecture-based instruction, and for the performance of highly directed and replicative laboratory experiments. While the participants were able to remember very few specific understandings from these classes, these courses did appear to influence teachers' views of the nature of science and science pedagogy.

This influence was partly due to how teachers perceived their level of expertise in science, and how those perceptions affected their understanding of the nature of science and science teaching. For example, Mark's appreciation of "hard" science and his conception of the nature of science were formed, at least in part, from his learning experiences in high school and college chemistry coursework. The remembered nature of Don's science coursework from his degree program in architecture contributed to his content knowledge and to his pedagogical understandings in science. Ted's experiences in high school biology appeared to have influenced his feelings of self confidence in science teaching as well as his approach to science instruction. Lia's negative experiences in high school chemistry had a similar effect on her confidence to teach science, regardless of her other successes as a student of science.

Pedagogical Knowledge from Teacher Preparation and Education

Key to understanding mentored learning to teach with novice teachers from traditional and alternative routes to the classroom is how those preparation programs served or did not serve as sources of pedagogical knowledge for elementary level, reform-based science. Traditional preservice teacher preparation for teaching science forms part of this analysis as does coursework in science pedagogy taken as part of graduate level programs and workshops offered as part of the TFA program.The analysis first looks at participants' background in science pedagogy, then it presents data from participants concerning their experiences in university-based science methods courses for teaching elementary science.

The data presented here present teachers' perceptions about their preparatory experiences along with interpretive commentary about how these perceptions may or may not have been evidenced in their own teaching.

Influence of teacher education on pedagogical understandings. Analysis of the data indicates below that preservice teacher education coursework was an important component in developing knowledge of pedagogy. It was only slightly less prominent in the data from novice teachers' reflections than their apprenticeship of observation (outside of field experiences for teacher education). However, analysis of other data sources (classroom observations, lesson plans) indicated a more central role for teacher education, especially for the TFA novices.

While Ted did not mention his university coursework as important to developing his classroom practice, Mark credited his experiences in his science methods course in helping him learn how to teach science. However, neither of these novice TFA teachers mentioned their brief field experience as being especially helpful to their understanding of the classroom, except that it provided "some hands-on experience" (Ted, interview).

Analysis of the data from the reflections of teachers with traditional teacher education preparation indicated that they perceived their field experiences as the most important part of their programs for learning how to teach, a common claim among teachers (Feiman-Nemser & Buchmann, 1985). For Lia and Don, the practical, procedural, and normative understandings built during student teaching were valuable assets in establishing their own classroom. Their field experiences provided these teachers with general teaching strategies that they then applied to their science teaching. Lia's field experiences also included some observations of her cooperating teacher and a science mentor as they taught some science lessons collaboratively, and experience that Lia credits with supplying her with a start in understanding how to teach science.

However, an appreciation for the acquisition of basic instructional tools during pre-service education and field experiences often prevents teachers from reflecting on their professional practice in light of educational research and reform (Cochran-Smith, 1991; Feiman-Nemser & Beasley, 1993). Lia's ideas about elementary science education as a collection of "fun experiments" were reinforced by her science methods coursework and might have been doubly confirmed in an instructional context that relied only on classroom experience as a souce of teacher knowledge. Fortunately, her field experiences in a school with a science mentor challenged this naïve conception and enabled Lia to begin to build a system of PCK toward reform-based science teaching.

Don's appreciation of efficient classrom management built during his pre-service field experiences might have, in a different school context, allowed him to develop a teaching practice that emphasized form over substance. Fortunately, he found himself in a situation with a science mentor who continued to challenge his assumptions about teaching. These two examples point to the importance of situated mentoring as an antidote to both surface-level understandings of reform-based science teaching developed in methods courses and procedural understandings of pedagogy developed only from classroom experience.

It is interesting that the TFA teachers, without substantial preservice field experiences or pedagogical training, appeared to respond less substantially than the traditionally prepared novices from their work with mentor teachers in terms of their movement toward building systems of PCK for teaching reform-based elementary science. This raises questions about possible influences on the dispositions of teachers from the TFA program for ongoing professional development.

Understanding The Nature of Science and Science Content

The *nature of science* (NOS) as defined in the documents of science education reform (AAAS, 1990, 1993; NRC, 1996) refers to the "epistemology of science, science as a way of knowing, or the values and beliefs inherent to the development of scientific knowledge" (Lederman, 1998, p.4). Uncovering novice teachers' ideas about the nature of science is important to understanding their development of PCK for reform-based science instruction because it is these views that provide the link between their content understandings and their orientation to teaching (Gess-Newsome, 2002). Gleaned from participants' narratives about their observations as students in science content courses, these ideas were generated from both affirming and frustrating school experiences in which the nature of science was often tacitly communicated (Lederman, 1998).

Apprenticeships of observation. All of the novice teachers in this research attached special importance to their observations of teaching as students themselves. However, the influence of these observations on their teaching were not the same for each participant. Each teacher's reflections on their particular apprenticeship of observation, "the protracted face-to-face and consequential interactions with established teachers" (Lortie, 1975, p. 61), provided evidence for how these experiences served as sources of knowledge about the nature of science and science content.

During interviews and conferences, the teachers talked about their experiences as students involved in learning about science content, including some experiences from the content coursework discussed above.

Ted: Knowledge of NOS and content. Ted's unhappy learning during high school science classes (that he attributed to his lack of technical vocabulary) appeared to have led him to limit his practice to a focus on vocabulary acquisition. The integral role of specific academic vocabulary in accessing and describing science content and processes seemed central to Ted's conception of science content, based on his challenging experiences in high school.

With a degree in international studies, Ted's college level science coursework consisted of one combination anatomy/physiology/exercise class and he felt that it was not very helpful to teaching elementary science. In one of the interviews for this research Ted expressed misgivings about the depth of his science content knowledge.

> In high school I took an AP biology class that was mostly lecture… I don't think I gained a lot from it…. There was a lot of terminology [that was difficult for me in college science classes]. I think it [the problem] may have been the approach to teaching it because it was more lecture-based. There wasn't anything to associate with the terminology….we did a few experiments now and then….That was the highest I went in science… Occasionally I get questions [in my own class], and just because I don't have a huge background in science, I'm not really certain how

to answer them [the students' questions]. Like why specific things occur…there have definitely been instances where I have [thought], "I'm probably going to need to look that up after school" (Ted, interview).

These qualms, combined with his own challenges (as described in the quote above) as a student of science, may have influenced his convictions about the importance of language and vocabulary in teaching about science. Data from classroom observations reiterate that Ted's classroom generally reflected this orientation to teaching throughout the period of time that data were collected for this research. However, as with any novice teacher, his practice also exhibited some uneven attempts at more reform-based instruction (see descriptions of lessons below). One entire wall of the room was covered with the "Stone Wall of Literacy Success" - lists of words from all subjects, including science. Learning objectives for science lessons were projected on a television screen at the front of the room, and were focused on vocabulary development.

For the three lessons observed during this research, learning objectives for Ted's science lessons were projected on a television screen at the front of the room. The three observed lessons were framed in terms of vocabulary acquisition, even if the listed objective was expressed as a more process-oriented goal.

For example, for one observed lesson the objective listed was, "We will be able to review scientific information. How? By reading, writing, discussing with our group, and sharing with the class." In this lesson, the "scientific information" that was reviewed was science-specific language (environmental factors, range of tolerance, controlled variables, optimum conditions, preferred environment) that was facilitated through the sharing of answers students were using to complete a teacher-created worksheet.

In another more process-oriented lesson, students worked in groups to design an experiment to test environmental preference. This lesson reflected practice that was more aligned to presenting vocabulary with reform-based instruction. As students worked on their experimental designs together, Ted visited groups to ask questions about their work and to reinforce connections to scientific vocabulary. "How will you say…some like one and some like another? … So our predictions should say the isopods prefer one over the other." Ted's reflections at the end of this lesson indicated that he wasn't sure how effective the lesson had been. "I don't know how helpful the student sheets were [to guide set up of experiment] – they used vocabulary we haven't learned yet."

In yet another lesson (discussed by the mentor teachers below), the lesson objective listed was, "We will be able to identify range of tolerance and optimum conditions. How? By reviewing our observations, discussion, and recording." The focus of the lesson was expressed in terms of language learning as it was supported by science activity, rather than the other way around. This is not aligned with reform-based practices outlined in the NSES (NRC, 1996) in which the objectives of science lessons should be science processes and content, supported through the use of subject specific vocabulary developed in context.

While part of scientific knowledge is to also be able to express ideas with specific vocabulary, the concentrated drill on targeted vocabulary alone may not necessarily ensure understanding of science content. Ted's perceptions about the need to design instruction to *focus* on the acquisition of vocabulary "is in direct conflict with the central goal of having students learn scientific knowledge with understanding" (NRC, 1996, p.

21) – whether or not this understanding is always described by students using academic vocabulary.

During his lessons, Ted spent the majority of his time at the whiteboard recording definitions or results of investigations for students to copy into their notebooks. As students were investigating in groups, Ted sometimes moved from group to group to observe students' work, questioning students about how their work illustrated vocabulary targeted for that lesson (see field notes of classroom observation included in Appendix B, selected from among the data exemplars of the analytic points), rather than probing avenues of student inquiry related to the task at hand.

Ted appeared to think of science as an intellectual endeavor, grounded in language. Ted's conception presented language as tool to transmit information, and more importantly, to promote thinking, questioning, and extension, in contrast to Don's vision of science as an active process,

Don: Knowledge of NOS and content. Intially an architecture major, Don took university classes in physics, chemistry, engineering, and biology as part of his undergraduate studies before he completed his degree in education. Don's recollections of his experiences as a science learner were framed almost entirely by the kinesthtic elements of the science coursework in which he participated.

> High school…I remember we dissected something/ (I can't remember what it was, but I remember dissecting.)….in chemsitry… I remember doing something where we mixed things…. I remember the physics teacher…dipping a rose into something and breaking it …. We did that in

like a lab set-up and we used Bunsen burners....we did the ring with the ball....I remember doing Bunsen burners....expansion and contraction.... As an undergrad in architecture....I had physics and chemistry. So I remember again, being in a lab. I don't remember any of those experiments....The Bachelor of Science in Architecture was really about the art/science of figuring out how to build buildings. So that's the stuff that's memorable to me – working with models to build things.... Engineering courses dealing with loads and masses, which is physics, I remember that....We had chemistry class, we had physics class....I remember memorizing the periodic table" (Don, interview)

Don also spoke about what he learned about how *not* to teach from his own apprenticeship of observation as he described his worst learning experiences. "We read and did summaries in class. It was all theory....There was no lesson plan on the table. There was nothing!" (Don, interview). Because observations of Don's own lessons illustrated that his plans were very carefully planned and orchestrated, it appeared that this negative experience, in contrast to those of Ted (decribed above) and Mark (described below) may have had a beneficial effect on Don's teaching practice.

Don's classroom practice also reflected the influence of his most positive learning memories. In speaking of of his favorite teacher, Don remarked, "I don't remember him so much for the content he taught, but for his teaching style" (interview). This statement is reflected in his description of the nature of science content and, again in contrast to Ted and Mark, in Don's orientation to science teaching.

It's not content, it's methodology. It's [taking] notes that make sense, that you can study from and explain to somebody else and do a project from, and do your own experiment. It's like having confidence to do something...Adults don't walk around with everything in their heads... It's the process. Content doesn't matter. (Don, interview)

Don's description tallies with his account of high school science courses that put an emphasis on using a standard format for implementing the traditional "scientific process."

Often, on my board, I do it because it's the way I learned it: Objective, Materials, Method, Results, Conclusion. I remember doing that over, and over, and over... It was always the same. Copy this off the board and do your science. (Don, interview)

The way that Don framed his memories of science learning in terms of actions rather than content understandings was related to the way he described his learning about pedagogical content. Don's view of the nature of science and science teaching as being dominated by active engagement in scientific processes. Don's positive recollections of interesting hands-on experiences as a student of science led him to emphasize that aspect of his own teaching. While Don's understanding about the nature of scientific process has evolved into a more sophisticated view of scientific inquiry (see the discussion under pedagogy below), it was telling that his description of high school science classes was filled with reports of "doing science" that were not necessarily connected to content understandings.

Mark: Knowledge of NOS and content. Mark's case evidenced a discrepancy between his experiences as a science learner and his orientation to classroom instructional practice. Mark's apprenticeship contained both positive, inquiry-based science learning and less affirming school experiences in more traditional science content classes. While he enthusiastically described the former, he relied on the latter to inform much of his approach to science teaching. Mark's continued perception of the value of "hard" science in preparing his students for academic success seemed to be the most influential element in his system of PCK for teaching elementary science.

Another Teach for America recruit, Mark came to his fifth grade classroom with an undergraduate degree in political science. Placed at Love Elementary School, Mark was completing his second year of teaching at the time of this study. Mark's father was a high school science teacher, and Mark perceived that his background knowledge in science content was formed mainly during his high school years.

Mark studied statistics, anthropology, sociology, and chemistry during his undergraduate program as a political science major. Even though his college major required substantial work in social science, Mark's interviews indicated that he had formed a positivist orientation toward the nature of science from his experiences as a learner in classes studying physical science. Mark found what he described as "hard" science difficult and unrewarding as a student, yet credited his work in a high school chemistry course for helping him form an idea of the nature of scientific study. During one interview he proposed a definition for "science" based on perceptions he constructed during his personal studies of science content. (A transcript of this interview, which was selected from among the data exemplars of the analytic points, can be found in Appendix D.)

> My knowledge of chemistry is mediocre, at best... I don't have a really great foundation of fundamental understandings in chemistry.... Even though I didn't like it, I think that chemistry was most influential in forming what I think science is... Hard science...[is]more finite, ...it can be represented by a hardened scientific formula... There's almost no room for interpretation in that kind of science... There are things that are widely accepted in scientific community as hardened fact. (Mark, interview)

On the other hand, he described his work in "soft," social science classes at the university with enthusiasm. Especially important to Mark was the way in which information from his classes in anthropology and sociology could be applied to his work in studying political trends.

> The soft sciences – [are]very interpretive and based on the way data can be shown. Two different people can look at the same data and come to different conclusions, and it is based on how you want to support that theory... in hard sciences...you're trying to learn what somebody else has already proved. (Mark, interview)

Mark's remarks illustrate one of the "dilemmas of science teaching" described by Wallace and Louden (2002, p. 22) - the tension between knowledge gained through situated, personal experience and the formal knowledge of science content often represented as *laws* in secondary and tertiary science courses. It appears that Mark's apprenticeship of observation led him to view the hard facts he memorized in chemistry as having greater authority as enduring science content than did any understandings about the process of scientific investigation used to examine phenomena that he built from his social science classes.

It is interesting, however, that Mark expressed ideas about the definition of *science literacy* that appeared to be more greatly influenced by his (undervalued) understanding of the processes he used as a student of social science.

> [Being literate in science means] understanding scientific process, scientific inquiry, understanding like how scientists come to their conclusions based on data, understanding all that vocabulary that goes into it, being able to like read data and display data – all the elements of the scientific process. If you can take somebody else's findings or create your own. It takes a certain amount of academic vocabulary and literacy in the things that are related to science, just statistics and having a decent math background. Yeah, being able to like read and interpret somebody else's findings that are presented in a scientific manner. (Mark, interview).

It appeared that although Mark's explanation of science literacy was closely aligned with reform-based descriptions, his practice (as described below) remained more aligned with his views of the nature of science formed from his less positive experiences as a learner of science. (The influence of Mark's negative learning experiences in forming understandings of the nature of science is similar to the findings for Ted's, described above.)

In contrast to Mark's competing assumptions about the fixed nature of hard scientific knowledge and the more fluid characteristics of science literacy was Lia's description of challenges in teaching elementary science. Lia's successful experiences as a student in science classes led her to believe in the importance of text-based learning, but it also led her to emphasize process skills of organizing and recording data in her classroom practice.

Lia: Knowledge of NOS and Content. Lia completed two semesters of biology ("We had to dissect a, um, a baby pig. It was memorable, it was sad"), an anthropology class, and a course in geology for her degree in elementary education. She felt most confident in teaching "geology stuff - about land formations" (Lia, interview), but less confident in teaching areas of physical science.

Lia felt anxious about trying to teach science units for which she felt she had little content knowledge, particularly in the areas of physical and earth science. She wished she had enough science background to "explain" to her students connections between the activities they were doing in class and understandings about scientific content.

> For example, we just did the Environments [FOSS module]. That *sounds* simple, but explaining it to them was really difficult because they didn't understand, they didn't see any connections at all. It seems really easy, and going through the whole entire lesson was really easy. But when it came to them giving me these challenging questions it was really difficult. It was like, "Wow! I wish I knew." (Lia, interview)

Like Mark, Lia's content understandings about the nature of science reflected in these remarks seem to indicate a positivist orientation toward science as a collection of accepted knowledge that can be transmitted to students, rather than the view of the science as an historical endeavor that is supported in the NSES (NRC, 1996).

> In learning science, students need to understand that science reflects its history and is an ongoing, changing enterprise. The standards for the history and nature of science recommend the use of history in school science programs to clarify different aspects of scientific inquiry, the human aspects of science, and the role that science has played in the development of various cultures. (NRC, 1996, p. 107)

The NSES further call for a change in emphases in science instruction from, "studying subject matter disciplines (physical,life, earth sciences) for their own sake" to "learning subject matter disciplines in the context of inquiry, technology, science in personal and social perspectives,and history and nature of science" (NRC, 1996, p. 113). While Lia seemed to endorse the former viewpoint, further conversation and observation indicated that, unlike Mark, her practice reflected an appreciation, if not substantial implementation, of the latter definition.

"My kids told me one thing they didn't like about science is all the note-taking they had to do, and the [science] journal...Because they think it's like play" (Lia, interview). Lia's view of the importance of documentation to the study of science was drawn from her own successful experiences in high school and college biology courses. She told how she was always chosen by her lab teams to be the note taker as they completed their investigations. "I was very good at the labs because I was very organized...I liked doing labs, and I liked recording everything" (Lia, interview).

Lia's characterization of science learning as language-focused is supported by her tentative definition of science literacy. "[Being] literate in science ...[that] would be maybe reading information or expository text and understanding it. Kind of like reading and comprehension, but with science text" (interview). Lia's definition is at odds with the view of *scientific literacy* in the NSES (NRC, 1996), which is defined as the "knowledge and understanding of scientific concepts and processes required for personal decision making, participation in civic and cultural affairs, and economic productivity" (p. 22).

While Lia's definition of science literacy differs from that expressed in the literature on science eduation reform, issues around students reading about science content and providing written evidence for their ideas about science surfaced throughout the examination of the data from Lia and from other participants.

Summary of Apprenticeships of Observation

While these apprenticeships of observation were not transformed directly into the novices' teaching, it gave them a sense of what counts as important science learning that shaped and focused their teaching practices. The teachers rarely took into account the limitations of these memories in reflecting the true nature of these experiences.

> The student's learning about teaching, gained from a limited vantage point and relying heavily on imagination…does not represent acquisition of the occupation's technical knowleledge. It is more a matter of imitation…a potentially powerful influence which …[does] not favor informed criticism, attention to specifiics, or explicit rules of assessment" (Lortie, 1975, p. 63).

Examining teachers' tales of their experiences as students revealed a list of instructional practices they felt contributed to the poor quality of the science instruction: (a) lecture or text-based lessons, (b) disorganized or unprepared instructors, (c) lack of independent inquiry, and (d) teachers who did not make the content comprehensible or meaningful.

It is interesting to compare these reminiscences to these teachers' current classroom practice: Ted's focus on helping his students understand academic vocabulary; Don's emphasis on active learning; Mark's interactive class discussions. It appears that, to some extent, these teachers have taken to heart lessons about teaching unintentionally provided by their former instructors. It is interesting that these practices are also aligned with some of the changes in emphases outlined in the NSES: the emphasis on connecting language to concrete experiences in science, the active involvement of students in learning activities, and the accent on the role of communication in learning to teach science.

On the other hand, participants' tales of their "best" experiences as students also revealed a common set of instructional qualities (also reflective of standards for reform-based science teaching): (a) active learning methods, (b) opportunities for peer collaboration, (c) opportunities for inquiry and application, (d) challenging, interesting, and relevant content. The positive experiences of some of the novices appeared to have also affected their practice to a certain extent. Lia's preference for project-based learning, and Don's perception of the importance of teaching style may both be traced to these influences. However, there was no evidence that either of the TFA teachers were attempting to mimic those instructional practices that they found so appealing. Mark's insistence on the goals of instruction being limited to measureable achievement on standardized testing, and Ted's classroom-bound instructional practices seemed to be at odds with the practices of their most fondly remembered teachers.

Based on the themes that emerged from this study, it appears that while their positive and negative experiences as learners may have, in some cases contributed to novices' understanding of effective pedagogy; in other cases these understandings may be mitigated by situated mentoring and/or overshadowed by more pressing constraints on their classroom practice (e.g. expectations for student achievement on standardized tests),

Knowledge of Pedagogy and Teaching Experience

Analysis of the data around the effect of classroom experience provided a glimpse into how teaching experience helps develop subject matter knowledge as well as pedagogical skill and an understanding of context. As might be expected, the role that classroom experience plays in building teachers' knowledge of science content and pedagogy was not plentiful in data collected from novice teachers. Ted spoke of how he began to develop greater understanding of content as he taught.

Ted: knowledge of pedagogy. Observations of Ted's classroom practice indicated some ongoing concerns with classroom management during active learning situations that may have influenced his choice of instructional design. The three classroom observations made during this research revealed a pattern of student behavior during Ted's science instruction. The behaviors (playing with things in their desks and with science materials, talking about other subjects, making signs to communicate with students across the room, doodling, writing notes to other students, etc.) of the majority of Ted's students during time allotted for group investigations of environmental factors during these lessons indicated that they were often disengaged, distracted, and/or off task. Ted's apparent response to this management challenge was to embrace an approach to teaching science that was more teacher-centered and relied more on students acquiring information than on discovering knowledge.

As she reflected on one of Ted's science lessons, Kate (Joy ES mentor teacher) traced the sequence of instruction that the lesson used to introduce new vocabulary (*optimum condition*) related to a unit of study on environments (see field notes for this lesson in Appendix B, which were selected from among the data exemplars of the analytic points). Ted was careful to introduce the phrase only after students had "lots of experiences with looking at the plants and their growth in the environments. They [students] shared what they had observed over time...They kind of summarized their findings on one big chart... they talked to each other" (Kate, mentor conference) to come up with a definition that they then copied from the board. This carefully scaffolded progression tallies with Ted's understanding from his own apprenticeship of observation about the importance of associating terminology with students' concrete experiences, and reflects a level of reform-based approach for teaching scientific vocabulary.

It is interesting to note this description in light of Ted's explanation of his own worst science learning experiences, in which a college professor "talked a lot and explained nothing" (interview). Ted's consistently careful explanations of science vocabulary may have been prompted by this negative experience. On the other hand, the effect of Ted's best learning experience was not readily apparent in his teaching practice. In describing his favorite elementary teacher, Ted said, "She took us everywhere – all over the place, to show us what we were learning about" (interview). None of the data collected for this research indicated that Ted had ever taken his students out of the school for a learning experience. (This finding - the greater influence of negative personal experiences as a science learner on teaching practice - was paralleled in the case of Mark, described below.) These contradictory data raise questions about how novice teachers choose to incorporate pedagogical knowledge derived from their own experiences. It is possible Ted choose to ignore his positive reflections as a young science learner because they were contradicted by his views of the purpose of science teaching or because they ran contrary to the practices and orientations to science content and practice demonstrated in his more recent science learning experiences. The exact nature of the influences, or combination of influences operating on Ted's system of PCK are unclear.

Don: Knowledge of pedagogy. Don described his field experiences as important sources of pedagogical knowledge. He related what he learned about teaching from his field experiences with two cooperating teachers who were job-sharing a teaching position for the classroom in which he was completing his student teaching.

> [One of the cooperating teachers] was English....She was very - "Sit down! Get ready to sit down! You come and sit here. Right here." It was very, very tightly controlled. [The other cooperating teacher] was the opposite. The kids kind of knew where to go, and the classroom ran very smoothly. But the English teacher...micromanaged the kids. I was like, *that* I don't want to do. But she wrote really strong curriculum, and she was very good with helping me figure out and reflect on things. Whereas the other teacher was like,... "I need to see complete unit plans from you," – with zero support. But she was very good with kids.
>
> I got a little bit from each of them....Trusting the kids to do what they knew to do [was a strength from one teacher], and then having the strong [English teacher as

an example for] writing the curriculum,...following standards, and being able to show me how she did it.(Don, interview)

While these reflections have more to do with classroom management than science-specific teaching strategies, Don's reflections were especially interesting when compared to observations of his teaching practices during science lessons. While he bemoaned the micromanaged classroom of the English teacher, his own behavior with his students as they sat in a semi-circle at the front of the room to discuss their work during these lessons was very similar to some of the patterns he observed as a student teacher. After students were seated on the floor, Don checked to make sure that they were sitting in a boy-girl sequence. If they were not, they were told to rearrange themselves, and if the proper placement was still not achieved Don arranged the students himself. (This was very like the method of his English cooperating teacher - "You come and sit here. Right here.")

Don was reluctant to take a more inquiry-based approach until he felt confident enough in his knowledge of content and pedagogy. His lessons were very highly structured, efficient (again like the English cooperating teacher) and fast-paced. Yet his classroom also ran very smoothly even when he was not giving explicit direction; the students appeared to have internalized classroom procedures and expectations. Students were engaged in the lesson, and they seemed to be aware that they were responsible for getting ready to learn, participating in classroom activities, and working collaboratively to solve problems (like the students with his other cooperating teacher).

It cannot be assumed that Don acquired these methods of classroom management only from his field experiences – they may also have been formed from his own apprenticeship of observation, or they may have been formed from the synthesis of both kinds of experience. It may be, as suggested by Tabachnick, et al. (1982), that Don self-selected from his field experiences those strategies for his own practice that were already tied to his ideas about the nature of teaching, similar to the way that Ted and Mark selected the emphases in their teaching. However, because Don participated in a traditional teacher preparation program that included field experiences, he was able to observe the situated implementation of these strategies and practice them himself before establishing them in his own classroom. Another implication of this narrative is that Don formed some generalized strategies for classroom management during his field experiences that he used during his science lessons, although not all of these strategies were aligned with the approach to science teaching outlined in the NSES.

As may be expected of a novice teacher, Don's (and the other novice teachers') methods of instruction indicated an evolving understanding of reform-based science instruction. Teaching standards from the NSES call for teachers "to focus and support inquiries" (NRC, 1996, p. 32)and "nurture a community of science learners" (NRC, 1996, p. 31). Observations of Don's lessons show that he attempted to implement both of these approaches to instruction, but his instruction was most often teacher-directed. Don prefaced time for student investigation with very explicit oral directions and written prompts. For example, in a lesson from the FOSS Environments module on the effect of organisms on their habitat (see notes and artifacts for this observation that were selected from among the data exemplars of the analytic points, in Appendix C), information for the student investigation (drawn from, but not suggested by the FOSS curriculum) was displayed on the whiteboard prior to the lesson (see Figure 3).

In the first part of the lesson, student groups prepared cups of water treated with bromo-thymol blue (BTB), an indicator for acidity. The students performed various cooperative "jobs" to add either a guppy, a piece of elodea (water plant), or nothing to the water (see Figure 3), according to procedures outlined on student sheets and modeled by the teacher. The cups were left on sheets of white paper while students went to eat lunch.

Figure 3:Lesson Information Displayed on Board

LO [Learning Objective]: I will explain how I designed an experiment to find out: How do goldfish affect the acidity of the water they live in?
[Student jobs] Getter 1, Getter 2, Captain, Recorder, Zookeeper
[Words on sentence strips] aquariums, controlling the variables

1 goldfish	Elodea	Nothing
100 ml water	100 ml water	added
6 drops BTB	6 drops BTB	100 ml water
		6 drops BTB

Blue	No acid
Green	Some acid
Yellow	Significant amounts of acid

Returning from lunch, Don called the class to sit on the rug to discuss how they had set up the investigation and to make predictions on the amount and source of acidity in the water. He also modeled how the students should record their results by coloring in circles on their student sheets.

Following this discussion, Don gave each group of four students a small beaker of water and a straw. He asked each group to put 6 drops of BTB in the water. Don restated the focus question and demostated how to use the straw to gently blow into the treated water. As students mimicked his demonstration, Don called their attention to the change in water color as they continued to blow. He called the class back together to refocus on the acid question, this time validating the "correct" answer. He introduced the terms *carbon dioxide* and *carbonic acid* and recorded them on new sentence strips along with their definitions.

Although this lesson was deliberately designed for guided, rather than open, inquiry, the amount of information and direction provided prior to investigation appeared to affect student learning. Student work samples showed that, although the water in all of the cups remained different shades of blue at the time students observed and recorded the results of their investigation, 25 of the 29 students in the class colored the circles on their student sheets yellow, green, and blue.

Don did not address this event at the time, although it has important implications for students' understanding of both science content and science process. He chose to forgo the opportunity to use this experience as a vehicle for addressing issues of accuracy and truthfulness in recording results, and he decided to skip the associated understanding of science content (factors affecting the results of BTB tests). Instead of viewing the discrepant results observed by his students as a "teachable moment" on the nature of scientific investigation or an opportunity for further inquiry, Don saw the lack of standard results for this test as an impediment to completing the lesson provided by the FOSS manual. This illustrates an approach to instruction that reflects the gradual development of novice teachers' conceptualization of curriculum from externally-devised propositions to contextually sensitive facitliations that is described by Grossman and Thompson (2004).

This commentary does not propose that Don would have been better able to respond to this lesson in a manner more consistent with reform-based instructional practice had he completed a preservice science methods class, but it does seem that his training for teaching (content coursework, general pedagogy classes, field experiences, and even situated mentoring) did not provide him with sufficient PCK to identify students' naïve conceptions about content and process, or to understand the importance of addressing them as they occurred. Or perhaps Don chose to disregard these practices in favor of conforming to a specific timeline for the lesson. For whatever reason, Don decided to teach the lesson instead of the students (see example above). His preparation for classroom practice appeared to have failed to help him build a teaching practice in science that could be improvisational as needed in response to student input, a characteristic of instruction generated from a depth of pedagogical content knowledge.

While Don struggled with meeting the needs of the learners over implementing curriculum, other observations of his classroom practice demonstrated his evolving understanding of connections between context and pedagogy in his system of PCK. Following conversations with Lois in which she urged him to rely less on published lesson plans for his lessons, Don decided to redesign a lesson from the curricular materials to better align with reform-based practices for inquiry outlined in the NSES (NRC, 1996). In an investigation into the effect of environmental factors on beetles and isopods, Don decided to ask students to devise their own experiments (within very specific parameters) to determine the organisms' preferences for the moisture level in the soil rather than using the prepared materials available from the FOSS curriculum. This time, teams of students worked to plan their procedures. The students then met as a class to share and compare their plans. During this discussion, Don was able to address his students' naïve understandings of science process that may not have been evident if his students had merely completed a lesson from generic instructions for investigation contained in the curricular materials. In this instance, Don considered the context of his classroom in redesigning this lesson to meet the needs of his students.

This example illustrates that the process of mentored learning to teach is an ongoing development of a system of PCK for reform-based science teaching. In this instance, Don demonstrated that his understanding of pedagogy was being transformed through the combination of his work with Lois, his past experience in working with this science content, and his observation of the effect of Lois' suggestions on his students' learning. While Don was not directed to by Lois to write his lesson plans in any specific manner, rather he followed her suggestions about to use his understanding of student needs to inform his own practice rather than relying on preformed lesson plans.

Don's comments showed how his understanding of inquiry has developed over the length of his classroom experience. "I'm ready to be out of my comfort zone with this material, now that I know it" (Don, interview). He talked about how he had changed the way he had facilitated an investigation into environmental factors and isopods to be more consistent with reform-based standards for science instruction.

> If I would have dictated this experiment, I would have gone [labeled the isopod environments]: dry, moist, mud. But in teaching this experiment

> for the third time, I was *way* more hands-off. When Lois came and sat and listened to me, she said, "You were way more allowing of inquiring, allowing of difference" than I have been. (Don, interview)

This comment supports the need for experience in developing novices' systems of PCK, and illustrates how Don's particular understanding of pedagogy is developed in the context of mentored learning to teach. Without Lois' guidance and challenge, Don may not have considered leaving the comfortable teaching niche he had previously carved for himself and in order to allow his students more autonomomy in designing their investigations.

Mark: Knowledge of pedagogy. Mark provided some positive examples of inquiry-based experiences from his days as a student.

> In seventh grade…I was taking a look at what made the best natural battery by looking at what went into a battery. So I figured it out on my own by reading in the library that a battery had PH acid levels and so do fruits and vegetables. So that all came from them letting you have free reign and teaching you about scientific inquiry. (Mark, interview)

Not all of Mark's observations from his experiences as a student of science were as positive, though they still appeared to be influential. Mark shared memories of his "worst teacher" scenario.

> The lab work [in chemistry] was, "Here, this is the exact lab [result] you're supposed to get." It was never inquiry-based ….I put chemistry in [a list of pedagogical influences]… because [it helps me] remember how *not* to teach

science…I remember thinking, "If I taught science like this [with long lectures], my students would wind up not enjoying this subject matter." (Mark, interview)

While this quote may be interpreted in multiple ways, it helps to illustrate the apparent disconnect between Mark's views about effective science teaching and his conceptual understanding of science content. It was Mark's ideas about the nature of authentic scientific content as collections of facts that appeared to dominate his teaching practice. This is illustrated in part of a collection of questions scripted during a lesson based on material in the FOSS Landforms module that was co-taught by Mark and Helen (see below, Table 9).

Prior to teaching a session on making a topgraphic map, Mark and Helen met to plan the lesson. First they identified the big ideas underlying the unit and the lesson (understanding the relationship between two-dimensional and three-dimensional representations of landforms; creating a topographical map). Then they looked at a cross section of student work from the previous lesson, and determined if any review of prior learning was needed. Finally, they used the FOSS lesson plans as a starting point for designing the instructional procedures for the lesson and for determining key vocabulary.

During the lesson, Mark's students built a foam model of Mt. Shasta, they disassembled the model and traced the pieces to create a topographic map. As the students struggled to reconceptualize the three-dimensional model with its two-dimensional represenation, both Helen and Mark circulated around the classroom, asking questions they hoped would guide the students toward a more solid understanding of the process (for a more complete list of the questions used, which were selected from among the data exemplars of the analytic points, see Appendix D.).

Table 9: Comparing Mentor and Novice Questions

Helen's Questions	Mark's Questions
What do you notice about the mountain? *(open, understanding)* What kind of a landform is it? *(closed, remembering)* What makes you think so? (*open, understanding)* What else could it be? *(open, applying)* What do you think these numbers mean? *(open, understanding)* Do you see a pattern in those numbers? *(open, understanding)* If you were going to hike up the mountain, which way would you go? Why? *(open, analyzing)* Can you see ways that these topographical maps are similar to or different from the maps of the schoolyard that we made before? *(open, understanding)*	Who's your partner? *(procedural)* Did you listen? What happened? *(procedural)* What do you think this landform is? *(closed, remembering)* Why do you think so? *(open, evaluating)* What is the elevation of the base? *(closed, remembering)* What is the elevation of the peak? *(closed, remembering)* What's the elevation of this part of the map? *(closed, remembering)* How high does this map show? *(closed, remembering)* What else do we notice about what is the same or what is different? *(open, understanding)*
Closed questions: 1 - Remembering, 1 Open questions: 7 - Understanding, 5 - Applying, 1 - Analyzing, 1 - Evaluating, 0 Procedural questions: 0	Closed questions: 5 - Remembering, 5 Open questions: 2 - Understanding, 1 - Applying, 0 - Analyzing, 0 - Evaluating, 1 Procedural questions: 2

A comparison of the two teachers' questions shed light on the relative levels of pedagogical content knowledge of mentor and novice. Helen's questions were more open-ended, asking students to make observations, defend their ideas, propose alternate solutions, look for patterns, apply understandings, connect to previous activities, and make comparisons.

These questions were recorded during one section of the lesson in which both Helen and Mark were circulating and assisting students complete a worksheet. They were grouped as closed (requiring a single predetermined reponse) or open (available to more than one acceptable response) as identified in the FOSS (n.d.) guidelines for teachers. They were also identified according the criteria for the levels of intellectual behavior developed in the revised Bloom's Taxonomy (Anderson, L.W. & Krathwohl, 2001), as interpreted by the researcher within the context of the lesson.

Helen's and Mark's approaches to questioning during this lesson reflected contrasting views of the nature of science teaching. Because Mark's experiences had led him to define content in terms of facts, his questions were often concerned with uncovering and expressing those facts. This orientation appeared to be unaffected by Mark's preservice learning about science pedagogy. He commented on his experiences during the TFA Summer Institute during a brief, optional inservice on teaching science:

> We were still learning everything. I thought, ..."Well, I don't know anything about science." So I attended one or two of the workshops that talked about FOSS [Full Option Science System] and talked about different things you can do for science instruction and integration of science. But I still didn't get it then. (Mark, interview)

Mark's positive accounts of a science methods class taken as part of his graduate work in education would seem to have led to greater understanding of reform-based practice.

> In the elementary science methods [class at the university], actually sitting down and being able to discuss with somebody who has been in a classroom how to

approach science for elementary students has been very helpful. Because...it's been a long time since I've been in elementary school and.... A lot of times the teacher would treat you as you would treat your elementary students for a time... [it] reminds you of where they [elementary students] are coming from and what their limited knowledge is of the world, of science (Mark, interview).

For Mark, the practical and contextual nature of many of the teaching methods classes was key to understanding reform-based teaching practices, even though he often chose not to use these understandings in his classroom practice.

> A lot of times they ask you to create units of study that you can use directly in your classroom. In fact, you're encouraged to really take a look at your classroom and use data from your own classroom to help create it [a unit of study], or use your own students' work to help drive how you're going to create it ....These have direct application to your class. I gained a lot of new information from these classes and new ways to approach [instruction]... They happen to be very hands-on and model how things should occur in the classroom...You get to see the direct modeling, which is really helpful....These were *very* helpful my first year. (Mark, interview)

While Mark evidently enjoyed and appreciated his learning in this methods class (as evidenced in his remarks about it above), it is curious that he did not consistently employ an approach to science teaching that demonstrated the "new ways to approach instruction" that he learned about there. This may have been because Mark's understanding of another element of PCK, knowledge of context, was exerting a more powerful influence on his conception of science pedagogy than his methods coursework.

Lia: Knowledge of Pedagogy. Lia's comments indicated that her pedagogical content knowledge may have only developed to the point where she expected that she, as the teacher, should know all the answers so that she could transmit the information to her students. This orientation to instruction is also in contrast to the NSES call for changing the emphasis in science teaching from presenting scientific knowledge to "guiding students in active and extended scientific inquiry" (NRC, 1996, p. 52).

Lia's experiences as a student of science had shown her that science teaching should involve more than one learning modality. Her professed preference for language-based science instruction (interview) was, in part, contradicted by descriptions of her attitude toward biology lab work.

> I did well in...geology because it was text-based, and I'm comfortable with that. As far as biology, it was lots of visuals [with] the text....But then we had the biology lab in which we had to connect the two [lab experiences and information in the text]. I think I had ... a problem connecting the two. But I enjoyed the lab...the only time I went to those classes was when I knew we were going to do a fun lab....[but] there are learners who like text-based stuff. (Lia, interview)

Lia recognized that she had experienced some of the same difficulty in her own learning with connecting labwork with content information that her students demonstrated, and she was uncertain about how to help them link science activity to science content knowledge. The ability to select, create, and use representations that help students make connections between doing and knowing is an important indicator of pedagogical content knowledge (Shulman, 1986; Gess-Newsome, 1999), and while Lia's system of PCK was not yet functioning at this level, her recognition of the need to weave together various representations of knowledge showed that she was perhaps ready to develop these abilities. Lia's quote indicates that she could at least identify this important characterization of PCK.

Lia also recognized that a crucial element had been missing from her preservice education in science teaching. "I'm not comfortable – because I really didn't learn how to teach it [science]." Even though Lia was the one novice participant who had actually participated in preservice coursework in teaching science, she had asked her mentor and principal for more training in science teaching.

> [In my] science methods [class I] didn't learn a lot...I was able to do a lot of fun experiments that I remember, and I can still do it here....[but] I didn't learn much about *teaching* it [science]....We wrote lessons, we made up a lesson. I would have loved to teach the lesson, but we didn't teach it, we just turned in the lesson....It was more learning about different things you can do. We did a lot of experiments every day. We wrote a lot of stuff. But teaching it to children? That's probably why I'm still uncomfortable with it....I felt that during my practicums I learned more than I ever did during all four years of college about teaching....I was able to work with a science mentor at this school, and that helped me [know how to teach science]. (Lia, interview)

Unlike Don's avowed emphasis on doing as learning, Lia's remarks indicated that she suspected there must be some crucial distinction between doing science and teaching science. Lia realized that there was more to teaching science than planning and implementing fun activities. Her remarks showed that, while she did not yet appear to have a clear understanding of strategies and methods of instruction for teaching science, she understood that science instruction was more than just implementing a collection of discrete, hands-on experiences. This understanding is aligned with expectations from the NSES (NRC, 1996) that emphasize the need for extended units of learning in science.

The inconsistent and evolving nature of Lia's system of PCK for teaching science was also evidenced in the kinds of questions she asked during lessons. During one observed lesson, Lia asked very few, low level questions, leaving the bulk of the probing to Helen. However, in Lia's case (as in Ted's), this practice evolved during the course of her work with the science mentor.

Table 10: Comparing Mentor and Novice Questions: Lia

Helen's Questions	Lia's Questions
Tell us what you did – how did you set this up? *(open, applying)* What landforms did you notice? *(closed, remembering)* What happens to the pieces of sand and clay after they are eroded? *(closed, remembering)* What did you notice about the water flow? *(open, understanding)* Why did the delta form there? *(closed, understanding)* Why did the sand stop there? *(closed, understanding)* What do we call the path that the river takes? *(closed, remembering)* Why is a channel considered a landform that is caused by erosion? *(closed, analyzing)* What makes erosion different from deposition? *(closed, remembering)* Can you think of other examples? *(open, evaluating)* Why don't you write that question down in your notebook? *(procedural)* How did they get there? *(open, analyzing)* What formed them? *(closed, understanding)* What can we do to help you stay focused? *(procedural)*	How do landforms get there? Do they just appear? *(open, understanding)* Who is recording what is happening? *(procedural)* How did the beach form? *(closed, understanding)* What is this like that we talked about in class (New Orleans flood)? *(closed, analyzing)* Were the deltas in the same place? *(closed, understanding)* Why did the deltas form there? *(closed, understanding)* What is an example of erosion? *(open, understanding)* What is an example of deposition? *(open, understanding)* What is called when you have rivers at the bottom of the canyon? *(closed, remembering)* How did this happen? *(open, applying)* What do you see? *(open, understanding)* How do you think that the river changed course? *(open, analyzing)*
Closed questions: 7 - Remembering, 4 - Understanding, 2 - Analyzing, 1 Open questions: 4 - Understanding, 1 - Applying, 1 - Analyzing, 1 - Evaluating, 1 Procedural questions: 2	Closed questions: 5 - Remembering, 1 - Understanding, 3 - Analyzing, 1 Open questions: 6 - Understanding, 4 - Applying, 1 - Analyzing, 1 Procedural questions: 1

In another lesson in which the students were working with stream tables to investigate the formation of landforms, Lia used a variety of questions that were similar in scope to Helen's (see Table 11). Both teachers used questions that addressed a variety of levels of thinking, and both included both open and closed questions.

Finally, Lia identified other sources of learning about pedagogy as she ranked her teacher education coursework according to the ways in which they influenced or facilitated her pedagogical understandings. Lia placed her courses on multicultural education, teaching English as a second language, and her field experiences at the top of the list. She felt that these courses were important in preparing her to teach in the context of a school in which the many of the primary languages and cultures of the students were different from her own. This may suggest that Lia felt that her system of PCK for teaching was most influenced by elements of her preparation that addressed the context of her practice.

Contextual Forces

Contextual forces are used in this analysis as an embedded category for examining their function as sources of PCK, as well as influences upon that knowledge. This section of the analysis presents evidence from the data interpreted to show how different contextual forces contribute to the generation and adaptation of the participants' pedagogical understanding.

Students and Community. Both of the school sites were located in urban communities whose populations were largely Hispanic. Almost all of the students at each school spoke English as a second language; nearly two-thirds of the student populations were designated as students with Limited English Proficiency. Many of the students' parents spoke little or no English, and Spanish was the predominant language in neighborhood businesses. Both schools were located in a section of the city with low socioeconomic status, and the transiency rate among students was high (39-45%).

Much of the data around the role of context concerns the way in which the participants viewed the effect of contextual elements on their classroom practice. Ted was especially concerned that students who spoke English as a second language should develop the academic vocabulary they would need to be successful in science in middle school. Don viewed the purpose of his instruction as the internalization of processes of investigation that would serve his students in any context.Mark saw his task as a teacher as providing opportunities for his students to practice with discrete bits of content that would help them demonstrate acceptable achievement on English-only standardized testing. Lia voiced concerns about context in reference to how she could use science learning to help open the world to the students in her classroom who, for various economic and cultural reasons, had limited access to that world.

This deficit view of the community (no one spoke of or employed in their lessons the advantages that cultural diversity may offer science teaching) was echoed by all participants (including mentors) as they talked about the instructional strategies they used to address students' needs as second language learners. All of the participants identified some of the community characteristics listed above (socioeconomic status, English as a second language, transiency) as sources of challenge for student learning. Helen's conferences with Lia and Mark always contained references to teaching strategies to help second language learners access the vocabulary and literacy skills needed to facilitate their understanding of the lessons' content. Kate's conversations with Ted and Don about the importance of academic vocabulary to understanding science content also illustrates a concern for the dual task of teaching content and language to students who spoke English as a second language.

Educational Policies and School Culture. Mark's conceptual orientation to science knowledge and processes was reflected in the way he viewed his teaching responsibilities in science. The influence of administrative pressure to increase standardized test scores in reading and mathematics directly influenced how Mark's students were learning about science. Pressure for increasing test scores from district administrators and from Teach for America expectations led Mark to seriously curtail science instruction in his classroom in favor of devoting extra time to material in math and literacy that would be tested. Ted's emphasis on vocabulary acquisition was designed to help his students demonstrate understanding on standardized measures of achievement.

Lia and Don did not specifically address issues of standardized testing in interviews or mentor-novice conferences, however both of these teachers were working at schools with low standardized test scores. School-wide meetings, conversations, and workshops on how to raise these scores were a common feature at both Love and Joy Elementary Schools during the period during which this research was conducted, and science lessons that were scheduled to be observed for this research were sometimes rescheduled to accommodate test preparation and administration.

Other elements of school culture appeared to have a more beneficial effect on teacher learning. Ted's reflections of his experiences as a novice teacher at Joy ES indicated that he identified school culture was a key element in his development of PCK for teaching elementary science. He talked about his induction experiences at a school that did extensive professional development in science and other areas of the curriculum, including mentored learning to teach. Ted compared his time in the classroom at Joy with those of TFA cohort members placed in schools with very different cultures of teacher learning. "Very fortunately, I got placed at [Joy ES]. In talking to other people in Teach for America, I realize just how lucky I was" (Ted, interview). Even though Ted's practice did not always show evidence of considerable movement toward reform-based science teaching (e.g. in the way he facilitated group investigations and, at time, used assessment of student work to guide instruction), it may be that he had developed this to a significantly greater degree than those novice teachers placed in a less supportive environment.

Research Question Two: Mentoring and Teacher Preparation

Mentored Learning to Teach as Situated Professional Development

While most of the novice participants in this research failed to identify their mentoring relationships as important factors in learning to teach science, observations of classroom practices and mentor-novice conversations indicate that subject-specific, situated mentoring was central to their development of systems of PCK for reform-based science teaching. Observations of classroom lessons for every novice teacher contained elements of reform-based strategies for science teaching, even if those elements were not consistently or expertly implemented. The use of students' science notebooks as a tool for recording data, observations, and questions, the consistent use of "hands-on" investigations to make connections to academic science vocabulary and science content, and the teaching of substantial units of science content were three examples of important aspects of reform-based science teaching (NRC, 1996) observed in the novices' lessons.

While this research contains no comparisons to the practice of novice teachers who do not have the advantage of collaborating with mentor teachers in teaching science, data gathered for this dissertation indicated that there were certain budding practices common to the teaching of the novice participants that could be traced to the potential influence of their mentors. Evidence presented in the data for each novice teacher indicates that these practices were a) the use of curricular materials (FOSS) designated as "exemplary" by the National Science Foundation; b) the modeling of lessons based on reform-based practices outlined in the NSES (NRC, 1996) (e.g. guided inquiry); c) the generally consistent use of science notebooks for recording data from investigations and for maintaining a record of content understandings about science content; d) instruction that addressed both science processes and content; and e) the design of lessons based on formal and informal assessments.

These particular qualities of instruction will be evidenced in the data discussed in the following section as observations of novices'classroom practices are connected to the content of mentor-novice conferences and data from participants' interviews. Cross-case analysis provided the following the findings for my second research question: How might the nature of elementary teachers' general pre-service pedagogical training and their preparation in science content and pedagogy affect the mentored development of pedagogical content knowledge for reform-based science teaching?

Faced with the task of mentoring novice teachers with very different notions of the nature of science, very different backgrounds in science content, very different conceptions of science teaching, and very different levels of preservice experience in classroom teaching, the mentor teachers at Joy and Love elementary schools developed very different structures to support the mentoring experience at their site.

This section will briefly identify and describe important characteristics of novices' preservice preparation and propose the nature of their effect on novice and mentor participants' PCK prior to entering the classroom.

Teacher Preparation and PCK for Science Teaching

One important insight evidenced in the data considering teacher preparation as a source of novice elementary teachers' PCK for science instruction is the serious lack of consistent, significant, and meaningful science-specific pedagogical training in both traditional and alternative certification programs. Mark's hazy recall of brief TFA Summer Institute workshops on teaching science indicated that this experience did not significantly influence his understanding of science pedagogy. Except for Lia, none of the novice participants had any extensive, formal pre-service preparation for teaching science, and her recollections of the content of her methods coursework indicated that it only superficially addressed standards for reform-based science instruction. However, Lia's positive reflections on the value of her field experiences in learning about science teaching may point to another aspect of pre-service training that may be important to teacher learning – the importance of situated learning opportunities that provide models of reform-based science teaching. (This benefit was also cited by Mark as he described how he was able to connect the content of his methods course to his work as a classroom teacher during his graduate program.)

The following table (Table 11) represents a summary of the data used for comparing novices' systems of PCK for science teaching according to their preparation to teach, and their preparation to teach science.

Table 11: Cross-Case Analysis of Teacher Preparation

Research Question 2: Comparing Pedagogical Preparation	TFA		Traditional	
	Ted	Mark	Don	Lia
MENTOR STRATEGIES				
• Modeling reform-based practice	I, CO	CO		CO
• Collaboration on reform-based lessons		CO, MC		CO, MC
• Mentor guidance toward reform-based practice	MC	MC	MC	MC
• Modeling general teaching strategies	CO	CO		CO
• Mentor-initiated training in general strategies	I		I	
EXPERIENCE				
• TFA Summer Field	I	I		
• Int'l field experience			I	
• Practicum				I
• Student teaching			I	I
• University science methods course	I	I		I
• Preservice science teaching experience				I
COMMITMENT TO TEACHING				
• Short-term	I	I		
• Long-term			I	I

Sources of data:
I= interview; CO= classroom observation; MC= mentor conference; SW= student work

One distinction in the analysis between traditional and alternative programs arose from the data around differences in the general pedagogical preparation. Both of the novice teachers from traditional programs (Lia and Don) participated in more extensive fieldwork components as well as coursework in methods of instruction for other areas of the curriculum, and observations of classroom lessons led by both of these teachers demonstrated a greater command of pedagogical knowledge and procedural skills than did their TFA counterparts. They employed a greater variety of engagement strategies (e.g. patterns of interaction and anticipatory sets), and they spent less time dealing with behavioral issues during their lessons.

Mentoring Teachers from Alternative and Traditional Paths to the Classroom

While it is impossible to generalize to a population from a sample of two, it is worth noting these differences because they speak to some challenges that were outlined by mentors Lois and Kate as they discussed how they were mentoring teachers from alternative certification programs. Kate spoke about how she had instituted a weekly after-school study group for novice teachers that focused on addressing strategies for addressing challenges in classroom management and lesson planning. Kate and Lois also spoke about how TFA teachers' limited knowledge of general teaching practices and their lack of experience in implementing instructional methods also affected their understanding about how to teach science. The TFA teachers participating in this research were dealing with their induction experiences at the same time that they were first exposed to educational coursework, mentoring for general classroom management, and mentoring for implementing reform-based science teaching.

> The first year [for TFA teachers] is almost like a student teaching year, where "I'm reading what I'm supposed to do," and "I'm trying to learn [the content] while I'm learning what to do." And you're not even focusing on the students. (Kate, mentor conference).

Kate identified the challenge of helping TFA teachers form a "vision" of effective elementary science teaching that they were not able to form from observing exemplary practices during their preparatory experiences. From the view of Kate and Lois (interviews), the preparation of novice teachers in the TFA program negatively impacted the development of their PCK for reform-based science teaching, at least during their induction years, because they did not have the opportunity to observe and question experienced teachers about their classroom practice prior to assuming full responsibility for their own. Guidance and debriefing during the TFA Summer Institute field experiences was provided only by members of the TFA organization. These guides were TFA employees with no personal teaching experience or were former cohort members with limited (generally one or two years) classroom experience (novice teacher interviews, interview with local TFA coordinator).

While teachers from traditional preparation programs (e.g. Don) may also not have had the opportunity to observe reform-based science instruction in their field experiences due to the particular orientation of their cooperating teachers, the structure of these programs at least offers the possibility that teacher candidates will encounter a model of effective instruction in science. The structure of the TFA program, as demonstrated in the data for Mark and Ted, does not allow for such a possibility.

Even so, it is interesting to note that Helen continued to model science teaching for both Mark and Lia, regardless of the level of their prior training, and Lois and Kate offered many of the same opportunities to both Ted and Don despite differences in their preparation. This may indicate that the process of building systems of PCK for teaching elementary science may not be an endeavor that is easily or quickly facilitated, regardless of teachers' general or science-specific preparation.

One last difference between the traditionally prepared teachers and their TFA colleagues stems from the nature of their commitments to the teaching profession. Both traditionally prepared teachers, Lia and Don, had chosen to invest in teaching as a career, and both of these teachers were choosing to continue their professional development. Lia was beginning her work on a Masters program and attending professional development workshops, and Don was continuing to work with Kate in her study group on implementing effective classroom practices.

However, the TFA teachers' short-term commitments to the teaching profession appeared to influence their attitudes toward further professional development. Although both of these teachers were completing their Masters programs in education as part of their requirements for state licensure, neither teacher had plans to continue their professional development beyond these requirements. At the time of this dissertation research, both Ted and Mark had decided to terminate their time in the classroom. Ted had decided to quit at the end of the current school year (after his second year), and Mark had decided to leave at the end of the following year (after his third year). Ted had stopped attending Kate's after-school study group. While both Mark and Ted were required to continue to attend intermittent TFA meetings, neither of these teachers had plans to continue their professional development for teaching.

In summary, the inconsistent nature of teacher education between and among categories of preparation programs clouds any comparison of the influence of those programs on novice teachers' development of PCK for elementary science instruction.

The reform of elementary science teacher preparation appears to hinge not on how much field experience or how many courses in science content or science pedagogy are included in preservice experiences, but on the way they address the contextual elements of elementary science teaching and on their connection to classroom experiences. Evidence from this dissertation's limited data implies that effective programs for preparing novice teachers to implement reform-based science instruction at the elementary level may be those that, like the situated mentoring programs in this study, include multiple experiences that are deliberately designed to model reform-based instruction and provide extended opportunities to practice teaching in the kind of cross-disciplinary and cross-curricular framework that is similar to the situated experiences of elementary teachers.

Mentoring Strategies for Developing PCK for Elementary Science Teaching

While the structure of the mentoring contexts for the novice teachers involved in this research varied from site to site, several of the strategies used by the mentors were similar. Analysis of the data identified five foci of mentoring conferences. The first topic approached by both science mentors in most of their conversations with novice teachers was identifying the "big ideas" or the most important content understandings for each unit of study. The element common to both Helen's and Lois' mentoring in science that occurred most frequently in their mentoring was their insistence on connecting assessment and instruction. These discussions often led to mentoring conversations that included the third common element, the discussion of how to adapt context-free curricular materials to better serve the needs of the students. The needs of the learners were also the focus of the fourth element common to the mentors' practices, the discussion of the role of language, especially acquisition of academic science vocabulary, for English Language Learners. The final category of common practices included general teaching strategies (e.g. grouping patterns) and classroom management issues, although many of these addressed issues peculiar to science instruction (e.g. management and maintenance of science equipment).

Also common to the mentors' practices were certain strategies they used to address the needs of the novice teachers. These included modeling, collaborative planning, and the use of probing questions to challenge and/or guide novice teachers' thinking (see Lois' and Ted's mentoring conversation above).

While the discovery of commonly used foci and strategies is not unique in the mentoring literature, this dissertation proposes that the real value in examining these practices lies in the way they may, or may not, lead to the development of novices' systems of PCK that will encourage student learning in science. The following section will attempt to trace the connections between mentored learning to teach and student learning.

Research Question Three: PCK Reflected in Student Learning

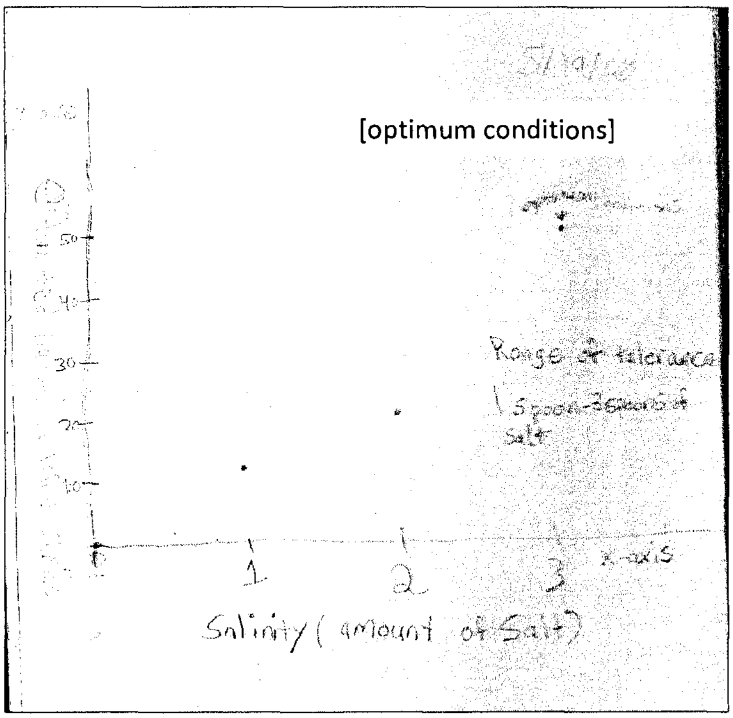
For my third research question, "How is the mentored development of novice teachers' pedagogical content knowledge for reform-based science instruction reflected in classroom practice and student learning?" my cross-case analysis lead me to the following findings.

Ted: Evidence of student learning. Ted's language-based approach to science teaching was reflected in the way his students consistently used (correctly or incorrectly) academic vocabulary in their science notebooks. What was also evident in his students' work was the way his students were able to use written language (many of them in a second language) to tell about what they were doing in science and what they thought it meant. As might be expected, the writing evidenced some naïve or undeveloped understandings of science content. However, the students' reflections were sophisticated enough that Ted was able to use them to identify areas of concern about their content understanding (see novice-mentor conversation with Lois, selected from among the data exemplars of the analytic points, in Appendix C). This evidence shows that his students were developing an understanding of scientific endeavor as doing *and* reflecting, ideas that are consistent with reform-based standards for science learning.

The evidence of student work in Ted's class demonstrated that his manner of teaching had both a positive and negative effect on student learning as envisioned by reformers. They became accustomed to reflecting on their work, but these reflections were sometimes limited to copying material from where the teacher had recorded it on the board (see example below). As students in Ted's class recorded their learning during science lessons in a science notebook, they frequently used the science words that their teacher had taken such care to introduce in class. Attempts to quantify these instances were not helpful in understanding the evidence of student learning because these instances often occurred isolated from other writing or in the context of pictures or tables of data created in whole group discussions (see *salinity, range of tolerance, optimum conditions* in Figure 2, below). This sample notebook entry is included here because it represents the way that vocabulary included in student notebooks as part of teacher-directed record keeping, rather than as part of students' independent work. (The notebook entries for this lesson in all of the student notebooks were very similar to this sample.)

To some extent, this is evidence that Ted's students are becoming familiar with the vocabulary they will need to talk and write about their content learning. But because observations of Ted's lessons showed that pages like the one pictured here were often created by copying models from the board, what is not as clear from this evidence is the extent to which his students are able to understand what the words mean and how they may be used in the context of their studies.

Figure 4: Sample of student work from Ted's class



On an assessment of student learning about the effect of an organism's (guppy's) respiration on water as shown by the indicator bromo-thymol blue (BTB), one typical response (in which the spelling has been edited to make it comprehensible) was, "It [the water] changes color because the fish breathes out an acid named carbonic acid, and if mixed with water [it] makes water change." However, there were also a few responses like this (also edited a little), "Because the goldfish is breathing and something comes out that is called carbon dioxide, and that mixes with the water. It has a name when it mixes - the name is carbonic acid." (There were few student responses that did not use the vocabulary introduced in the lesson and/or were illegible or incomprehensible.) These two representative answers illustrate that Ted's approach to science instruction was fairly successful in helping his students use scientific vocabulary, but only partially successful in helping them understand how to use it correctly.

Without personal experiences in learning science through inquiry, teachers may carry more positivistic views of science; especially if these views go unchallenged by professional education in reform-based pedagogy that explicitly address the nature of science. Individuals "without this background...teach only the knowledge aspects of science, emphasize vocabulary rather than balance knowledge claims with knowledge generation and evaluation, and present science as *the* method of understanding the world" (Gess-Newsome, 2002, p. 56).

Don: Evidence of student learning. Don used student work in their notebooks as well as more formal assessment tools contained in the FOSS materials to assess student learning. These tools indicated that student learning was affected by Don's instructional practice.

Student recording sheets for the investigation into the environmental effects of respiration on water indicated that the students generally perceived what they had been expecting to see when they looked at the cups after lunch: cups with yellow, green, or blue water in them (as was listed on the board). This is evidence that these students did not yet have an understanding of some important standards for recording scientific results. They appeared to see the value of their science lessons from a view of the nature of science that was similar to that of their teacher: science was active engagement with materials or phenomena, and "doing science" was more important than aquiring content (even if that content concerns science as inquiry).

Student work samples from a follow-up activity showed how Don's students unclear understandings from this lesson affected their future learning. In the follow-up investigation, the students put a cup with water, 6 drops of BTB, and elodea in a dark cupboard, along with a control cup (just water and BTB). The following day they retrieved the cups and observed the color of the acid indicator. While this time they were able to observe more of a change in color in the cup, the students' explanations indicate that they still harbored some naïve conceptions about what caused the water to become acidic (see student work that was selected from among the data exemplars of the analytic points, in Appendix C).

In contrast to these pages in students' science notebooks, were those from Don's less structured lesson on the investigation of environmental preferences of beetles and isopods described above. In examining these pages, Don felt that his students' work showed evidence of understanding about how to design an experimental procedure, as well as some knowledge of environmental factors.

> The experimental set-up has three distinct areas: wet, moist, and dry. The drawings are all labeled and have some kind of texture on the page to indicate the

difference between the three environments....All three students kept track of the quantity of water they used to achieve both moist and wet environments....One of them recorded the information in milliliters....One student indicated how many spoons of water....One student indicated the number of spoons and the milliliters...(Don, interview)

Whether or not these pages illustrate enduring understandings about the relationship between living and nonliving environmental factors, they do provide evidence of instruction that is designed to address reforms outlined in the NSES. The two examples of Don's instruction provided above illustrate that his teaching was inconsistent in the manner in which it incorporated reform-based practices. However, his reflections on his practice and his students' work indicate a progression toward the construction of a more sophisticated system of pedagogical content knowledge for teaching elementary science.

Mark: Evidence of student learning. During their time in the lab, students in Mark's class showed that they had some understanding of science processes in the way they recorded information about their investigations in their science notebooks. Diagrams were drawn and labeled, and they were accompanied by explanations of how their activities with models and streamtables in the lab were connected to the real world. While their interpretations were often inconsistent with conventional scientific views, and often unsupported by evidence from their experiences, the students showed that they were developing an understanding of science processes (observing, recording, explaining). Analysis of student work on assessments indicated that many of the students had an incomplete conceptual understanding of the uses of different representations of landforms (maps and models).

Students' work in these notebooks during their lab lessons also included a few pages of writing and drawing about their experiences using stream tables, along with a couple of thinking maps that were created during whole class discussions and some student sheets provided by the FOSS manual that had been filled in. However, the topographic maps created in the lesson described above were nowhere to be seen in these notebooks, and there was no evidence of student thinking about their experiences recorded there either. In contrast to the practice encouraged by Lois at Joy ES, student assessments were kept separately from their science notebooks, and were scored by either the mentor or the teacher. It is unclear why Helen allowed this practice to persist in her work with Mark, especially as her task was to help him develop reform-based instructional practice for teaching science.

In a follow-up lesson to the topographic map activity, the students were asked to compare their topographic maps to models of the schoolyard they had made in an earlier lesson using a double-bubble Thinking Map (an organizer used to compare). Helen and Mark had identified as one of the key ideas of this unit of study as the ability to identify different representations of landforms (models and maps) and their uses. Helen created this visual on the whiteboard during the lesson, and the students copied it into their science notebooks (see Appendix D for samples selected from among the data exemplars of the analytic points). Students were asked to write about these differences using the organizer they had just recorded.

Most of the students were able to copy the Thinking Map from the board into their notebooks, however, few of them wrote any coherent responses from that organizer. One student (of only four out of 26) who completed the assignment wrote (as edited),

> A topographic map shows elevation. It can show you the steepness of a type of mountain. A topograhic map shows you how many meters you need to get to the top. A topographic map is similar to a school [model] map because you could see them from a birds-eye view. They are different because a school map shows you structures and a topographic map just shows you elevation. Another way they are both connected is that they both were created from models. Cartographers will like a topographic map so they can study the landforms. A school map wouldn't help them because they are in the wild and a school map shows structures.

This response shows that while this student was able to use subject-specific vocabulary to describe some differences and similiarities of the surface structures of the two representations (a topographical map and a physical model), she was unable to make larger generalizations about them, about how and why they are useful in one way or another.

The lack of generalizations in this student's work may have just been a result of inexperience: further examination of the work in science notebooks from Mark's class over the academic year revealed that the few pages completed during his students' time in the science lab with Helen were the only entries completed. This illustrates how Mark's view of the goals of science teaching as the acquisition of enough knowledge to address items on standardized testing appears to have influenced the value that his students placed on completing written records of their work in science. Further observation of science lessons in Mark's own classroom were not possible. Mark reported (personal communication) that he was using his instructional time during this period to prepare his students to score well on upcoming standardized tests – at the expense of any further science teaching.

Lia: Evidence of student learning. Students in Lia's class demonstrated inconsistent mastery of science content on formal assessments during their unit of study in the lab(see also an example that was selected from among the data exemplars of the analytic points, in Appendix E). After the class had some experiences building models and making maps in a unit on landforms, they responded to a scenario for formative assessment that asked whether representatives from a Girl Scout troop who were asking the city council for a new playground should use a map, a model, or both in their presentation. An example of the typical response for this assessment stated:

> I think Adri (one of the Girl Scouts) should make a map because if she makes a model she will have to carry it and the model you have to put in a tray and the tray is heavy. And the map is not heavy. (student work, Lia's class)

Most of the student responses to this assesment question used a line of reasoning related to the relative weight and portability of maps and models, but did not enter into any discussion of other particular characteristics that might make one more suitable than another for the purposes of presentation.

An examination of science notebooks revealed that Lia's students were, however, developing consistent habits of scientific investigation. During this unit of study (and in other classroom-based units) Lia's students showed that they could almost all consistently observe and accurately record data from extended investigations into science content, practices consistent with reform-based learning outlined in the NSES. However, there were few examples in data from student notebooks or observations of student responses in class lessons that the majority of students were able to make generalizations, draw conclusions, or assemble evidence to justify their ideas in science – higher-level process skills that are built through consistent, long-term experiences in reform-based practices. This may be attributable to Lia's still evolving system of PCK for reform-based teaching. While she consistently asked her students to carefully record data, her lessons did not include any explicit instruction on how to use the data to form generalizations, draw conclusions, or justify ideas. The inconsistent nature of science education at the elementary level in Lia's (and other) schools may also make it difficult for students to accumulate the long-term experience needed build these skills.

For example, in their observations of stream-tables Lia's students drew and compared the landforms created by water as they varied the slope of the table. They kept track of where the landforms were created and how long it took them to form in each scenario. They used this data to write about the effect of slope on the processes of erosion and deposition.

> Me and my group [sic] figured out how to make erosion and deposition occur faster. All you hve to do is make more slope...Here are the differences between [what happened with our streamtable on a] slope and flat.[With more] slope the erosion occurred in one area. [There was] faster erosion and deposition. Slope made larger landforms. Canyons were longer and closer to the water sources. [When the streamtable was] flat, erosion occurred in many areas. It was a lot slower. [There were] smaller landforms. The landforms needed more time to

form. In both, erosion started after 1 minute. Canyons, meanders, deltas and beaches were formed [in both streamtables]. (student work, Lia's class)

Most of the student work followed this pattern, in which students were able to compare and describe phenomena, but often failed to include any conjectures about cause and effect or any predictions for any changes based on their observations.

The consistent focus of the collaboration of Helen and Lia on the processes of observing and recording data was evidence in the work of Lia's students. The entries in their science notebooks consistently included detailed drawings with labels or keys, dates, times, written descriptions of results, and student questions for further investigation. Even though the quality of the entries varied from student to student, all of the students in Lia's class demonstrated that they were using process skills (observing and recording data) in science. Evidence from formative and summative assessments indicated that while most of her students only superficially understood the major concepts of the unit of instruction, at least some of her students were able to clearly communicate important content understandings in their writing that were drawn from their hands-on experiences. This evidence suggests that Lia's evolving system of PCK for reform-based science teaching may have been influencing student learning.

Novice Development of PCK for Teaching Elementary Science

This section will attempt to show the differences in how the novice participants in this research developed PCK for reform-based elementary science teaching, answering research question four. An overview data analysis for this section is represented in Table 12 (below), however, because the entries on this chart do not reflect information about the levels or frequencies of performance for the elements listed, further discussion is contained in the narrative that follows it.

Table 12: Evidence of Mentored PCK

Research Question 3: Evidence of Mentored PCK in Classroom Practice and Student Work				
COMPONENTS OF PCK	TFA		Traditional	
	Ted	Mark	Don	Lia
KNOWLEDGE OF CONTENT				
• Identification of big ideas	MC	MC	MC	MC
• Accurate, effective representations of content	CO, SW	CO, SW	CO, SW	CO, SW
• Vocabulary acquisition	I, CO, MC, SW	I, CO, MC, SW	I, CO, SW	I, CO, MC, SW
o Used as goal of science lesson	CO			
o Used as one objective of science lesson	CO	CO	CO	CO
o Use of science word bank	CO	CO	CO	CO
KNOWLEDGE OF PEDAGOGY				
• Reform-based strategies				
o Intro of science vocab	CO	CO	CO	CO
o Curriculum adaptations	CO	CO	CO	CO
o Experiential learning	CO, MC	CO, MC	CO, MC	CO,MC
o Development of process skills	CO, SW	CO, SW	CO, SW	CO, SW
o Use of assessment to guide instruction	CO, SW	CO, SW	CO, SW	CO, SW
o Cross-curricular connections	CO, MC, SW	CO, MC, SW	CO, MC, SW	CO, MC, SW
KNOWLEDGE OF CONTEXT				
• Second-language adaptations	CO, MC	CO, MC	CO, MC	CO, MC
• Educational policy	CO	CO		CO

Sources of data:
I= interview; CO= classroom observation; MC= mentor conference; SW= student work

Information for each area of PCK is elaborated in the following sections in order to clarify data included on the preceding table.

Knowledge of Content. All science mentoring conversations observed for dissertation study identified the key science concepts that were being covered in each unit of study (see examples selected from among the data exemplars of the analytic points in Lois' and Ted's conversation, in Helen and Lia's lesson plans in Appendix E, in the way Lois, Ted, and Don assessed student work, and in Mark's and Helen's lesson planning session). Helen and Lois both used a question similar to "What is the big idea we want to get across?" when working with novice teachers on planning science lessons. Whether or not the novice teachers were also thinking this way on their own is unclear from the data collected here.

Because all of the novice participants in this research used the FOSS curriculum as the basis of their units of study, the representations of content in lesson activities during observed lessons was consistently accurate (see descriptions of lessons in data for each participant presented above). However, as in Don's case with the BTB test, there were instances where the FOSS investigations did not go exactly as planned. Don's students recorded information about the investigation that indicated some naïve conceptions about the purpose of recording data and about the connections between their inquiries and science content (see the description of Don's lessons above and the lesson observation, selected from among the data exemplars of the analytic points, in Appendix C). Don's lack of response to their inaccurate representation of the investigation results may indicate a level of PCK that is may have been influenced by his understanding of the nature of science and science teaching as "doing," and the relative importance of action over reflection on content understanding.

Because Mark and Lia worked collaboratively with Helen in implementing FOSS lessons, there were no observed inaccuracies in the representation of content (see examples in lesson observation, selected from among the data exemplars of the analytic points, in Appendix D). However, assessments of student understanding indicate that these representations were not always effective in promoting student understanding (see description of Mark's and Lia's student assessment responses). This may indicate that these teachers may not have had the level of PCK for science teaching necessary for creating additional representations of content that would to promote student learning.

Ted also relied on the representations included in the FOSS lessons, but he appeared to emphasize the role of language to represent science content (see descriptions of Ted's lessons). Examples of student work indicate that this approach may have been effective to some extent in helping his students describe science content. This writing sometimes evidenced naïve or undeveloped understanding of science content, and Ted was able to use it to identify areas of concern about their content understanding.

Observations of Ted's science lessons indicated that he planned and implemented lessons in which his students were slowly and carefully introduced to the content through a focus on the acquisition of scientific vocabulary. Ted's students consistently used academic vocabulary in their science notebooks, although the words were not always connected to pictures or sentences that conveyed meaning.

In their work with Helen, both Mark and Lia adopted a procedure that systematically employed introduction of vocabulary in context and review of vocabulary at the beginning of each lesson (see examples in field notes and lesson plans in Appendices D and E). Helen maintained an illustrated word bank in the science lab (see photos, selected from among the data exemplars of the analytic points, in Appendix D). Students in both Marks' and Lia's classes were able to use content vocabulary to some extent in their science notebooks to record information and to describe their understanding of content. This is evidence of PCK for science teaching, however, it is again unclear from evidence in the data whether Mark and Lia are imitating Helen's practice or if they have added these strategies to their own systems of PCK.

Don was much less exacting in his requirements that students use academic vocabulary to represent scientific content (see Don's comments above). However, Don (as did all of the novice teachers) maintained a word bank of content vocabulary in his classroom, and he introduced new vocabulary in context. Student work from Don's class (see example, selected from among the data exemplars of the analytic points, in Appendix B) indicate that his students were able to use this language in their written work to represent their understanding of science content.

It appears from this data that all of the novice teachers have some tools for vocabulary acquisition in their systems of PCK for developing content area vocabulary.

Knowledge of pedagogy. Don's fast-paced, efficient facilitation of whole group, small group, and partner interactions during reform-based activities from the FOSS curriculum actively engaged his students in learning. Don's students were consistently alert and involved in classroom activities. His students remained on task during the lessons, and a number of class members volunteered to contribute to whole group discussions.

Other observations of Don's classroom practice indicate that while he generally relied heavily on implementing the guided inquiry lessons contained in curricular materials (FOSS), he was able to take a step toward more student-created investigations based on assessment of their work (see notes of mentor conference, selected from among the data exemplars of the analytic points, in Appendix C). This indicates that his system of PCK for teaching elementary science was beginning to include some measure of reform-based practices for fostering independent student work. Evidence of student learning from this lesson from artifacts of group work illustrate that he was at least partially successful in facilitating this approach (see evidence for Don, above).

Ted's slow-paced, highly structured lessons were generally dependent on teacher explanation, and were not always engaging to his students, even though they included hands-on activities. It appeared from observations of Ted's science lessons that he had not yet developed the particular component of PCK for student engagement to its fullest extent.

Much of substance of Lois' mentoring conferences with Ted developed from the use of FOSS assessments with his students as he implemented lessons from the teacher manuals. Through his work with Lois, Ted had also developed a level of pedagogical content knowledge that allowed him to understand the connection between assessment and instruction. While Ted's lessons exhibited one level of pedagogical knowledge about engagement strategies in teaching science, they evidenced a much greater level of understanding about how to use assessment to inform instruction. Lois' conversations with Ted guided him to use what he had learned about his students' understanding of content and process to plan subsequent instruction. Through these experiences, Ted's began to try lessons that were not wholly consistent with the FOSS curriculum, but designed to specifically address his own students' learning.

During Mark's time working with Helen, they planned and implemented generic, cross-curricular, as well as science-specific strategies for reform-based instruction based on the FOSS curriculum (see descriptions of Mark's lesson). Their lessons made cross-curricular connections to expository writing and reading, vocabulary development, math skills, and social studies content. Hands-on science activities were always linked to activities designed to help students make connections to understandings of science content (see use of Thinking Maps, selected from among the data exemplars of the analytic points, in Appendix D). Helen worked with Mark to identify key concepts in the unit and design assessment tools to measure what students understood about those ideas (see description of lesson planning for Mark, above). The unit of study in the lab consisted of lessons that were connected to an ongoing study of important, standards-based content.

As Mark began to assume greater and greater responsibility for instruction during his time in the lab, he implemented these strategies as they were planned together with Helen. Students in Mark's class showed that they had some understanding of science processes in the way they recorded information about their investigations in their science notebooks (see field notes of lesson observation, selected from among the data exemplars of the analytic points, Appendix D). While their interpretations were often inconsistent with conventional scientific views, the students showed that they were developing an understanding of science processes (observing, recording, explaining). Assessments indicated that many of the students had an incomplete conceptual understanding of the uses of different representations of landforms (maps and models). The data collected during observations of these lessons show that Mark was able to imitate many of the strategies that Helen had been modeling. However, an examination of student work in their science notebooks completed after his work with Helen indicated that Mark taught and assessed very little science at all in his own classroom. This may be due to Mark's understanding of the constraints of educational policy on implementing reform-based science instruction.

Knowledge of context. Mark's reluctance to include any significant science teaching in his own classroom schedule indicates that at this point, he sees more value in preparing his students for standardized testing than in preparing them to understand science processes. Mark's conception of science content as sets of accepted principles and theories continued to dominate his practice despite evidence of his increasing knowledge of reform-based practices developed during his work with Helen. In Mark's case the influence of his prior beliefs about the nature of science and his view of the goals of teaching as the acquisition of knowledge needed for achievement on standardized testing may have inhibited the implementation of instruction using his system of PCK for elementary science teaching.

While Mark's decision to forego science teaching in favor of test preparation was overt, the influence of educational policy for raising test scores on other novice teachers was also apparent. Ted maintained a list of test-related educational goals at the front of his room. Lia shortened some of her lessons in the lab with Helen in order to have time to work on practice tests. However, both Ted and Lia continued to try to include science instruction as much as possible within these constraints. Only Don did not alter or cancel his science instruction to accommodate test preparation.

Other contextual factors also formed part of these novice teachers' PCK for teaching science. One important element all of these teachers considered in their instructional practice was how to address concerns of second language learners. In all of the lessons observed for this research, the teachers established and maintained a word bank of science vocabulary (see discussion above). The novices' lessons also included opportunities for their students to talk to one another and to contribute to class discussions of science content (see descriptions of lesson observations above and in Appendices). The lesson plans for Mark's and Lia's lessons with Helen also identified "target" vocabulary for each lesson (see Lia's lesson plan, selected from among the data exemplars of the analytic points, in Appendix E). While these strategies were designed to help English Language Learners, they were also key to the development of all students' academic vocabulary for science. Mentoring practices seemed to have been most consistently influential in the practice of these novice teachers in respect to implementing strategies to encourage the development of academic vocabulary.

A Continuum of Development

Taken in conjunction with the matrix representing novices' use of elements of PCK for reform-based science teaching, the accompanying narrative suggests that it is not, as first proposed in framing the literature review of PCK for this dissertation, whether or not certain identified practices are present or not present that determines the presence of PCK. Novice teachers' systems of PCK are present at all time, even though all of the elements of reform-based practice may not be functioning to their upmost capacity. Rather than looking at the way these particular novice teachers have learned to teach science in terms of evaluating whether or not their understandings have reached the optimal temperature to create a special amalgam of pedagogy, content, and context for implementing reform-based practices, the narrative descriptions included above are intended to describe novices' developing systems of PCK on a continuum of how they may be incorporating these components. (See the matrix and its accompanying descriptions, selected from among the data exemplars of the analytic points, of how, and to what extent these novice teachers incorporated elements of reform-based practices into their classroom instruction above, along with the descriptions of PCK included above.)

Summary

> Seeing what a lot of the new teachers are coming with, it's the book knowledge, but not the, "Now how do I get this across to the students?" knowledge....What kind of questions do you need to ask? It's more than just reading what the teacher is supposed to say in the books. It's knowing that if you ask this question and you get a bunch of blank stares – now what do I do? (Kate, interview)

The development of pedagogical content knowledge for teaching elementary science appeared to be formed from the interaction between these teachers' experiences as students, their experiences as teachers, and their exposure to knowledgeable mentors. There appears to be no clear cut differences in teacher preparation programs in the way they do not prepare novice teachers to teach reform-based elementary science. However, participation in traditional field experiences may offer the opportunity to observe reform-based practices, and traditional teacher education programs may offer pedagogical coursework that would encourage reform-based science instruction. Furthermore, there seems to be evidence that substantial science coursework especially designed to incorporate the content and pedagogical knowledge needed for elementary instruction is an effective alternative to the current structure of many elementary teacher education programs for preparing novice teachers to teach science.

An examination of teacher and student learning in relation to mentoring practices indicated that, as with any teaching experiences, the individual characteristics of the learners greatly influence the scope of the instruction as well as the insructional outcomes. Teachers without prior exposure to examples of reform-based science instruction appeared to benefit to some degree from opportunities to observe effective teaching models. Working on assessing student work together with mentor teachers helped novices make better connections between assessment and instruction, and helped them develop a better understanding of curriculum that was responsive to student needs.

Key issues raised in this analysis about developing PCK for teaching elementary school science include elements of teacher preparation and prior experience that may be important to helping develop PCK for teaching reform-based science at the elementary level and how situated mentoring programs may serve as ongoing professional development for reform-based science instruction. A more detailed discussion of these implications from the research will is included in Chapter Five of this dissertation.

CHAPTER 5

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

The analysis presented in the previous chapter has some implications for understanding issues and challenges associated with teacher education for elementary science. This discussion will begin with examining how findings from this research may confirm or call into question discussion in the literature around how novice elementary teachers develop pedagogical content knowledge for teaching science, how that development may be influenced by the way they are, or are not, prepared for classroom practice, and how situated mentoring programs may serve as ongoing professional development for reform-based science instruction.

Rather than looking at how this research informs any single issue, however, this discussion will continue to regard the development of PCK for reform-based science instruction as the assemblage of interlocking components, affecting and affected by other elements of the system.

This chapter will begin with a discussion of the results of the data analysis from the previous chapter in relation to the three research questions for this dissertation study. Following this discussion I will present some brief interpretive conclusions drawn for the analysis and suggest some avenues for further research.

Discussion of Results

Sources of PCK

Over the course of their lived experiences the novice teachers in this study had built an understanding of the nature of science content and pedagogy by assimilating and accommodating information gathered as students of science, as observers and students of pedagogy, as teachers of science, and as members of global and local cultures. For good or for ill, the combined effect of all these elements must be considered when describing how teachers build systems of PCK for teaching reform-based science at the elementary level and when considering the process of mentored learning to teach.

The findings in this dissertation study uncovered patterns for the influence of the various sources of PCK (discussed in Chapter Four) on individual novices' understanding of how to teach reform-based elementary science. Each novice's system of PCK for teaching science appeared to be influenced in different ways by various sources (see case descriptions, Chapter Four), including the nature and substance of their preservice field experiences. This finding contributes to the current understanding of the influence of sources of PCK in developing novice teachers' understanding of how to teach science in three ways. First, it adds to the literature (e.g. Luft & Patterson, 1999, 2002; Roehrig & Luft, 2006) about how teachers with alternative certification learn to teach science, especially because it looks at this issue at the elementary level. This finding also informs the mentoring literature as it adds sources of PCK to the considerations for how to mentor novice teachers toward reform-based science teaching, especially in the context of the elementary curriculum (e.g. Jarvis, 2001; Hudson, 2003, 2004, 2005; Hudson & Skamp, 2003; Hudson, Skamp, and Brooks, 2005). Finally, findings in this research related to sources of PCK pose further questions for research on the possible effect of situated mentoring on transforming novice teachers' systems of PCK for teaching reform-based science built from these sources.

Content and Pedagogical Knowledge

Generally speaking, the elementary teachers in this research were not well prepared to teach science in a manner consistent with reform-based practices outlined in the NSES in light of either content or pedagogy, whether or not they are prepared in TFA or traditional programs.

The lack of elementary teachers' expertise in science content is often cited as an area of concern (Abell & Roth, 1992; Bybee, 1993; Akarson & Reinkens, 2002; Appleton & Kindt, 2002; Howes, 2002; Roehrig & Luft, 2006) for science instruction and science reform, a concern which is somewhat supported by the data in this research. While three of the four novice teachers had taken a few undergraduate science courses, they did not have extensive backgrounds in science content. What was not as clear in the literature (e.g. Wenner, 1993, 1995) or from the data gathered for this research was the extent to which their college level classes in science actually contributed (and continued to contribute) to their PCK for reform-based science teaching at the elementary level.

While the teacher participants in this research came to the classroom with a certain degree of science content knowledge from their undergraduate education, the diverse nature of this coursework did not guarantee a consistent level of expertise across scientific disciplines, a facet of preparation for teaching elementary science that is somewhat different than the preparation needed for teaching secondary science. There was also little evidence that these teachers were connecting any remembered college-level, discipline-specific content from these classes to what they were teaching in elementary science lessons, except as this content informed their views of the nature of science either as a collection of specialized information (Mark, Ted), a or as a set of processes for investigating phenomena (Lia, Don).

In the cases for this study, as in cases from the literature, it appeared that the teachers' coursework in science content actually had greater unintended consequences for the development of novice teachers' pedagogical understandings for teaching science (Wenner, 1993, 1995; Haney, Czerniak & Lumpe, 1996). These novice teachers' content preparation in science did not seem to enhance their understanding of how to teach reform-minded science to elementary children, except as they may have provided negative and positive examples of effective pedagogy. Even in the case of Mark, who had fond recollections of inquiry-based learning experiences in science, it was his traditional coursework - based on the acquisition of knowledge and the replication of standard investigations - that exerted greater influence on his notions of the nature of science content and pedagogy.

Role of Experience

As was found in this study, the literature on the relationship between teaching experience and the construction of PCK for teaching science suggests a situative component to its development (Hashweh, 1987; Smith & Neale, 1991; Sanders, Borko, & Lockard, 1993; Clermont, Borko, and Krajcik, 1994; von Driel, Verloop, & de Vos, 1998; Gess-Newsome, 1999). In the absence of significant pre-service experiences in science teaching, novice teachers from alternative paths to the classroom (e.g. Ted and Mark) or teachers from traditional programs that did not include exposure to models of science teaching (e.g. Don) may rely more intensely on elements of their student experiences and apprenticeships of observation than on elements of professional development (e.g. university coursework and mentoring) to inform their practice. PCK constructed primarily from these observations offers "a limited vantage point...relying heavily on imagination...a potentially powerful influence which ...[does] not favor informed criticism, attention to specifiics, or explicit rules of assessment" (Lortie, 1975, p. 63). This influence was generally evidenced in the manner in which all the novice teachers in this study persisted in certain pedagogical practices despite ongoing efforts to mentor their practice toward science teaching aligned with reform-based standards for instruction (NRC, 1996), but it seemed especially strong in the cases of Ted, Mark, and to some extent Don – all novice teachers with no pre-service field experiences in teaching science at the elementary level.

The absence of general pre-service classroom experience may also inhibit the construction of conceptual understanding for reform-based science teaching. While novice teachers from traditional teacher education programs (like Lia and Don) are provided the opportunity to observe and practice general classroom management strategies during their field experiences, teachers coming to the classroom without these opportunities (Mark and Ted) are faced with the responsibility of building these procedural understandings for the classroom during their induction years. This may make any concurrent construction of more sophisticated, reform-based pedagogical understandings for teaching science problematic (see Kagan, 1992), and may be especially difficult when an inquiry approach to teaching science is discrepant to the novice teacher's ideas about how and why to teach science, as in the cases of Ted and Mark in this research (see also Bryan, 2003).

PCK, Classroom Practice, and Student Learning

This dissertation study adds to the literature in the way it attempts to trace the mentored development of PCK for reform-based science teaching to evidence form observations of classroom practice and examples of student work. Each participant's particular system of content knowledge, pedagogical understanding, and awareness of contextual influences was inferred from data gathered from interviews was triangulated with observations of lessons and evidence of student learning during those lessons. In each case, a these sources of data revealed how novices' evolving systems of PCK affected the implementation of reform-based strategies in their instructional practice, and how this practice affected their students' understanding of science content and process.

Ted's understanding of the nature of science learning as the mastery of academic vocabulary was reflected in observations of classroom lessons and in the way his students' incorporated science specific terminology in their written work. Mark's orientation to the purpose for science instruction was reflected in his emphasis on assessment of discrete objectives over the development of scientific process skills, a focus that was reflected in the relatively small number of written records of investigations maintained by his students. Don's increasing understanding of the changing emphases in the paradigm of science teaching reform was evidenced in the manner in which his lessons began to rely less on published curriculum and more on student-centered investigation. Examples of work completed during science lessons indicated that his students were moving from copying information about their investigations from the board to at recording and planning independent inquiries. Lia's lessons demonstrated her understanding of how to use facilitate student learning about the process skills involved in scientific investigations, and her students' work showed evidence of their ability to systematically record data from their investigations.

In each of these cases, novice teachers' varying levels of PCK were informed by their work with mentors at their school sites. The evidence from observations of mentor-teacher conversations could be traced to attempted implementations of reform-based science instruction in classroom lessons. Even when it appeared that their mentees' systems of PCK were influenced more by their accumulated experiences as students and classroom teachers than by the guidance provided by the mentoring relationship, it is important to note that mentored learning to teach provided the only source of systematic support and challenge for transforming novices' understanding of reform-based science instruction.

The need for ongoing, situated mentoring as a form of professional development addresses the need for continuing support for novice teachers, especially in the development of PCK for reform-based science teaching at the elementary level. As novices increasingly come to the classroom without significant pre-service experience (like Ted and Mark) and/or exposure to reform-based practices for science instruction (as in Don's case) the requirement for some method of long-term intervention becomes increasingly apparent. Mentored learning to teach provides the framework for those aspects necessary for encouraging the development of systems of PCK for science teaching: a) the guidance of a more knowledgeable other within the context of instruction, b) the opportunities to make explicit and timely connections between theory and practice, and c) the opportunities to form communities of learning for knowledge of practice.

Because the transformation of content knowledge from university coursework to novices' systems of PCK may not be able to be achieved until teachers have gained enough classroom experience (Gess-Newsome & Lederman, 1999), the situated nature of site-based mentoring may be the key to helping novice teachers build connections between theory and practice as they build their classroom experience. "The induction period is a time when science teachers' practices and cognitive modes are conceptualized, constructed, and crystallized, [and] the importance of this period is too often overlooked" (Luft, 2007, p.532). Site-based mentored learning to teach during teachers' formative classroom experiences offers one solution to the challenge of helping teachers develop the PCK necessary for teaching elementary science.

Situated Mentoring and PCK for Reform-based Science Teaching

In the case of the novice teachers participating in this research, it appeared that they developed much of their pedagogical content knowledge from their classroom experiences and from situated mentoring. While the residual effects of their own apprenticeships of observation remained an influence on their classroom practice, guided reflections on classroom practice with site-based mentors, in most cases, helped mitigate the effect of prior conceptions of the nature of science and science teaching.

Lois' conversations with Ted and Don helped them revise their views of science teaching as they looked with her at student work for evidence of learning. Ted began to realize that his students were writing the words he had taught, but they did not appear to be able to use the concepts those words represented to engage in aspects of inquiry learning that form an integral part of reform-based science teaching. Don came to understand that his students did not always learn content from scientific activity, an important element in the NSES standards for teaching (NRC, 1996). While both of these novice teachers held onto prior understandings to guide their classroom practice, these conceptions became tempered by Lois' mentoring.

To some extent, Lois' mentoring practice also encouraged Ted and Don to take a critical stance toward science curriculum. As mentor and novices discussed evidence of students learning, they began to also discover how the FOSS assessments did or did not make meaningful links to FOSS lessons, and made evident the need to adapt pre-designed curriculum to the needs of the students in their classrooms. These understandings formed an important aspect of these novice teachers' development of PCK, and addressed national standards of teacher development for reform-based instruction (NRC, 1996).

Kate's work with Ted and Don on helped them establish classroom routines and employ general strategies for effective teaching. To the extent that they were able to incorporate these practices into their science lessons, the lessons were engaging and successfully managed. The strategies she mentored the novice teachers toward (e.g. active learning, reflective discussion, varied patterns of interaction) were consistent with reform-based instruction. However, because Kate's mentoring was usually related to only general pedagogical training, it only partially addressed the novice teachers' development of pedagogical *content* knowledge.

Using a collaborative teaching environment for mentored learning to teach gave Helen an up-close and personal view of Mark and Lia's knowledge of content and pedagogy that she used to help guide their understanding of how to teach science aligned with national standards. Helen worked with helping Lia and Mark build both generic (e.g. reflective discussions) and science-specific (e.g. inquiry skills) strategies for reform-based pedagogy. Because the structure of the Love mentoring program required frequent mentor-novice interactions in the context of shared experiences with students, novice and mentor quickly began to establish a tiny community for building knowledge in teaching (Cochran-Smith & Lytle, 1999). Helen's work with Mark and Lia often centered on evidence of student learning displayed in notebook entries or formative assessment tools. As in Lois' case, their conversations helped the teachers make connections between curriculum, instruction, and assessment that are essential to developing PCK (Magnusson, Krajcik, and Borko, 1999; Barnett and Hodson, 2001).

Differentiating Mentoring Practices

The mentor teachers in this study pointed to the importance of observing or participating in models of reform-based practice in the construction of understandings of reform-based science pedagogy. Lois initially modeled science lessons for Ted because his limited experiences in science coursework and field experiences were affecting the way he was conceiving instruction. Kate co-taught lessons with him in order to demonstrate how to facilitate patterns of interaction among his students. Helen cited the collaborative structure of the mentoring program at Love as an element that allowed novice teachers without mental models of reform-based science teaching at the elementary level to observe what they might look like. All of the mentors recognized the importance of these models for developing general and science specific systems of PCK, and incorporated opportunities for novices to observe them teach into their mentoring practices for that purpose.

In summary, the novice teachers in this research showed that they were developing at least some of the pedagogical content knowledge needed to implement reform-based science teaching through their work with science mentors. This does not suppose that these two mentoring programs did all that they could have done, or the all that they will do in the future to facilitate novice teacher learning. Learning about mentored learning to teach, like all teaching, is an ongoing process. What they did do was provide ongoing professional development for science teaching. Given the contextual restrictions on science teaching outlined in Chapter 1, these mentors were still able to model, support, and encourage effective reform-based science teaching.

Conclusions and Recommendations for Further Study

How Should Elementary Teachers Be Prepared to Teach Science?

For some time teachers, educational theorists, and cognitive scientists have been well aware of the importance of identifying and addressing students' prior knowledge to developing curriculum and instruction that helps them learn (Dewey, 1938; Piaget, 1929; Posner, Strike, Hewson, & Gertzog, 1982; Vygotsky, 1987; Putnam & Borko, 2000). Constructivist theories of learning recognize that in order to facilitate learning, teachers need to find ways to recognize and challenge students' understandings through repeated, situated experiences with new ideas. Applying these understandings to elementary teacher education might yield some productive changes in educational programs that would result in more effective preservice and/or inservice preparation for teaching science (see NSES for professional development, NRC, 1996).

Unfortunately for elementary school teachers, much of the research on preparing them to teach science is performed within an additive, rather than a constructivist framework. Often recommendations for reform call for more elementary teachers to have more of the content coursework that is required for secondary science teachers (Wenner, 1993, 1995; Haney, Czerniak & Lumpe, 1996). Even ignoring implications from the research about the possible effect of college content courses in reinforcing traditional teaching practices at the secondary level (Luft & Patterson, 1992), these unworkable recommendations assume that pedagogical content knowledge for teaching science is the same for elementary and secondary teachers. This proposition ignores the critical role of context in defining PCK (Grossman, 1990; Magnusson, Krajcik & Borko, 1999; Barnett & Hodson, 2004).

Taking into account the importance of the interaction between content knowledge and other elements of PCK, it appears from the evidence in this research and from findings in the literature (e.g. Sanders, Borko, & Lockard, 1993; von Driel, Verloop, & de Vos, 1998; Gess-Newsome & Lederman, 1999; Luft & Roehrig, 2007), that an emphasis in teacher preparation on content knowledge in isolation from other elements of pedagogical and contextual knowledge does not facilitate the development of an effective of system of PCK. The evidence seems to imply that it is not the *number* of science courses included in elementary teacher preparation, but the context-specific *substance* of those courses that may be important to building systems of PCK for reform-based instruction. This evidence would seem to indicate that pre-service science content courses would better serve elementary teachers if they were interdisciplinary (rather than discipline-specific) in nature and taught in a way that modeled reform-based pedagogy.

Because they are situated in the context of the university, courses in content or pedagogy are limited in the manner that they may help novice teachers gain the experience necessary to make the necessary connections between theory and practice. Short-term training in science pedagogy often emphasizes a trivial constructivist (Tobin, 1993) approach to teaching elementary science (as described in Lia's description of her science methods course) that is inconsistent with national standards for reform (NRC, 1996).While university-based science methods courses may, as in the cases for Mark and Ted, model reform-based teaching practices, the implementation of these strategies does not appear to transfer to classroom practice. As illustrated by Mark's and Ted's cases, the reasons for this disconnect may be attributed in part to the competing influences of conceptual orientations and contextual factors on the development of pedagogical understandings in systems of PCK for reform-based science instruction.

Lia's comments about the status of science in the structure of elementary instruction, served to reframe the "teacher problem" in elementary science education identified in the literature (e.g. Abell & Roth, 1992; Bybee, 1993; Akarson & Reinkens, 2002; Appleton & Kindt, 2002; Howes, 2002; Roehrig & Luft, 2006) as an institutional problem. If the reduced status of science as a subject in the elementary curriculum has resulted in an inadequate level of science instruction, reform-based or otherwise, then perhaps an increased emphasis on science instruction at the elementary level as a vehicle for learning and practicing cognitive meta-strategies would generate higher expectations for teacher efficacy in science teaching.

Reconceptualizing Preparation

The "problem" of elementary science teacher preparation is often defined from a deficit perspective that fails to take into account the advantages that the structure of elementary sites might allow for connecting students' experiences across and within subject areas - structures that are not typically available at secondary and tertiary levels. The teachers in this research all recognized these opportunities as important, even if they did not have the pedagogical or content expertise to maximize them. Science learning as an integrative experience opens doors for the development of language (both informal and academic), especially for second language learners (Klentschy& Molina-DeLaTorre, 2004; Lee, et al., 2005). It presents opportunities for reform-based instruction centered on "unifying concepts" (NRC, 1996) that would allow students to generalize learning strategies (e.g. inquiry skills) across content areas. Elementary teacher education programs that could capitalize on these strengths of the elementary context might contribute much to the improvement of science instruction.

Furthermore, the knowledge base needed for teaching elementary science is different from that needed to teach secondary science, a contextual element that is often disregarded in critiques of the quality of elementary teachers' preparation to teach science. Because much of the literature on learning to teach science is written from secondary and/or tertiary perspectives, it has formed a paradigm for viewing elementary science teaching from a deficit model based on flawed assumptions about the optimal conditions for the development of reform-based science instruction at the primary level. More research is needed on how teachers develop subject and context-specific systems of PCK for science teaching at the elementary level.

There is a small body of more progressive research (e.g. Rosebery, & Puttick, 1998) that looks at changing the substance and structure of teachers' preservice and/or inservice experiences in science content and pedagogy as the road to reform. This research points the efficacy of providing teachers with long-term inquiry experiences in conjuction with a collaborative process to build knowledge *in,* and *of* (Cochran-Smith & Lytle, 1999) reform-based teaching practices for elementary science. Content preparation in science for elementary teacher education programs that is also designed to be cross-disciplinary and cross-curricular, and delivered in a way that is consistent with standards for reform-based teaching (NRC, 1996) may be a more reasonable and more effective approach to pursuing reform.

The importance of providing experiences for elementary teachers that include opportunities for them to engage in science inquiry as learners is supported in the literature on reforming elementary science teacher education (Rosebery & Puttick, 1998; Gess-Newsome, 1999; Zembal-Saul, Blumenfeld & Krajick, 2000). However, as Mark's case indicated, a greater background in inquiry-based science coursework alone does not necessarily contribute to PCK for reform-based science instruction. These experiences need to be coupled with ongoing, situated, and collaborative learning communities working with the guidance of a more capable other – as in the mentoring programs at the school sites participating in this research.

Future research

While research on the science mentoring programs in this study indicated mixed success in moving novices toward reform-based science teaching, it does provide evidence that they provided novice teachers with the opportunity to build systems of PCK for more effective science instruction. While the movement of some of the novice teachers in this research appeared in some cases to be inconsistent and insubstantial, these may only appear to be so in relation to the expectations of reform. It is important to remember that this dissertation study is limited in the way it only compares the learning of novice teachers at school sites with more progressive and ambitious agendas for reform-based teaching.

The development of PCK for science teaching by the novice teachers at these sites was not compared in this research to the learning of novice teachers at sites with lesser expectations or with little or no mentoring support for science instruction. For this reason, conclusions critical of the amount of the overall amount of progress these novice teachers may or may not have made in the context of science mentoring are not supported by the design of this research. Further study comparing situated mentored and non-mentored learning to teach with similar populations would better serve to answer questions about the particular effects of science mentoring on novices' classroom practice.

Consideration of the issues involved in research around the reform of elementary teachers' preparation for science instruction calls for further study of the ways this form might be enacted. What are the contextual elements of elementary schools that should form a part of proposals for science education reform? How should teachers from alternative programs who are placed in elementary classrooms be educated about how to teach science?

Developing Pedagogical Content Knowledge for Reform-Based Science Teaching

This data collected for this dissertation suggested that site-based science mentors form an important link in the continuum of professional development from the university to the classroom. Whether the mentoring program was based on Joy ES' expert guide approach or on Love ES' collaborative approach to mentoring, the assistance from a more capable other appeared to be crucial to developing an understanding and/or a practice of reform-based instruction.

One area of study might be concerned with examining the effects of various structures of programs for mentored learning to teach. The organizational frameworks for mentoring at Love and Joy appeared to encourage or discourage different aspects of teacher development. The unstructured, responder model generally used at Joy encouraged teachers to be more self-directed, while the structures, initiator model at Love provided a greater degree of support and interaction for novice teachers (Odell, 1990). Are there certain elements of program design that are more effective at facilitating novice PCK for science teaching? A related concern attached to the structure of mentored learning to teach concerns the manner in which different organizational frameworks encourage the establishment of communities of learners for building knowledge of teaching (Cochran-Smith & Lytle, 1999; Loughran, Mulhall, & Berry, 2004). Studies would be needed to examine mentoring practices that fostered teachers' knowledge building from a critical constructivist view.

This question suggests the need for further research to explore long-term effects of such programs on the ongoing development of elementary teachers' reform-based science instruction (Penick, 1994). One limitation of the research for this dissertation was its limited time span. In order to fully understand the effects of mentoring structures on teacher development, research on these questions would gather information early in teachers' preservice programs and into their early years in the classroom. These studies might also explore the special characteristics of the knowledge base needed for teaching elementary science, and how that knowledge may be facilitated by connecting preservice and site-based mentoring programs.

Making connections from teacher development to *student learning* in elementary science would imply areas of further research. While the analysis of the data attempted to make some connections between teacher preparation, mentoring, classroom practice and student learning, the question of student learning measured by examination of samples of student work was subjective in nature, and the question was confounded by the effects from a number of factors. The inclusion of science on the list of mandated subjects for testing may seduce researchers into assuming that these scores will be valid indicators of science learning. While such testing may give some indication of students' recall of content matter, it is questionable if they will be designed to effectively measure students' knowledge of inquiry and science processes. Comparing the validity of standardized measures of science performance to more authentic forms of assessment would be an interesting and important line of research.

Another area for research implied by the research for this dissertation concerns how the practice of reform-based science instruction at the elementary level is affected by the characteristics of the student community or the culture of the school. Much of the data collected from interviews with teachers and from observations of their lessons indicated that these contextual issues formed an important part of their understanding of pedagogy.

The inclusion of novice teachers from alternative certification and traditional teacher education programs as participants in this dissertation study also invites questions into the role of extensive field experiences in learning to teach elementary science. Since most of the novice teachers in this study observed no reform-based science teacher regardless of the length of their experience, it seems again to be a question of quality over quantity. However, given that elementary teacher candidates need experiences in observing and teaching a variety of subject matters, it would seem that longer field experiences might allow greater *opportunity* to acquire enough experience in science teaching to develop a beginning level of PCK (Lederman, Gess-Newsome, & Latz, 1994; Van Driel, Beijaard, and Verloop; 2001; Lee, E., Brown, M., Luft, & Roehrig, 2007). More evidence is needed in order to assess the valuable characteristics of extended experiences in relation to teacher efficacy for teaching science at the elementary level.

One other element affecting the efficacy of mentoring programs in this study that requires further study was the "short-timers effect" evidenced by the novice teachers recruited by Teach for America. Because these teachers were committed to only two years in the classroom, this element appeared to be a factor affecting the development of PCK of both of the TFA novice teachers in this research. Ted decided early in his second year in the classroom that he would not be returning the following year. While he continued to work with Lois on a fairly regular basis, he stopped attending Kate's after-school mentoring sessions. Mark's work with Helen marked the end of any sustained effort to teach science in his classroom. Although Mark intended to teach for one more year, he viewed his primary goal for teaching as the elevation of standardized test scores – a goal that in his view does not allow him to commit significant classroom time to science teaching (see Darling-Hammond, Holtzman, Gatlin & Heilig, 2005; Southerland, et al., 2007).

Contrasting these dispositions to those of the traditionally trained teachers offers an avenue for further research on the effect of short-term commitments on the development of PCK. Both Lia and Don continued teaching science. Don continued to work with both Kate and Lois to improve his practice. Lia was beginning her Master's program in education, and was planning on incorporating additional coursework on teaching elementary science. The differences in the long-term dispositions for teaching evidenced in their future goals did in some respects affect novice teachers' attitudes toward mentoring, even as it affected mentor attitudes toward teaching programs that were not aimed at developing long term commitments to educational reform (Southerland, et al., 2007).

In conclusion, I would propose that the study of mentoring structures and practices as ongoing, site-based professional development opens up a plethora of opportunities to study ways in which to restructure the disconnect between preservice experiences and classroom realities in teaching reform-based elementary school science.

APPENDIX A

INTERVIEW PROTOCOLS
(adapted from Grossman, 1988)

These protocols contain outlines of questions for both novice and mentor teachers. Certain questions were altered for mentors; these amendments are indicated in the protocol as "mentor amendments."

Interview #1: Content Background and Conceptions of Science Pedagogy

First, we'll be talking a little bit about your undergraduate and graduate background in science. At this point, we won't be talking about teaching science, but about science content, in general.

1 Would you tell me about your background in science?

   a. Tell me about what you remember about learning science in elementary school, in middle school, and in high school.
   b. What science courses did you take as part of your undergraduate (and/or graduate) level studies? Did you specialize in any one discipline? Can you describe a typical science lesson in your undergraduate (or graduate) studies?
   c. In what areas of science do you feel relatively strong in your own knowledge of content? In what areas do you feel uncertain in your own knowledge of content?

d. What areas of science were easy for you as a student? Which areas were difficult?

e. Do you have any memorable experiences from your own schooling in science?

2 What do you think is meant by the term "science literacy" means? What makes someone literate in science?

3 Would you talk about the major disciplines in science? How are these areas related to each other? (Would you create a visual representation of these areas and their relationships?)

a. Now I'd like to talk to you about what you think about teaching, particularly about teaching science.

4 What made you decide to become an elementary teacher?

5 What, if any, coursework have you completed in methods for science instruction?

a. **Mentor amendment**: Will you be taking any such coursework in the near future?

6 What areas of science do you think are important for elementary students to learn (probe for both conceptions of content and process)?

7 What do you think makes science difficult for students? What areas do you think students might have problems with? What is easy for students? What do you think would make the study of science easier and more meaningful for students?

a. **Mentor amendment**: What do you think makes teaching science difficult? What areas do you think novice teachers might have problems with? What do you think would make the study of science easier and more meaningful for novice teachers?

Interview #2: Teacher Preparation Interview

I've written out the names of each of the courses you took in college (and graduate school) in science content and science pedagogy. Would you first sort the cards according to how they influenced how you think about science? How did they influence your understanding of science concepts?

Now would you resort the cards according to how much you think they have influenced your ideas about how to teach science (probe for both positive and negative influences).

1. Are there any other experiences in your life that may have affected how you think about teaching science? Tell me about them.
2. Tell me about the best teacher you have ever had (in any subject). What made him/her the best?
3. Tell me about the worst teacher you have ever had. What made him/her the worst?
4. Here are the titles of courses that you took during your teacher education program. Would you sort them into categories that are meaningful to you? How have you grouped them? Tell me about each pile. Are there other ways you might group them? Tell me about the different ways.
    a. **Mentor amendment**: Here are the titles of courses that *your mentee took* during their teacher education or undergraduate program. Would you sort them into categories that are meaningful to you in describing your

mentee's understanding of science instruction? How have you grouped them? Tell me about each pile. Are there other ways you might group them? Tell me about the different ways.

Let's go through the titles one by one and talk about what you got out of each one (probe for both coursework and fieldwork).

b. **Mentor amendment**: What other experiences or resources do you see as important to helping you teach science?

c. **Mentor amendment**: Let's go through the titles one by one and talk about what you think your mentee got out of each one. What evidence do you see of any transfer from this coursework and/or fieldwork?

Interview #3: Teaching a Science Unit

This interview uses samples of student work specific to the unit of study participants are working with in their classrooms. First the participants will read through the samples.

1. Would you talk a little bit about these papers?
   a. What kind of classroom experiences in science do you think generated this work? What do you think each of the students did prior to creating these pages?
   b. **Mentor amendment**: What do you think the teacher did prior to asking the students to create these pages?
2. Tell me what you think each of the students represented by this work understand about science content and/or process. How do you know?

a. **Mentor amendment**: Tell me what you think the teaching practice represented by this work? What does the teacher understand about content and/or process? How do you know?

3. Do you see evidence of any naïve conceptions in the samples? Tell me about what you think these students may be misunderstanding.

    a. What evidence do you see that students are making connections to the big ideas (unifying concepts) behind the unit?

    b. **Mentor amendment**: What evidence do you see that the teacher is helping students make connections to the big ideas behind the unit?

4. If you were the teacher of these students, what kinds of follow-up questions would you like to ask, in order to determine their level of understanding about science concepts and/or process skills? How do these samples create, or fail to create, a picture of student learning?

5. If you were the teacher of these students, what do you think would be the next step in instruction that would address student needs?

6. What naïve conceptions about this science content have you observed in the students in your classroom? How did you address these ideas?

    a. **Mentor amendment**: What naïve conceptions about this science content have you observed in the students in your mentee's classroom? How did your mentee address these ideas?

7. What kinds of questions did students in your/ classroom generate about what they are studying? How does this reflect students' understanding of content and/or process?

a. **Mentor amendment**: What kinds of questions did students in your mentee's classroom generate about what they are studying? How does this reflect the mentee's understanding of content and/or process? What conversations have you had with the mentee about their classroom instruction in science?

8. How would you respond to the following student question: Why do we have to draw and write about what we do in science?

9. How would you respond to student questions related to the science content?

   a. **Mentor amendment**: How would you respond to mentee questions related to the science content?

APPENDIX B

DATA FOR TED'S CASE

Field Notes from Lesson Observation

Context

Teacher (s): Ted
Lesson: Environments, FOSS
25 students (15 girls, 10 boys), arranged in groups (3-4 members); students have job cards (recorder, getter, starter, reader)
Materials: terrariums (1 per group), student sheets (FOSS)

Description of Classroom Environment:

Objective (projected on TV):

- We will be able to identify range of tolerance and optimum conditions. How? By reviewing our observations discussing and recording

Bulletin boards:

graphs/charts of student work from math lesson
Stone Wall of Literacy Success (word wall);
Fluency Vision – paper boats (representing student progress) posted in categories of 10, 20, 30, 40

Big Goals (on whiteboard):

- We will master all math standards at 80% or better
- We will grow 1.5 grade levels in reading
- Our fluency will increase by 40 words per minute

We will grow by 6 points on the Nevada Writing Rubric

Test Talk poster (on whiteboard) – bridge map for testing vocabulary and meanings/synonyms

List of science vocab for unit (poster on wall) –

- environment,
- organism,
- biotic,
- abiotic,
- environmental factor,
- variable,
- preferred environment

Entire side wall covered with words for writing (vivid vocab)

	Dry	Moist (trace water)	Wet (40 ml water)	Very wet (80 ml water)	Swamp
Peas		x	x		
Corn		x	x		
Barley		x			
radish		x	x		

PROCEDURES

Time	Student Activity	Teacher Activity
1:00	student volunteer reads aloud objectives for lesson projected on a monitor in the room	teacher asks student to read aloud objectives for lesson.
1:15	students get out science notebooks; students work in groups to fill out info on plant profile (this is a recording sheet for showing the progress of different seeds planted in soil with varying amts of water - dry, moist, wet, very wet); ea students keeps track of one particular kind of seed over time;	teacher asks students to turn to info on plant profile, to the sheet that says part 2 of 2; t give students 3 minutes to fill out info with group (part 3); t circulates and assists, asks questions, keeps students on task
1:30	students volunteer reads directions for part 4 – put an x in each box where your seed grew; share info about your seed with other group members; students share info,	teacher recreates table from part 4 on students sheet on whiteboard (see below);t elaborates/models directions; t reviews info in FOSS folio, rearranges charts on whiteboard while students share info; writes "range of tolerance" on whiteboard; gives class 30 sec warning;
	students volunteers share info on seeds w/class	teacher records info from a few volunteers on table on board; introduces "range of tolerance"; connects to students experiences w/younger siblings; illustrates meaning of range with info from chart; writes definition of range of tolerance on board, "environmental factor that an organism can survive in"
1:45	students write definition in notebooks,	teacher circulated and monitored behavior; t read directions for next part of chart (circle environment where plant grew best); gave groups 1 min, 30 sec to finish this part; t

	students share information in small groups and complete next part of students sht	circulated and assisted/monitored; at end of allotted time brought class together, modeled recording data on board (circled xs on chart); introduced “optimum condition”, wrote on board; asked students to share ideas on what optimum condition meant; t writes “environment factor that is most favorable to growth and development” on board; ask students to interpret info on chart for optimum conditions for each plant
	students volunteers share a range of ideas about “optimum condition”	
	students write definition in ntbks	
	students volunteers share interpretations on chart for optimum conditions for each plant	
2:00	students listen to lesson objectives, raise hands to indicate achievement of goals; students clean up, get ready to go home	reread lesson objectives and asked students to raise hands if they did goals listed

Teacher Questions/comments

What do you think you will do next?

What does “range” mean?

Does anyone know what “tolerance” means? How many of you have a younger brother or sister who cries a lot, until you just can’t stand it anymore?

What is the range of tolerance for the radish?

How can we figure out what environment each plant grew best in?

Am I going to have any circles in boxes that don't have any Xs?

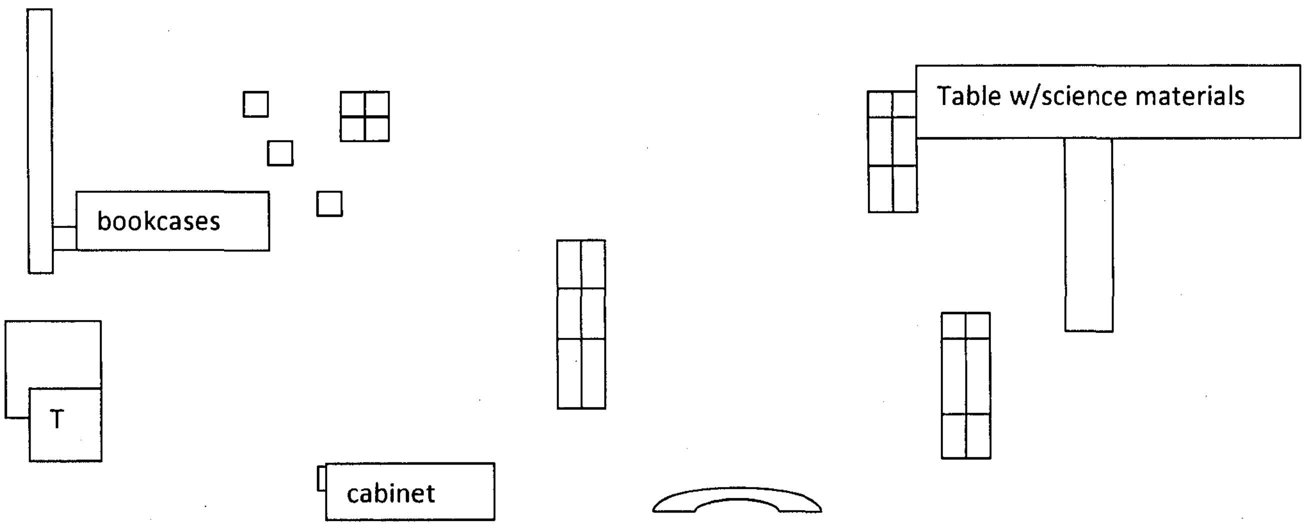
What are the optimum conditions for the corn? Peas? Etc.

Whiteboards (flag)

TV on tall cabinet

sink,

tiny fountain



APPENDIX C

DATA FOR DON'S STORY

Observations of Mentor-Novice Meeting: Lois, Don, Ted

Participants met on Sat. am to process student work on response sheets for FOSS Environments module, response sheet 2 according to ASK protocols for coding student responses according to evidence for level of content/process understanding. They all (mentor and mentees) blind reviewed and coded student work samples individually. They shared their coding and examined the reasons behind any discrepancies between the marks and reach consensus, looking closely for evidence of understanding from student responses.

1. How does the nature and substance of the mentoring conversation illustrate the mentor's conceptual orientation toward the mentoring relationship? Is the focus on a humanistic, situated apprentice, or critical constructivist perspective (Wang & Odell, 2007)?
    a. "science fairy" – situated apprentice
    b. used prepared form to look at student work in terms of N, R, C and how these are addressed for content outlined in FOSS questions (Environments, p. 20)

   c. used predetermined categories of learning (from Project ASK)
   d. conceptual change model – functions as expert
2. How does the nature of the conversation illustrate the role of knowledge *for* teaching in the novice teacher's practice? (Cochran-Smith & Lytle, 1999)
   a. Collaborative work w/colleague
   b. Peer questioning of one another's coding
3. How does the nature of the mentoring conversation lead to the creation of the novice teacher's knowledge *in* teaching? (Cochran-Smith & Lytle, 1999)
   a. Looking at student work from context of teacher's own practice
4. How is the reciprocal nature of the mentoring relationship contributing to the creation of knowledge *of* teaching in science in this context? (Cochran-Smith & Little, 1999).
   a. Not observed

Evidence for these questions will be drawn from the ways in which the mentor teachers facilitate the conversation.

1. How did the mentor guide the novice to understand what he/she intended the students to learn about science content or process from their lesson(s)?
   a. Looking at how to assess ST work (Notions: some idea of concept, but not clear; Recognition: incomplete understanding, uses vocabulary; Conceptual: mastery; Strategic: application); coding samples from ST science notebooks
2. What did the mentor do to help the novice clarify why it is important for students to know this? Not observed

3. How did the mentor probe the novice's content understanding to find out what they know (or do not know) about this science content or process?
    a. What do you think? (use of open-ended questions)
    b. Why do you think they're including soil? (in the temp test for response questions) Repeated question to focus attention on qualities of soil needed for temp control.
    c. What's their environment if they remove the soil? What is the big idea of the unit?
    d. What do you think would happen if we put all moist soil or all dry soil (for tests of light)?
4. How did the mentor help the novice identify any difficulties or limitations connected with teaching this idea?
    a. Discussion of how to assess student knowledge of control of variables
5. How did the mentor help the novice identify his/her knowledge about students' thinking and how it influenced the teaching of this idea? Did the conversation touch on students' naïve conceptions about science content or process?
    a. Looking for key science concepts (organisms in test prefer warm temp), and process (evidence, controlled variables) in FOSS student response sheets (Environments Response Sheet, Investigation 2)

b. What's the big thing in the language that will tell us what they understand?

6. How did the mentor identify or help the novice to identify other factors that influenced the design and implementation of the lesson?

    a. Issues about D's understanding of variable control in context of environment addressed thru discussion of student work

7. How did the mentor probe the novice's selection of teaching procedures used? How did the mentor probe for any particular reasons for using these?

    a. What do we do with students who are at the N level?

    b. What are some things that T might use to help student demonstrate understanding?

    c. Why was it important to do this assessment piece before the next (similar) investigation?

    d. Set up follow-up meeting to discuss next steps

8. How did the mentor ascertain the novice's use of assessment strategies? How did she encourage the novice to identify specific strategies he/she will use to ascertain students' understanding or confusion around science content or process?

    a. How would you score this? (individually or as a whole) – agreed to look at whole, but made suggestions for looking at evidence from individual items

    b. Mentees' coding of student responses and justification for marks

c. What does that tell you about what this student knows?

9. Is there evidence that this student is making connections between content?

    a. Not observed

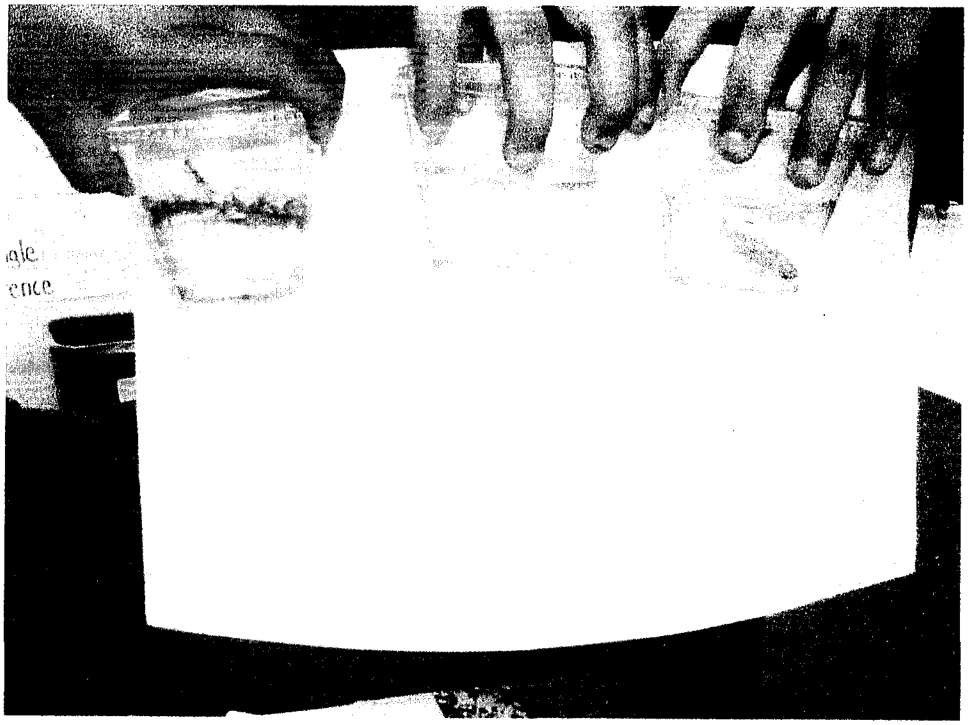
10. How did the mentor's questioning and selection of topics for conversation reflect their own knowledge of content and pedagogy?

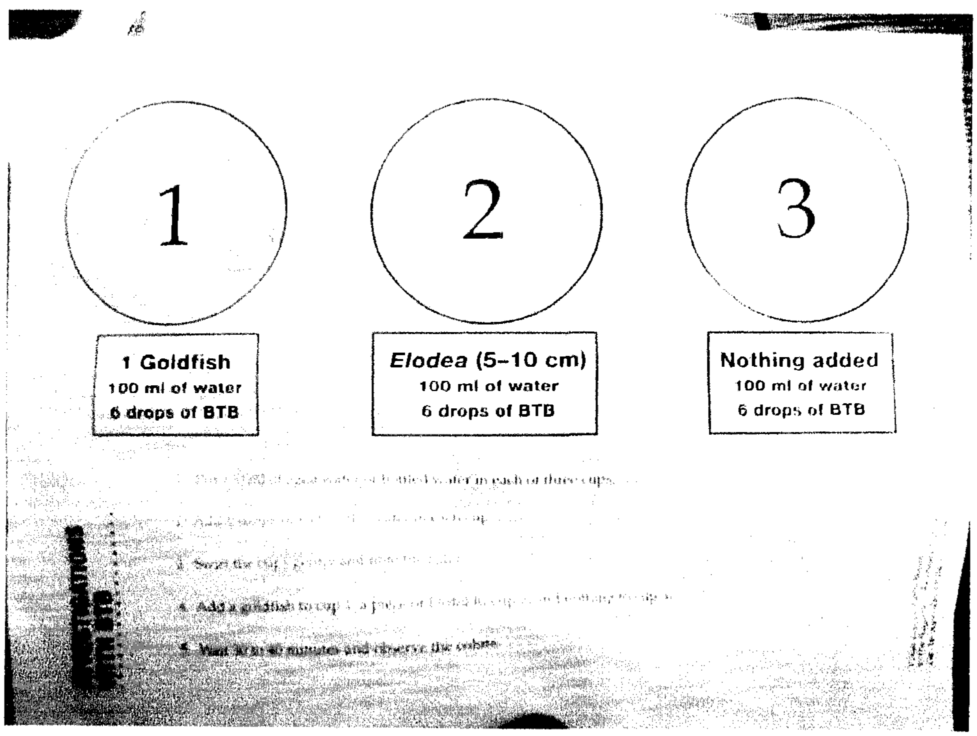
    a. Modeled questioning strategies for peer discussion

    b. Guided conversation toward mentees' naïve conceptions of content and process and assessment of ST work – Is there an understanding of control of variables?

This meeting was followed by a meeting with other teachers around ASK protocols for student assessments in FOSS. Discussion of Class Map, software for recording student scores on assessment pieces.

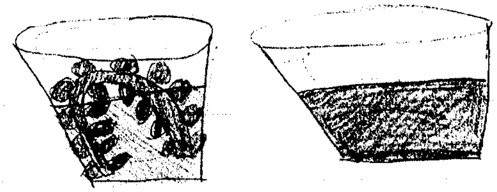
Student Work Samples





Elodea observations 4/1/08

Now after the Elodea has been in a dark closet for a while the Elodea has more acid in the cup then the fish water but there was acid in the fish water because when you blow acid comes out of the mou but the acid goes through the fish's body and out through the gills so how can acid be in the Elodea cup if it doesn't have a mouth or gills Elodea put acid in the water.



When you blow carbondioxide comes out of your lungs and the carbondioxide would come out of the gills and into the water. Does Elodea have gills? or carbondioxide? do they have lungs?

Now after the elodea has been in a dark closet for awhile, the elodea has more acid in the cup than the fish water. But there was acid in the fish water because when you blow, acid comes out of the mouth. But the acid goes through the fish's body and out through the gills. So how can acid be in the elodea cup if it doesn't have a mouth or gills? Elodea put acid in the water.

When you blow carbon dioxide comes out of your lungs and the carbon dioxide would come out of the gills and into the water. Does elodea have gills? Or carbon dioxide? Do they have lungs?

APPENDIX D

DATA FOR MARK'S STORY

Transcript of Interview: Mark

I: All right. Fist we'll talk a little bit about your undergraduate and graduate background in science. At this point, we're not going to be talking about teaching science, but about science content, in general. Would you tell me about your background in science?

M: You know…where?

I: In your undergraduate years.

M: Science background…uh…I was a political science major, and so my science aspect was more towards liberal arts and statistics. So, um, the only science… I never got into hard sciences. But more in the studies of sociology, behavior sciences as they related to political science, and so I got a lot of that.

I: Tell me what you remember about learning science in elementary school, or in middle school, and then in high school.

M: Um, in elementary school science was limited to kind of a string of unrelated events that didn't really teach any theory. It was basically just an activity-driven...I don't remember any science curriculum. There was no science fair or any… the content was very disconnected in elementary school, from what I can remember. I can remember creating like a, creating an oven using certain things to try to heat a hot dog. We didn't know why, it's just an activity to do it. Middle school – I had two great science teachers, and that was in a gifted program. So it was completely, it was like in a separate building. We were with them all day, 6 periods a day. It wasn't until, like 8th grade that we had like Spanish – one class outside of it. We had a pretty intense science curriculum and the same science and math teacher, actually. And we did science fair every year, and all the things that led up to that. Talking about the scientific process, and scientific inquiry, and by the end – our culminating experience was creating our own science fair project. But it had a lot of meaning. It wasn't like, throw something together or have your parents do it. We were very well prepped, and we all had these fantastic ideas. In fact, in 7th grade I was in the state science fair after winning like local, regional, because I was taking a look at what made the best natural battery by looking at what went into a battery. So I figured it out on my own by reading in the library that a battery had like PH acid levels and so do fruits and vegetables. So that all came from them letting you have free reign and teaching you about scientific inquiry, and the separate parts, like the method part (inaudible) and science projects. High school- I took AP chemistry, (inaudible) biology, some other… I just…the teachers that I had were "teach to the test" – not really – the stress at my high school at the time was very much "teach to the test." It doesn't really foster scientific creativity. And now it's changed, actually. Because my father teaches in the school now, and so now they have better test scores supposedly because they do a lot more hands-on.

It's a lot more inquiry-based. They do a lot of outside-the-classroom, things like that. So...

I: In what areas of science do you feel relatively strong in your own knowledge of content? In what areas do you feel uncertain?

M: My knowledge of chemistry is mediocre, at best. I really didn't care for chemistry. I can do an oxidation-reduction reaction, I can do these horrible things. But I don't have a really great foundation of fundamental understandings in chemistry. I understand statistics, behavioral sciences, how to create a non-biased census or things of that nature. For like certain studies, creating like a census or a study, a voluntary study or things like that, I'm pretty good at creating – it's not biased and I can read the statistics and you know, speak to those things. That's just, that's like math – behavior sciences. It's really the only place I feel really strong, because I've done it in the real world a lot.

I: Okay, thanks. What areas of science were easy for you as a student?

M: Um...actually, none, now that I think about it. Other areas of academia always seemed easy, history, writing, a lot of the liberal or language arts always seemed easy. Math and science never came naturally to me. I enjoyed it, I enjoyed like the logic puzzles and some of the free thinking that goes along naturally with it, but I never just came naturally. It always came with a load of work, relatively speaking. I could always just write. I could always just do those things. I could never sit down and understand, you know, do the algebra. It never just came to me like some of my friends.

I: So what areas of science did you find especially difficult?

M: Chemistry was very difficult for me. I still did all right because I understood what was going to be tested and you know, memorized these things and got through it – muddled through. But it never, like when I was in the lab, it never felt like I was really immersed and looking forward to it. "Oh, today we're going to learn about, you know, cobalt!" And you just sit in the lab and this is what this is intended to prove. It was all very contrived. It was like, this is what chapter 13 lab is supposed to do, this is what your lab book is supposed to look like, and then you're going to practice for homework the chemical reaction that you did in the lab. Like it makes sense, but the way it was taught, it was never…it just wasn't that fun. It was like, okay I have to remember how to do this now. It's very logical and it took a long time for me to get it. Luckily, my friend that I played poker with back in high school, he and I are still good friends, got me through it. He's this kid who could never go to class (inaudible) and it just made sense to him. Never (inaudible).

I: All right. Besides your science fair battery, do you have any memorable experiences from your own schooling in science? Good or bad?

M: I do remember, actually relating to the hot dog oven, I got a thing…I was asking my dad about it. It was in 4th grade, no 5th grade. It was definitely 5th grade. And everybody else had laid out a design – it was like a shoebox and there were like other things that you could use. A heater – you could use the sun as a natural heater. Well, I was like, well let's see if we can find something no one else will have, you know, like a lot of peoples'. You want to be creative or unique, show something. And I had this Renault lens or something like that that will really magnify the sun. So I looked it up so I felt prepared for it. So we set it up and it like blew up my hot dog. It was phenomenal. I thought that it was great, you know, I was showing off and everything. And no one else's really worked because it was kind of an overcast day and it still worked for mine. And the teacher said, "Oh well, we're just not going to count any grades for this." And I was like, "Wait a minute!" I got so upset. I still remember that to this day, being like…arguing completely with her. Being like, "Look just because everybody else's didn't work…" You know, that was like one of the first experiences in science. I don't, I mean, I don't know that that's really fair to science. It's one of the earliest and most vivid memories I have.

I: What do you think is meant by the term, "science literacy"? What makes someone literate in science?

M: Literate in science… just in a broader sense, understanding scientific process, scientific inquiry, understanding like how scientists come to their conclusions based on data, understanding all that vocabulary that goes into it, being able to like read data and display data – all the elements of the scientific process. If you can take somebody else's findings or create your own. It takes a certain amount of academic vocabulary and literacy in the things that are related to science, just statistics and having a decent math background. Yeah, being able to like read and interpret somebody else's findings that are presented in a scientific manner.

I: What do you see as the major disciplines in science? Can you talk about them? And how are they related to one another?

M: Major disciplines in science…um…not sure…just in terms of mathematics, how it relates to science?

I: Well, the parts of science, like the areas of science.

M: Okay. Different areas of science and how they're related...(sigh)... I see what you're saying, I'm just trying to figure out...

I: Like physical science...

M: Oh right. (pause) Trying to figure it out...I mean, obviously, the way it's been broken out into curriculum like you have your physical science, and you have your like chemical or biological sciences. I mean, they're all related in that they all use the scientific process. And they all have some element of math (inaudible). It depends on the content they're studying. They're related in that they're all basically part of the scientific process, but there's so much that can be considered science. You have to break it apart into different classifications.

I: Yeah, right. Early on you talked about soft science and hard science. What do you see as the difference between those two branches?

M: Hard science I see as more finite in the fact that it can be represented by, like a hardened scientific formula. For instance, I used like oxidation-reduction reaction, like that is a scientific...it's something that can be recalculated, like there's almost no room for interpretation in that kind of science. I mean you can do certain things and certain reactions or scientific theories that ...well, theory technically isn't proof. There is only three scientific proofs, so everything's up for debate. There are things that are widely accepted in scientific community as hardened fact, that until somebody else can prove otherwise, that's what we're using. So in the case of like chemistry, while you can discover it on your own, there's a textbook there. People that have, you know, using certain things shown that an atom is composed of electrons and neutrons, you know. That's the way we classify it until somebody else can prove otherwise. The sciences that I was involved more with are the soft sciences – very interpretive and based on the way data can be shown. Two different people can look at the same data and come to different conclusions, and it is based on how you want to support that theory. You still have like that in other cases, but it's just like it seems in chemistry, anatomy, more hard sciences are where you're trying to learn what somebody else has already proved, until somebody else proves it and we have a new proof that we're using for that field. So...that's a great explanation.

I: Now I like to talk to you about what you think about teaching science. First of all, what made you decide to teach at the elementary level?

M: Huh...I, from, in my mind, when I signed up for Teach for America, I thought I was going to be a secondary teacher. So I thought I was going to be a secondary political science teacher. They told me I was elementary. I went and shadowed at elementary schools, and I thought, "Am I really going to go out and teach elementary? Can I do it?" I went and shadowed, and "Oh, yeah, I think this is something I could do." Maybe it's even more influential. So that's kind of how it was backwards way, it wasn't actually a conscious choice. So afterwards...

I: What, if any coursework have you completed in methods for science instruction?

M: I took a 3 credit class at [name of university]. That was teaching science instruction with um...what's the gentleman's name again?

I: [Name of instructor].

M: Yeah, first semester. And that has been the extent of my science instruction, other than, I attended one or two smaller workshops at Institute that talked about science instruction. When you got like free choice for what you wanted to go do, I thought, I mean, we didn't do anything. We were still learning everything. I thought I had a handle on literacy, and I was like, "Well, I don't know anything about science." So I attended one or two of the workshops that talked about FOSS and talked about different things you can do for science instruction and integration of science. But I still didn't get it then, but it was nice to (inaudible)...

I: What areas of science do you think are important for elementary students to learn?

M: Talking about for like 5th graders, or for once they exit elementary school?

I: Yeah.

M: Hopefully, by the time they leave, they understand the basics of scientific process. They're able to use some of the basic scientific vocabulary, like what a variable is and things like that. That they have an idea of maybe what a scientist does. It's not just like some person with a lab coat and beakers, like actually, they're asking these fundamental questions and collecting data to support their answers. Just kind of broad strokes.

I: What kind of content do you think they ought to be responsible for?

M: I've only looked at 5th… I mean, I know 4th and 5th because it's very pertinent. I actually do like the way that FOSS does it, it terms of it's very broad, like the themes, they're not narrow. It's not like in 3rd grade, they get all things that are like earth sciences, in 4th …It's good that they're getting a nice mix of some earth, some physical, and they seem to – the ones they've selected, the ones that (inaudible) make a lot of sense. Like electricity and magnetism at 4th grade, it makes a lot of sense. 5th grade, like landforms and water cycle…things that they can relate and make connections to in their own lives, but still learn the scientific process through that and ask those, you know, fundamental questions. Like it wouldn't make any sense to teach them any basic chemistry, even if they could get it because they can't relate. They can't see two hydrogen atoms in their head. Like maybe they could, but it would be very difficult for your whole class. It would take a lot of time. It makes sense to teach landforms because they can, even though they've never been to Africa or even never been to the plains or see a lion, they understand what it is. So they can see a picture or a video and understand what it is and make that connection about animal traits. And anything they can make a solid connection to and still learn like the scientific process. (inaudible)

I: What do you think makes science difficult for students?

M: They have not been taught to be critical thinkers in their entire academic career. So they have to think critically, and say what do I have in front of me? What do I really think? And that's hard for a lot of the kids. Luckily, at this school they've been working on it, especially in math and so they're working at it a little bit. You can tell by their personalities even a little bit. It's hard for them to just sit down and make some guess about it and try to support it and that's what the whole scientific inquiry supposed to be based around. So they look to you and say like, "What does he want?" You know, and you have to ...there's nothing I want. I want you to sit and think about it and tell me what you actually think. And getting past that is really hard to do. They also get so excited when it comes to some of the kits. Because they don't get to do a lot of this stuff. So getting them to get beyond cutting out the boats and actually think about, okay, what's really the capacity...and remembering all the vocabulary, getting them settled down enough. I guess that comes from teaching a whole year of science, so they're beyond the giddiness.

I: What about science do you think is easiest for students?

M: The investment piece, easily. Because like a lot of the content, especially the way I teach reading, it's not literature circles. You know, it's hard. It's like you're learning context clues. Science, like when you say, "Science. Oh, like today we're doing variables. Let's get back to our boats." They just light up and they're enthusiastic and there's no, almost no, coaxing them into wanting to do science. So it's just the management piece, and getting them to do it the way that it...trying to be contrived without being contrived to getting them to the point where they can have that scientific inquiry.

I: What do you think would make the study of science easier and more meaningful?

M: By the time they get to 5th grade they've had it inconsistently at this school, and I know that at other schools it's been the same. If I got them where they already were familiar with keeping a science journal and collecting data, and all these things, it would be a lot easier. I wouldn't have to spend so much time in the first unit, when I teach pendulums, it's going to be a colossal process because it's like setting up the whole thing. I have to pretend like they've never seen science before. So from a 5th grade standpoint, that would be the nicest thing to happen. Come in and understand, even be able to tell me some of the things, like variables, maybe not understand them, but have heard them before. And they'd be "Oh, that's right. That's what we talked about." And be able to remember how to collect data, understand what that is.

I: Okay. Anything else you want to add to what you said about either science content or teaching science?

M: Um...in terms of what?

I: I don't know.

M: Anything at all?

I: Anything I've missed.

M: I do like, I don't think this is part of your study, but I do like the way FOSS makes it easier for, I mean teaching science is hard, very hard. And the way they break it down and make it... you know, a simple curriculum to follow. But it's still, it's not so contrived that it takes all of the thinking away from the kids by any means. It sets it up, if you do it right, they can still have that genuine experience of drawing their own conclusions, hopefully, do the process themselves.

I: Okay, one last thing I'd like to ask you to do. I want you to see if you can make a visual representation of science – the disciplines in science and how they connect to one another.

M: You want a representation of how the sciences…(sigh)…(long pause)…I keep going back to like, physical, biological, chemical, and so …

I: There are no right answers.

M: I know, I know. I understand you're not looking for anything. (pause) Anything?

I: Anything.

M: (long pause, drawing)

I: Tell me about your drawing.

M: Just like the way that when I think of science, it's like. This is just easiest, it's just like when I think of science because of the way that all the classes have been presented, been presented to me in academia, especially in college, like even through course catalogs, how you would look them up. And so it makes sense if you were to ask me about where a geology class would fall in this, there are elements of both, but there would be more physical science. But if you ask me about like age of dinosaurs, it would be more of a biological science, you know. So it's easier for me to classify them. But they're all very much related. So I just drew a triangle. They're all connected. Like biological science, you took a paleontology class that, you know, you're uncovering fossils, there's a chemical process by which you can extract DNA samples and things of that nature. But at the same time they're very much related to the physical science because you know what kind of rock deposit it is so that you don't destroy the fossil itself, you know. The biological remains, you kind of dig…and things like that, they're all related in the middle. Math and the scientific process, things kind of tie all of them together because they all use them in different ways. They all use them to draw their conclusions...

I: Okay. Thank you very much.

(end of transcript)

Field Notes for Observation of Collaborative Lesson

Mark

Context

- Teacher(s): M=Mentor (Helen); T=Teacher (Mark)
- Lesson: FOSS Landforms (mountain models)
- Materials: foam mt. pieces
- Description of Classroom Environment: tree map for for science notebooks on whiteboard; word wall of landform terms on whiteboard; bulletin board on left side shows posters of animals, bones; cabinets filled with lg. aquaria with fish, snails, worms, snails, a sprouter, books about trees, pine cones, tree rings, seed pods; right side of the room has added insect habitats for crickets; picture/maps of Mt Shasta & Grand Canyon

*Principal also observed lesson/interacted w/students

PROCEDURES

Time	Student Activity	Teacher Activity
9:50	Listening, volunteers	T reviewed ST presentations from previous lessons (of investigation from ST notebooks), emphasized

	answering questions	what should be included in the "conclusion" section of their presentations, and presentation techniques; introduced goals for lesson – making maps and models of landforms; reviewed vocab (model, map); gave very specific directions for working w/buddy to assemble mt. model (from FOSS foam materials); modeled assembly; stressed equal thickness of layers; positive reinforcement for behavior (waiting for instructions) M: circulating, assisting
10:00	Work in pairs to assemble mt models	T: stopped activity to explain that mt pieces may have numbers (elevations) on both sides
10:05	Listening, volunteers answering questions; finger walking	T. stopped activity; asked ST to id landform; confirmed id of landform as landform; asked ST to compare 3-D model w/real mts; into "topographical model"; explained that layers go in 500 m; intro "sea level"; connected to prior activity w/stream tables; guided "finger walk" of model M: draws diagram of model w/vocab on whiteboard (peak, base, sea level)
10:10	Listening, volunteers answering questions, finger walking	T: calls class to order, posed questions about differences in elevations between levels; reviewed vocab w/diagram drawn on whiteboard; intro "birds-eye-view" of model to make topo map; intro FOSS st sht to create topo map; gave specific instr for converting to 3-D map; used completed topo map of model to illustrate completed form M: brought out meter tape to show ST length of meter; brought out copy of completed topo map drawn from model
10:25	Make topo map by tracing layers of mt model w/buddy; (ST who finished first playing w/foam pieces)	T: circulating and assisting; visited teams to provide an additional copy of st sht so that ea ST will create map M: circulating and assisting

10:39	ST finish, clean up	M: gave 1 min warning for end of class
10:40	Listening, coming to board to point, looking in sci ntbks, talking to neighbors	M: called class back together, asks for ST to look for examples of topo maps in classroom, points out maps of Mt. Shasta, Gr. Canyon; asks volunteers to come up and point to base, peak of mt; intro vocab "contour lines"; asked ST to think back to schoolyard models – asks ST to refer to pgs in sci notebooks to make double bubble to compare school map and mt map
10:46	Indiv. ST contribute to double-bubble construction	M: creates double-bubble map on board w/ST contributions about maps; reinforced the relation between the nearness of the contour lines and the steepness of the slope; reviews vocab (contour lines, contour interval, topographic map, elevation, base, peak, birds-eye view)
10:55	ST write in sci ntbks (most ST copy bubble map from board, some also write on facing page too)	M: staples maps in ntbks; reviews heading for ntbk pages; gives ST time to write in ntbks; monitors and assists ST; reinforces "quiet writing time" T: assists ST

TEACHER/MENTOR QUESTIONS:

M: What do you notice about the mt?

What kind of a landform is it? What makes you think so? What else could it be?

What do you think these numbers mean? Do you see a pattern in those numbers?

If you were going to hike up the mt, which way would you go? Why?

What do we call it when the elevation goes up really fast? What about the slope?

(steep)

(On this topo map) Can you find the base of the mt? Can you find the peak?

Can you see ways that these topo maps are similar to or different from the maps of the schoolyard that we made before?

Think about these numbers – what do they show? Does this map show any elevation?

What do you mean by "shows elevation"?

What else is the same or different?

Where is the steepest part, the part where the contour lines are closest together?

What type of a map did we make today?

T: Who's your partner?

Did you listen? What happened?

What do you think this landform is? Why do you think so? (for incorrect response)

Where would you rather be – at peak or at base? (began to model w/groups after M. drew on whiteboard)

What is the elevation of the base?

What is the elevation of the peak?

What's the elevation of this part of the map? How high does this map show?

Do you have a bathroom pass?

Does that make sense?

If you were letting a bird go, and it only liked to fly at 12,500 m, show me where you could let it go.

What else do we notice about what is the same or what is different?

Suggestions for future observations: Evidence of pedagogical knowledge

1. How does the lesson illustrate the novice teacher's understanding of content, conext, and reform-minded pedagogy?
    a. T: modeled and gave very specific directions for assembly (vs learning thru discovery); pattern of interaction for discussion limited to T-ST-T; restates questions in different words; did not connect these models to models/maps of schoolyard created in previous lesson; short wait time
2. Are students asked to reflect on their learning to make connections to prior experiences in science, to experiences in other content areas, and/or to real-world situations? Are students asked to make generalizations and predictions based on evidence from their experiences?
    a. ST asked to evaluate usefulness of various representations (models, diagrams, maps)
3. Do the learning objectives relate to national standards?

a. Science as inquiry: develop descriptions, models, interpret data

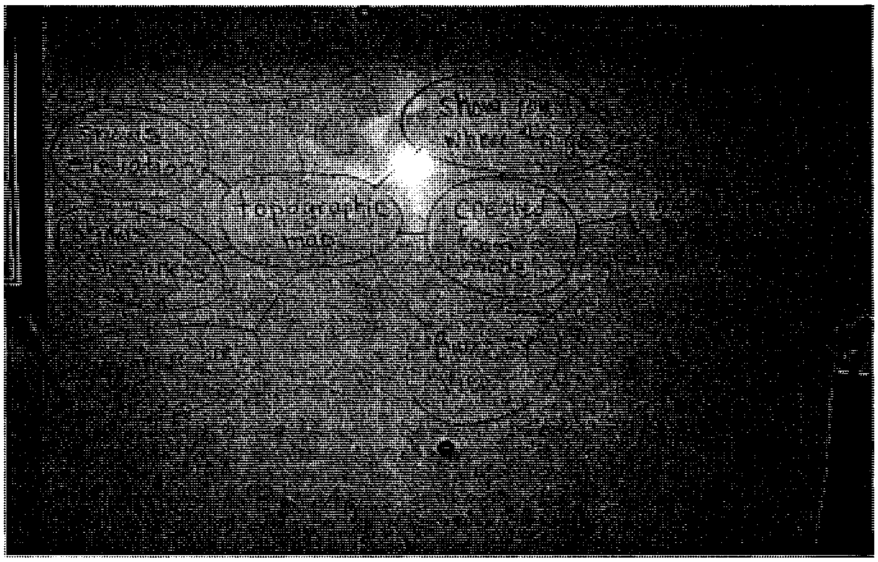
4. Do the lesson activities allow students to use process skills (observing, sorting, comparing, classifying, predicting, doing a fair test, collecting, recording, and/or interpreting data, and communicating findings)?
    a. ST collaborate to observe, compare
5. Does the teacher use observation, questioning, and/or group discussion to informally assess student learning? Does the teacher use informal assessment results to adjust the lesson?
    a. All- lesson elements based on M-T discussion of ST learning
6. Does questioning allow for a variety of responses? Does questioning require students to compare, organize, evaluate, or synthesize?
    a. See above
7. Do class discussions allow students to share their science findings? Does the teacher use class discussions to help build or clarify students' understanding of science content?
    a. T-led class discussion used mainly to clarify/intro science vocab and/or directions for activity
8. Does the teacher recognize and respond to students' naïve conceptions about science content?
    a. M, T both responded to ST naïve understanding of relationship of contour lines to slope
9. Are students encouraged to generate new questions based on evidence or results of their investigation? Do they have opportunities to share and discuss these

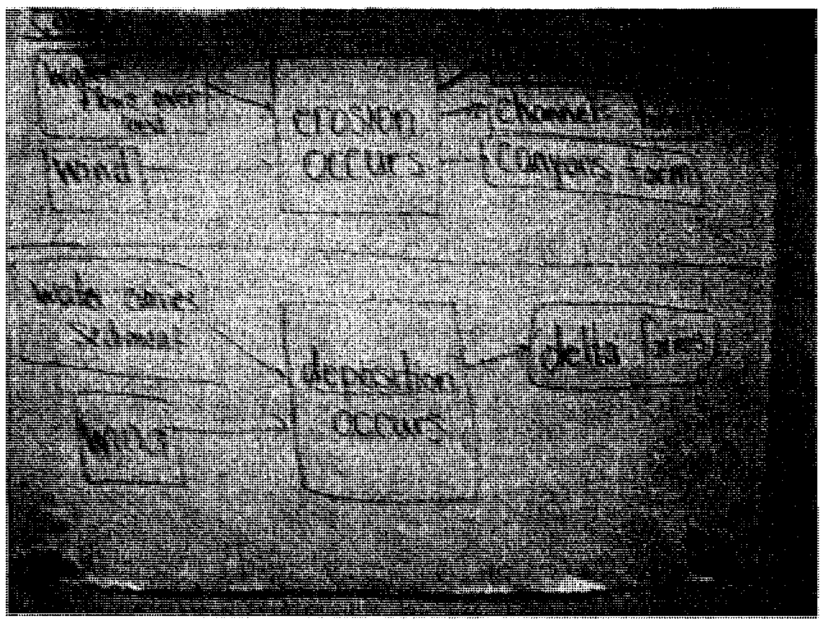
questions with others? Do they have opportunities to design procedures to answer their own questions?

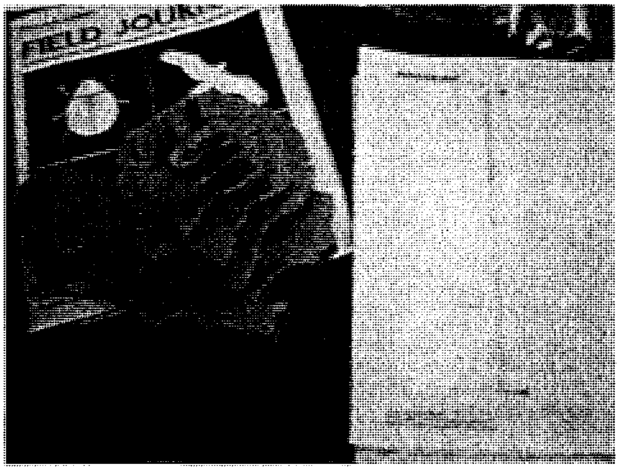
a. None evident

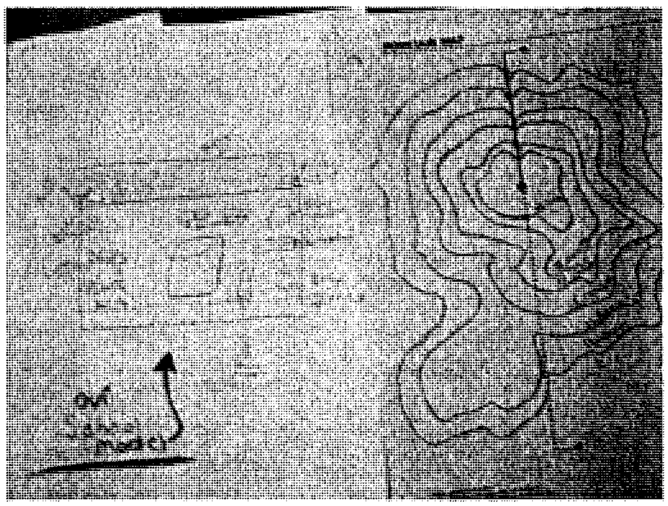
10. Does the teacher appear to have a clear understanding of the science content? Yes

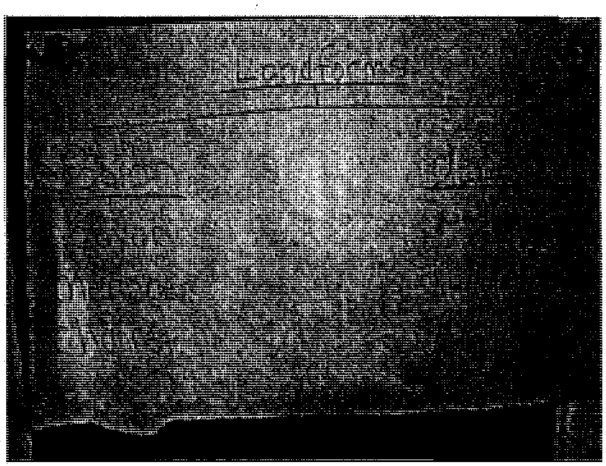
a. Does the teacher apply suggestions for practice drawn from interactions from his/her mentor teacher? M-T designed lesson together

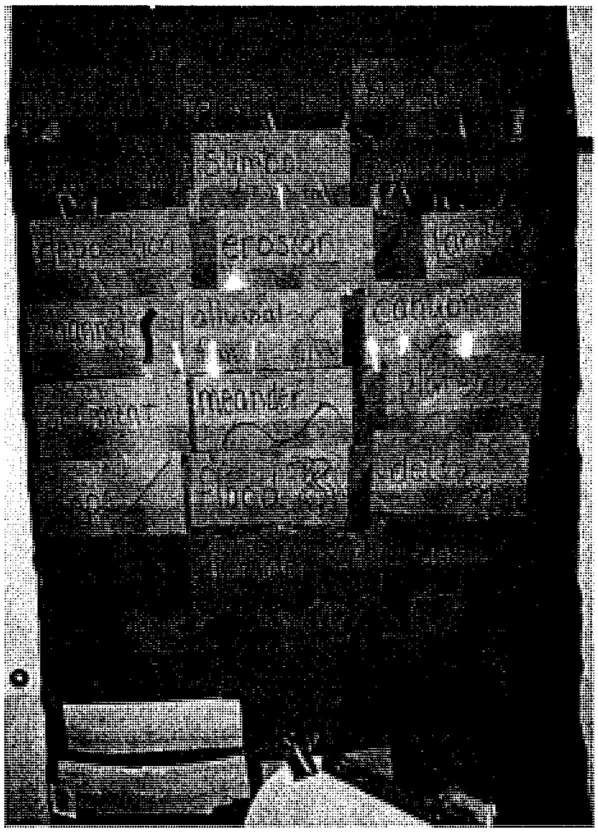


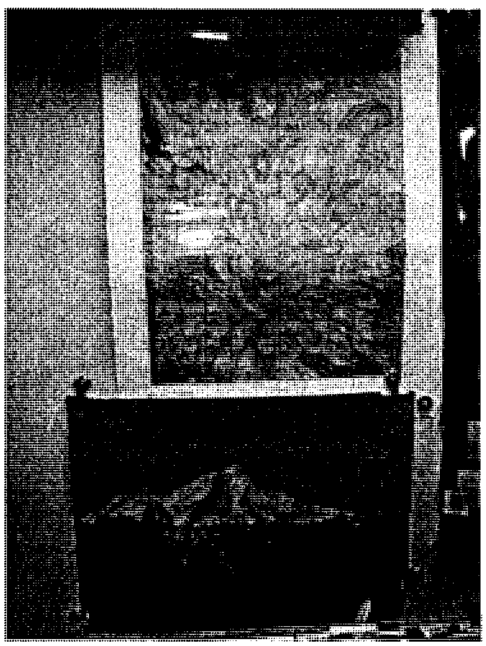







Landforms


erosion
alluvial
meander
delta



APPENDIX E

DATA FOR LIA'S CASE

Sample Plans for Collaborative Lessons

Power Standards

Theme: Landforms

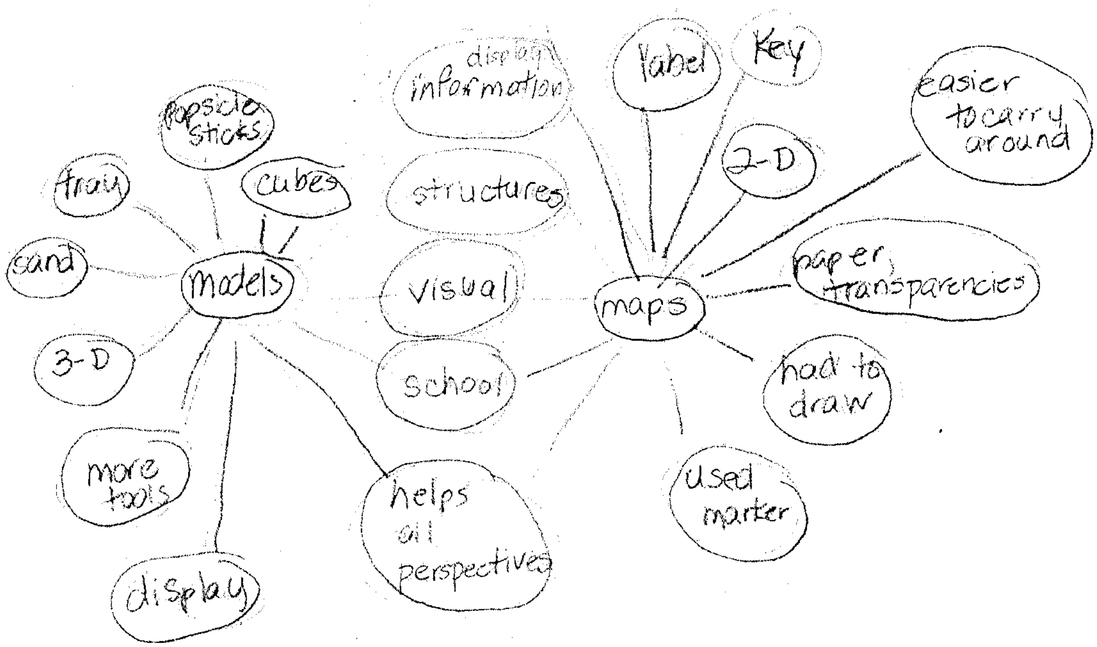
Language Arts:
4.5.1 Use format, graphics, sequence, diagrams charts and maps to comprehend text.
4.5.3 Read to evaluate new information and hypotheses by comparing them to unknown information and ideas.
4.5.6 Read and follow multi-step directions in order to complete tasks.
10.5.1 Participate in discussions as a contributor and leader.
10.5.2 Ask and answer questions to clarify or extend ideas.
11.5.1 Formulate research questions; establish a focus and purpose for inquiry.

Mathematics:
4.5.3 Graph coordinates representing geometric shapes in the first quadrant

Science:
N.5.A.6 Use models as tools to explain how something works or is constructed.
N.5.A.7 Use observable patterns to organize information and to make predictions.
E.5.C.2 Explain that water, wind and ice constantly change the Earth's land surface through erosion and deposition.
E.5.C.3 Identify which landforms result from slow processes and from fast processes (volcanoes, earthquakes, landslides, flood and human activity).

Date	Day	Procedures/Materials/ Assessment	Targeted Vocabulary
2-6	Wed. 1:35-3	Procedures: 1) Intro. To lab and set expectations. Make name plates. 2) Pre-assess compare/contrast maps. 3) Intro. Model making of school yard. Model procedures and materials. Discuss what boundaries of model will be. 4) Students construct models. Do a gallery walk so students see all models. 5) Create a flow map to show procedures for writing. 6) Students draw and write how they made their model and label. 7) Introduce project folder and have students thinking about adding ideas to the folder. Materials: Trays, sand, blocks, notebooks, name tag, pre assessment copies Assessment: pre-assessment	Model Boundary structure
2-7	Thurs. 9:50-11:10	Procedures: 1) Review model making from Thurs. and word of the day (boundary). 2) Challenge students to think of other ways to represent the school area. Intro. cartographer. 3) Model how to use the grid paper to transfer map. 4) Students transfer maps and clean up. 5) Complete response sheet, what are the benefits and difficulties with maps and models. 6) Shared Reading: Maps and How: they are made (FOSS Stories) Materials: grid transparences, markers, response sheets, student readers. Assessment: Response sheets.	Cartographer Map Grid
2-8	Fri. 9:50-11:10	Procedures: 1) Review grids from Thurs. and word of the day (cartographer). 2) Intro. To map grid and discuss	Symbol key

Double-Bubble Thinking Map Comparing Models and Maps



Sample Assessment Response

Adri and a group from her Girl Scout troop were studying a local park to find out the best place to put the new playground. They needed to present their plan to the city council. They hoped that the council would approve their plan.

She and her friends couldn't decide whether making a model of the playground or drawing a map would be the best way to present their ideas.

What do you think Adri and her friends should do? Write your ideas in the space below about whether to include a map, a model, or both in their presentation.

Well I really say map because look
a model you have to build it it
and when you build you have
to bring it to the city council and
is going to be alot of people
and when you make it they're
going to see it and what
happened is it small and
the can't see it a map
You could get a gigantic
paper and make it and label
it with big words and they
could understand better and also
you could make alot of map
and give it to them and they
could take it home and that's
why map is better.

3

BIBLIOGRAPHY

Abell, S., Dillon, D., Hopkins, C., McInerney, W.& O'Brien, D. (1995). Somebody to count on: Mentor/intern relationsips in a beginning teacher internship program. *Teaching and Teacher Education*, *11* (2), 173-188.

Abell, S. K., & Roth, M. (1992). Constraints to teaching elementary science: A case study of a science enthusiast student teacher. *Science Education, 76*, 581-595.

Akarson, V. & Reinkens, K. (2002). Preparing preservice elementary teachers to teach for conceptual change: A case study. *Journal of Elementary Science Education, 14*(1), 29+.

Akarson, V. L., Flick, L. B., & Lederman, N. G. (2000). The influence of primary children's ideas in science on teaching practice. *Journal of Research in Science Teaching, 37*, 363-385.

Amaral, O., Garrison, L. & Klentschy, M. (2002). Helping English learners increase achievement through inquiry-based science instruction. *Bilingual Research Journal, 26*(2), 213-239.

American Association for the Advancement of Science. (1989). *Science for all Americans.* New York: Oxford University Press.

American Association for the Advancement of Science (AAAS). (1993a*). Benchmarks for science literacy.* New York: Oxford University Press.

American Association for the Advancement of Science (AAAS). (1993b*). Atlas of science literacy.* Washington, DC: American Association for the Advancement of Science and National Science Teachers Association.

Anderson, L.W. & Krathwohl, D.R. (2001). A taxonomy for learning, teaching, and assessing: A revision of Bloom's taxonomy of educational objectives. New York: Longman.

Anderson, R. D., & Mitchener, C. P. (1994). Research on science teacher education. In D. L. Gabel (Ed.), *Handbook of research on science teaching and learning*. New York: Macmillan.

Appleton, K., & Kindt, I. (2002). Beginning elementary teachers' development as teachers of science. *Journal of Science Teacher Education, 13*(1), 43-61.

Atkin, J. & Karpus, R. (1962). Discovery or invention? *The Science Teacher, 29*(5), 45-51.

Ball, D.L. (1988). Research on teacher learning: Studying how teachers' knowledge changes. *Action in Teacher Education*, 10 (2) 17-24.

Ball, D.L. (2000a). Bridging practices: Intertwining content and pedagogy in teaching and learning to teach. *Journal of Teacher Education,* 51(3) 241-247.

Ball, D. L. (2000b). Forward. In M. Stein, M. Smith, M Henningsen & E. Silver, *Implementing standards-based mathematics instruction: A casebook for professional development (pp ix-xix).* New York: Teachers College Press.

Ball, D.L. & Cohen, D. K. (1999). Developing practice, developing practitioners: toward a practice-based theory of professional development. In L. Darling-Hammond & G. Skyes (Eds.), *Teaching as the learning professional: Handbook of policy and practice*. (pp. 3-32). San Francisco: Jossey-Bass.

Ball, D. L., & Feiman-Nemser, S. (1988). Using textbooks and curriculum guides: A dilemma for beginning teachers and teacher educators. Curriculum Inquiry, 18(4), 401-422.

Ball, D.L. & McDiarmid, G.W. (1990).The subject matter preparation of teachers. In W.R. Houston (Ed.), *Handbook for research on teacher education.* New York: Macmillan.

Ballou, D., and Podgursky, M. (1997). Reforming teacher training and recruitment. *Government Union Review,* 17(4), 1-47.

Bandura, A. (1981). Self-referent thought: A developmental analysis of self-efficacy. In J. H. Flavell & L. Ross (Eds.), *Social cognitive development: Frontiers and possible futures.* New York: Cambridge University Press.

Bandura, A. (1982). Self-efficacy mechanism in human agency. *American Psychologist, 37,* 122–147.

Barnett, J. & Hodson, D. (2001). Pedagogical context knowledge: Toward a fuller understanding of what good science teachers know. *Science Education, 85*, 426-453.

Baxter, J. & Lederman, N. (1999). Assessment and measurement of pedagogical content knowledge. . In J. Gess-Newsome & N. Lederman (Eds.), *Examining pedagogical content knowledge: PCK and science education* (pp. 3-17). Netherlands: Kluwer Academic Publisher.

Ben-Peretz, M. & Rumney, S. (1991). Professional thinking in guided practice. *Teaching and Teacher Education*, *7*, 517-530.

Berliner, D.C. (1986). In pursuit of the expert pedagogue. *Educational Researcher, 15*(7), 5-13.

Berliner,D. C. (1989). Knowledge is power. *Equity and Excellence, 24*, 2-6.

Bettancourt, A. (1993). The construction of knowledge: A radical constructivist view. In Tobin, K. (Ed.), *The practice of constructivism in science education* (pp. 39-50). Hillsdale, NJ: Lawrence Erlbaum Associates.

Bianchini, J., Johnston, C., Oram, S. & Cavazos, L. (2003). Learning to teach science in contemporary and equitable ways: The successes and struggles of first-year science teachers. *Science Education, 87*, 419-443.

Black, A., & Ammon, P. (1992). A developmental constructivist approach to teacher education. *Journal of Teacher Education*, 43, 323-335.

Blosser, P. E., and Howe, R. W. (1969). An analysis of research on elementary teacher education related to teaching of science. *Science and Children 6*(5): 50-60.

Bodzin, A. & Beerer, K. (2003). Promoting inquiry-based science instruction: The validation of the science teacher inquiry rubric. *Journal of Elementary Science Education, 15*(2), 39-49.

Bonk, C. & Cunningham, D. (1995).Searching for learner-centered, constructivist, and sociocultural components of collaborative educational learning tools. In C.J. Bonk & K.S. Kin (Eds.), *Electronic collaborators: Learner-centered technologies for literacy, apprenticeship, and discourse*(pp. 25-50). Mahwah, NJ: Erlbaum.

Borko, H. (1993). The integration of content and pedagogy in teaching. In Gardner, A. & Cochran, K. (Eds.), *Critical issues in reforming elementary teacher preparation in mathematics and science conference proceedings* (pp 25-45). Greeley: University of Northern Colorado.

Bowman, C. & Giebelhaus, C. (2002). Teaching mentors: Is it worth the effort? The *Journal of Educational Research, 95(*4), 246 +. Washington, D.C.: Heldref Publications.

Brill, J. M.. (2001). Situated Cognition. In M. Orey (Ed.), *Emerging perspectives on learning, teaching, and technology*. Retrieved July 31, 2007, from http://projects.coe.uga.edu/epltt/.

Brooks, V. (1996, February). Mentoring: The interpersonal dimension. *Teacher Development*, 5-10.

Brown, C. (1992). Classroom teachers as teacher educators: towards building collaborative linkages. *Action in Teacher Education, 14*(2), 30-37.

Brown, C., Vaughn, C. & Smith, J. (2004). Constructions of teaching: Alternative certification and the education profession. *Action in Teacher Education, 26*(1), 85-97.

Brown, J., Collins, A. & Duguid, P. (1989). Situated cognition and the culture of learning. *Educational Researcher*, *18* (1), 32-42.

Bruning, R., Schraw, G., Norby, M. & Ronning, R. (2004). Problem solving and critical thinking. In *Cognitive psychology and instruction* (4th ed., pp 162-170). Upper Saddle River, NJ: Pearson.

Bryan, L. (2003). Nestedness of beliefs: Examining a prospective elementary teacher's belief system about science teaching and learning. *Journal of Research in Science Teaching, 40*(9), 835-868.

Bryan, L., Abell, S., & Anderson, M. (1996). Coaching reflective practice among preservice elementary science teachers. In P. Rubba & J. Rye (Eds.), *Proceedings of the 1996 Annual International Conference of the Association for the Education of Teachers in Science* (pp. 397-411). Pensacola, FL: Annual International Conference of the Association for the Education of Teachers in Science. (ERIC Reproduction Service No. ED 398 060).

Bybee, R. W. (1993). The reform of elementary school science: The critical issues. In Gardner, A. & Cochran, K. (Eds.), *Critical issues in reforming elementary teacher preparation in mathematics and science conference proceedings* (pp. 13-23). Greeley: University of Northern Colorado.

Carlsen, W. (1999). Domains of teacher knowledge. In J. Gess-Newsome & N. Lederman (Eds.), *Examining pedagogical content knowledge: PCK and science education* (pp. 3-17). Netherlands: Kluwer Academic Publisher.

Carter, K. (1990) Teachers' knowledge and learning to teach. In W. R. Houston (Ed.), *Handbook of research on teacher education* (pp. 314-338). New York: MacMillan.

Carter, K. & Richardson, V. (1989). A curriculum for an initial-year-of-teaching program. *Elementary School Journal, 89*(4), 405-419.

Cavanagh, S. (2004). NCLB could alter science teaching. *Education Week.* Retrieved June 30, 2006, from http://www.edweek.org/ew/articles/2004/11/10/11science.h24.html?r&levelId+1000&levelId=1000.

Center on Education Policy. (February, 2008). Instructional time in elementary schools: A closer look at changes for specific subjects. *A report in the series, From the*

Capital to the Classroom: Year 5 of No Child Left Behind Act. Washington, DC: Author

Clermont, C.P., Borko, H., & Krajcik, J. (1994). Comparative study of the pedagogical content knowledge of experienced and novice chemical demonstrators. *Journal of Research in Science Teaching, 31*, 419 - 441.

Clewell, B., & Forcier, L. (2001). Increasing the number of mathematics and science teachers: A review of teacher recruitment programs. *Teaching and Change, 8*(4), 331-361.

Cochran-Smith, M. (1991). Learning to teach against the grain. *Harvard Educational Review, 61*(3), 270-310.

Cochran-Smith, M. (2005a). Taking stock in 2005: Getting beyond the horse race. *Journal of Teacher Education, 56* (1), 3-6.

Cochran-Smith, M. (2005b). The new teacher education: For better or for worse? *Educational Researcher, 34*(7), 3-17.

Cochran-Smith, M., & Lytle, S. (1993). *Inside outside: Teacher research and knowledge.* New York: Teachers College Press.

Cochran-Smith, M. & Lytle, S. (1999). Relationships of knowledge and practice: Teacher learning in communities. *Review of Research in Education, 24*, 249-305.

Crawley, N. (1991). A summary of research in science education-1989. *Science Education* 75(3): 1-35.

Creswell, J. (1998). *Qualitative inquiry and research design: Choosing among five traditions*. Thousand Oaks, CA: Sage Publications.

Creswell, J. (2003). *Research design: Qualitative, quantitative, and mixed methods approaches* (2nd ed.). Thousand Oaks, CA: Sage Publications.

Czerniak, C. & Lumpe, A. (1993). Relationship between teacher beliefs and science education reform. Journal of Science Teacher Education, 7 (4), 247-266.

Daloz, L.A. (1986). Strategies for guiding adults through difficult transitions. In L.A. Daloz, (Ed), *Effective teaching and mentoring: Realizing the transformational power of adult learning experiences* (pp. 209-235). San Francisco: Jossey-Bass

Daloz, L. (1986). *Effective teaching and mentoring*. San Francisco: Jossey, Bass.

Darling-Hammond, L. (1990). Teaching and knowing: Policy issues posed by alternate certification for teachers. *Peabody Journal of Education , 67* (3), 123-154.

Darling-Hammond, L. (1995). Changing the conceptions of teaching and teacher development. *Teacher Education Quarterly, 22*(4), 9-26.

Darling-Hammond, L. (2000a). *Educating the New Educator: Teacher Education and the Future of Democracy.* Taylor & Francis.

Darling-Hammond, L. (2000b). How teacher education matters. *Journal of Teacher Education, 51*(3), 166-173.

Darling-Hammond, L., & Bransford, J. (Eds.) (2005). *Preparing teachers for a changing world: What teachers should learn and be able to do*. San Francisco: Jossey-Bass.

Darling-Hammond, L., & Cobb, V.L. (1996). The changing context of teacher education. In F. B. Murray (Ed.), *The teacher educator's handbook: Building a knowledge base for the preparation of teachers* (pp.14-60). San Francisco: Jossey-Bass.

Darling-Hammond, L., Holtzman, D. J., Gatlin, S. J., & Heilig, J. V. (2005). Does teacher preparation matter? Evidence about teacher certification, Teach for America, and teacher effectiveness. *Education Policy Analysis Archives, 13*(42). Retrieved June 1, 2008 from http://epaa.asu.edu/epaa/v13n42/.

Darling-Hammond, L. & Youngs, P. (2002). Defining "highly qualified teachers": What does "scientifically-based research" actually tell us? *Educational Researcher, 31*(9), 13-25.

Decker, P., Mayer, D. & Glazerman, S. (2004). *The effects of Teach for America on students: Findings from a national evaluation.* (MPR reference No. 8792-750). Princeton, NJ: Mathematica Policy Research Inc.

Dewey, J. (1938). *Experience and education.* New York, NY: Simon & Schuster.

Eady, S. (2008). What is the purpose of learning science? An analysis of policy and practice in the primary school. *British Journal of Educational Studies, 56* (1), 4-19.

Elliot, B. (1995). Developing relationships: Significant episodes in professional development. *Teachers and Teaching: Theory and Practice, 1*(2), 247-264.

Elliot, B. & Calderhead, J. (1995). Mentoring for teacher development: Possibilities and caveats. In Kerry, T. & Mayes, A. (Eds.) *Issues in Mentoring* (pp. 35- 55). New York: Routledge.

Feiman-Nemser, S. (1990). Teacher Preparation: Structural and conceptual alternatives. In W. R. Houston (Ed.), *Handbook of Research on Teacher Education* (pp. 314-338). New York: MacMillan.

Feiman-Nemser, S. (2001a). From preparation to practice: Designing a continuum to strengthen and sustain teaching. *Teachers College Record, 103*(6), 1013-1055.

Feiman-Nemser, S. (2001). Helping novices learn to teach: Lessons from an experienced support teacher. *Journal of Teacher Education*, 52(1), 17-30.

Feiman-Nemser, S. & Parker, M. (1992). Making subject matter part of the conversation for helping beginning teachers learn to teach (Research Report No. 90-3). East Lansing: National Center for Research on Teacher Learning.

Feiman-Nemser, S. & Beasley, K. (1993). Discovering and sharing knowledge: Inventing a new role for cooperating teachers. Paper presented at the Workshop on Teachers' Cognition, Tel Aviv University, Israel.

Feiman-Nemser, S. & Buchman, M. (1985). Pitfalls of experience in teacher preparation. *Teachers College Record, 87*(1), 53-65.

Feiman-Nemser, S. & Remillard, J. (1996). Perspectives on learning to teach. In. Murray, F. (Ed.), *The teacher education handbook: Building a knowledge base for the preparation of teachers* (pp. 63-91). San Francisco: Jossey-Bass.

Fenstermacher, G. (1994). The knower and the known: The nature of knowledge in research on teaching. In L. Darling-Hammond (Ed.), *Review of Research in Education*, *20*, 3-56. Washington, D.C.: American Educational Research Association.

Full Option Science System. (n.d.) *Recent projects*. Retrieved July 15, 2008, from http://www.lawrencehallofscience.org/foss/index.html.

Gallagher, J. (1991). Prospective and practicing secondary school science teachers' knowledge and beliefs about the philosophy of science. *Science Education, 67*(1),121-133.

Gess-Newsome, J. (1999). Pedagogical content knowledge: and introduction and orientation. In J. Gess-Newsome & N. Lederman (Eds.), *Examining pedagogical content knowledge: PCK and science education* (pp. 3-17). Netherlands: Kluwer Academic Publisher.

Gess-Newsome, J. (2002). The use and impact of explicit instruction about the nature of science and science inquiry in an elementary science methods course. *Science & Education 11,* 55–67.

Glesne, C. (1999) *Becoming qualitative researchers: An introduction*. New York: Longman.

Goodman, J. (1988) University culture and the problem of reforming field experiences in teacher education. *Journal of Teacher Education, 39*(4), 45-53.

Grimmett, P & MacKinnon, A. (1992). Craft knowledge and the education of teachers. *Review of Research in Education, 18,* 385-486.

Grossman, P. (1989) A study in contrast: Sources of pedagogical content knowledge for secondary English. Ph.D. dissertation, Stanford University, United States -- California. Dissertation Abstracts International, 49(10), 2999. (Publication number AAT 8826145).

Grossman, P. (1990). *The making of a teacher: Teacher knowledge and teacher education*. New York: Teachers College Press.

Grossman, P. & Richert, A. (1988). Unacknowledged knowledge growth: A re-examination of the effects of teacher education. *Teaching and Teacher Education, 4*(1), 53-62.

Grossman, P. & Thompson, C. (2004). Curriculum materials: Scaffolds for new teacher learning? A research report. Document R-04-1. University of Washington: Center for the Study of Teaching and Policy.

Haney, J., Czerniak, C., & Lumpe, A. (1996). Teacher beliefs and intentions regarding the implementation of science education reform strands. *Journal of Research In Science Teaching, 33*, (9), 971-993.

Haney, J. J., & Lumpe, A. (1995). A teacher professional development framework guided by science education reform policies, teachers' needs, and research. *Journal of Science Teacher Education*, *6,* 187–196.

Harlen, W. (2001). *Primary science: Taking the plunge* (2nd ed.). Portsmouth, NH: Heinemann.

Hashweh, M. (1987). Effects of subject matter knowledge in the teaching of biology and physics. *Teaching and Teacher Education, 3*(2), 109-120.

Hawkey, K. (1997). Roles, responsibilities, and relationships in mentoring: a literature review and agenda for research. *Journal of Teacher Education, 48*(5), 325+.

Hawkins, D. (1978, Autumn). Critical barriers to science learning. *Outlook, 32,* 3–23.

Hovey, A., Hazelwood, C., & Svedkauskaire, A. (2005). *Critical issue: Science education in the era of No Child Left Behind. History, benchmarks, and standard.* North Central Regional Education Laboratories. Retrieved July 1, 2006, from http://www.ncrel.org/sdrs/areas/issues/content/cntareas/science/sc600.htm#references.

Howes, E. (2002). Learning to teach science for all in the elementary grades: What do preservice teachers bring? *Journal of Research in Science Education, 39*(9), 845-869.

Hudson, P. (2003). Mentoring first-year pre-service teachers of primary science. *Action in Teacher Education, 25*(3), 91-98.

Hudson, P. (2004). Toward identifying pedagogical knowledge for mentoring in primary science teaching. *Journal of Science Education and Technology*, 13 (2), 215-225.

Hudson, P. (2005). Identifying mentoring practices for developing effective primary science teaching. *International Journal of Science Education, 27* (14), 0950-0693.

Hudson, P., & Skamp, K. (2003). Mentoring preservice teachers of primary science. *The Electronic Journal of Science Education*, 7. http://unr.edu/homepage/jcannon/ejse/ejse.html.

Hudson, P., Skamp, K. & Brooks, L. (2005). Development of an instrument: Mentoring for effective primary science teaching. *Science Education, 89*(4), 657-674.

Huling, L. (2001). Teacher mentoring as professional development. Washington DC: ERIC Clearinghouse on Teaching and Teacher Education. Retrieved October 24, 2004, from www.eric.ed.gov.

Huling-Austin, L. (1990) Mentoring is squishy business. In C.M. Bey and C.T. Holmes, (Eds.), *Mentoring: Developing successful new teachers.* Reston, VA: Association of Teacher Educators.

Ingersoll, R. & Kralik, J. (2004). The impact of mentoring on teacher retention: What the research says. Retrieved August 24, 2008 from the University of Pennsylvania, Graduate School of Education Publications Web site: http://repository.upenn.edu/gse_pubs/127

Jarvis, T., McKeon, F, Coates, D. & Vause, J. (2001). Beyond generic mentoring: helping trainee teachers to teach primary science. *Research in Science & Technological Education, 19*(1), 5-23.

Kagan, D. (1992). Professional growth among preservice and beginning teachers. *Review of Educational Research, 62*(2), 129-169.

Karplus, R. (1964). The science curriculum improvement study. *Journal of Research in Science Teaching, 2*(4), 293-303.

Kennedy, M. (1991). *An agenda for research on teacher learning.* (NCRTL Special Report). East Lansing, MI: National Center for Research on Teacher Learning, Michigan State University.

Kennedy, M. (1998). *Learning to teach writing. Does teacher education make a difference?* New York: Teachers College Press.

King, K, Shumow, L., & Lietz, S. (2001). Science education in an urban elementary school: Case studies of teacher beliefs and classroom practices. *Science Education, 85*(2), 89-110.

Klentschy, M. & Molina-DeLaTorre, E. (2004). Students' science notebooks and the inquiry process. In Saul, W. (ed.) *Crossing borders in literacy and science instruction: Perspectives on theory and practice*. Newark, DE: International Reading Association.

Koch, J., & Appleton, K. (2007). The effect of a mentoring model for elementary science professional development. *Journal of Science Teacher Education*, 18 (2), 209-231.

Korthagen, F. (1999). Linking theory and practice: Changing the pedagogy of teacher education. *Educational Researcher, 28(4)*, 4-17.

Lanier, J.E. & Little, J.W. (2001). Research on teacher education. In V. Richardson (Ed.). *Handbook of research on teaching.* American Educational Research Association.

Laczko-Kerr, I., & Berliner, D. (2002). The effectiveness of "Teach for America" and other under-certified teachers on student academic achievement: A case of harmful public policy. *Education Policy Analysis Archives*, *10*(37).

Lederman, N. (1992). Students and teachers conceptions of the nature of science: a review of the research. *Journal of Research in Science Teaching, 29*(4), 331-359.

Lederman, N. (1998). The state of science education: Subject matter without context. *The Electronic Journal of Science Education*, downloaded July 8, 2008 at http://ejse.southwestern.edu/original%20site/manuscripts/v3n2/articles/guest%20editorial/lederman.html.

Lederman, N. & Zeidler, D. (1987). Science teachers' conceptions of the nature of science: Do they really influence teaching behavior? *Science Education 71*(5), 721-734.

Lee, E., Brown, M., Luft, J., & Roehrig, G. (2007). Assessing beginning secondary science teachers' PCK: Pilot year results. *School Science and Mathematics*, *107*(2), 52-60.

Lee, O., Deaktor, R., Hart, J. Cuevas, P. & Enders, C. (2005). An instructional intervention impact on science and literacy achievement of culturally and linguistically diverse elementary students. *Journal of Research in Science Teaching, 42*(8), 857-887.

Lee, O., & Luykx, A. (2006). *Science education and student diversity.* New York: Cambridge University Press.

Little, J. (1990). The mentor phenomenon and the social organization of teaching. *Review of Educational Research, 16*, 297-351.

Lortie, D. C. (1975). *Schoolteacher: A sociological study.* Chicago, IL: University of Chicago Press.

Loughran, J. (2006). *Developing a pedagogy of teacher education: Understanding teaching and learning about teaching.* New York: Routledge.

Loughran, J., Mulhall, P., Berry, A. (2004). In search of pedagogical content knowledge in science: Developing ways of articulating and documenting professional practice. Journal of *Research in Science Teaching, 41*(4), 370-391.

Luft, J. (2007). Minding the gap: Needed research on beginning/newly qualified science teachers. *Journal of Research in Science Teaching, 44* (4), 532-537.

Luft, J. & Patterson, N. (1999). Final report: Project: Alternative support for induction science teachers (ASIST). Phoenix, AZ: Arizona Board of Regents: Eisenhower Mathematics and Science Program.

Luft, J. & Patterson, N. (2002). Bridging the gap: Supporting beginning science teachers. *Journal of Science Teacher Education, 13*, 287–313.

Lumpe, A., Haney, J., & Czerniak, C. (2000). Assessing teachers' beliefs about their science teaching context. *Journal of Research in Science Teaching, 37*(3), 275-292.

Magnusson, S., Krajcik, J., & Borko, H. (1999). Nature, sources, and development of pedagogical content knowledge for science teaching. . In J. Gess-Newsome & N. Lederman (Eds.), *Examining pedagogical content knowledge: PCK and science education* (pp. 3-17). Netherlands: Kluwer Academic Publisher.

Martin, D., Jean-Sigur, R., & Schmidt, E. (2005). Process-oriented inquiry – A constructivist approach to early childhood science education: Teaching teachers to do science. *Journal of Elementary Science Education, 17*(2), 13-25.

Marx, R. & Harris, C. (2006). No child left behind and science education: Opportunities, challenges, and risks. *Elementary School Journal, 106*(5), 467-477.

McDevitt, T. M., Heikkinen, H. W., Alcorn, J. K., Ambrosio, A. L., & Gardner, A. L. (1993). Evaluation of the preparation of teachers in science and mathematics: Assessment of preservice teachers' attitudes and beliefs. *Science Education, 77,* 593–610.

McDiarmid, G.W., Ball, D.L., & Anderson, C.R. (1989). Why staying one chapter ahead doesn't really work: Subject-specific pedagogy. In Reynolds, M.C. (ed.), *Knowledge base for the beginning teacher.* Elmsford, N.Y.: Pergamon Press.

McGinnis, Kramer, Shama, Graeber, Parker & Watanabe. (2002). Undergraduates' attitudes and beliefs about subject mater and pedagogy measured periodically in a reform-based mathematiccs and science teacher preparatin program. *Journal of Resesarch in Science Teaching , 39* (8), 703-737.

McIntyre, D., Hagger, H., & Burn, K. (1994). *The management of student teachers' learning.* London: Kogan Page.

McKibbin, M. (2002). One size does not fit all: Reflections on alternative routes to teacher preparation in California. *Teacher Education Quarterly, 28*(1) 133-149.

Merriam, S. B. (1998). *Qualitative Research and Case Study Applications in Education.*

San Francisco: Jossey-Bass Publishers.

Morine-Dershimer, T. & Kent, T. (1999). The complex nature and scources of teachers' pedagogical knowledge. In J. &. Gess-Newsome, *Examining Pedagogical Content Knowledge* (pp. 21-50). Boston: Kluwer Acadmic Publishers.

Murray, F. (1996). Beyond natural teaching: The case for professional education. In F. Murray (ed.) *The teacher educator's handbook.* San Francisco: Jossey-Bass.

National Board for Professional Teaching Standards. (1991). What teachers should know and be able to do. Retrieved August 4, 2007 from http://www.nbpts.org/nbpts/standards/intro.html.

National Center for Education Research. *Mathematics and science education research.* Washington, DC:U.S. Department of Education. Retrieved August 13, 2007 from heep://iesed.gov/ncer/funding/math_science/index.asp

National Center for Research on Teacher Learning. (NCRTE, 1991). *Findings from the Teacher Education and Learning To Teach Study: Final Report, The National Center For Research on Teacher Education.* East Lansing: Michigan: National Center for Research on Teacher Education.

National Commission on Mathematics and Science Teaching. (2000) Before it's too late:

A report to the nation from the National Commission on Mathematics and Science Teaching for the 21st Century. Washington, DC: Author. Retrieved August 4, 2007 from http://www.ed.gov/inits/Math/glenn/report.pdf

National Research Council (NRC). (1996). *National science education standards.* Washington, DC: National Academy Press.

National Research Council. (NRC). (2000). *Inquiry and the national science standards.* Washington, DC: National Academy Press.

National Science Resources Center (NSRC), National Academy of Sciences & Smithsonian Institution. (1997). *Science for all children: A guide to improving* *elementary science education in your school district.* Washington, D.C.: National Academy Press.

National Science Teachers Association (NSTA). (1992). Standards for Science Teacher Preparation. Washington, DC: National Science Teachers Association.

Nevada State Department of Education. (n.d.) *Nevada state standards.* Retrieved July 17, 2007 from the Nevada State Department of Education web site at http://www.doe.nv.gov/Standards_Science.html.

Odell, S. (1986). Induction support of new teachers: A functional approach. *Journal of Teacher Education, 37*(1), 26-29.

Odell, S. (1990). Mentor teacher programs. Washington, D.C.: National Education Association.

Odell, S. & Ferraro, D. (1992). Teacher mentoring and teacher retention. *Journal of Teacher Education, 43*(3), 200-204.

Odell, S.J. & Huling, L (Eds.) (2000) *Quality Mentoring for Novice Teachers.* Indianapolis, Indiana: Kappa Delta Pi.

Osborne, R., & Freyburg, P. (1985). *Learning in science: The implications of children's science.* Birkenhead, Auckland, New Zealand: Heinemann.

Pajares, M. (1992). Teachers' beliefs and educational research: Cleaning up a messy construct. *Review of Educational Research , 62*, 307-332.

Penick, J. (1994). Some thoughts on science teacher education. *Teaching and Teacher Education, Teaching and Teacher Education, 10* (6), 659-662.,

Piaget, J. (1929). *The child's conception of the world.* New York: Harcourt, Brace, and Company.

Posner, G. J., Strike, K. A., Hewson, P. W., & Gertzog, W. A. (1982). Accommodation of a scientific conception: Toward a theory of conceptual change. *Science Education, 66*, 211-227.

Putnam, R. & Borko, H. (2000). What do new views of knowledge and thinking have to say about research on teacher learning? *Educational researcher 29*(1), 4-15.

Raymond, M., Fletcher, S. H., & Luque, J. (2001). *Teach for America: An evaluation of teacher differences and student outcomes in Houston, Texas.* Washington, DC: Thomas B. Fordham Foundation.

Richardson, V. (1996). From behaviorism to constructivism in teacher education. *Teacher Education and Special Education, 19*(3), 263-271.

Richardson, V. (1996a). The role of attitudes and beliefs in learning to teach. In Sikula, J., Buttery, T. & Guyton, E. (eds.), *Research in teacher education*, 103-119. New York: Macmillan

Richardson, V. (2003). Constructivist pedagogy. *Teachers' College Record, 105*(9), 1623-1640.

Roehrig, G., & Luft, J. (2006). Does one size fit all? The induction experience of beginning science teachers from different teacher preparation programs. *Journal of Research in Science Teaching, 43*(9), 963-985.

Rogoff, B. (1990). *Apprenticeship in thinking: Cognitive development in social context.* New York: Oxford University Press.

Rosebery, A. & Puttick, G. (1998). Teacher professional development as situated sense-making: A case study in science education. *Science Education, 82*(6), 649-677.

Roth, K. (1991). Learning to be comfortable in the "neighborhood of science": An analysis of three approaches to elementary science teaching. In W. Saul & S. Jagusch (Eds.), *Vital connections: Children, science, and books: Papers from a symposium sponsored by the Children's Literature Center* (pp. 143-161). Washington, DC: Library of Congress.

Russell, T. (1987). Research, practical knowledge, and the conduct of teacher education. *Educational Theory, 37*, 369-375.

Saka, Y. (2007). *What happens to our reform minded beginning science teachers?* Unpublished doctoral dissertation, Florida State University, Tallahassee.

Salomon, G. (1996). Unorthodox thoughts on the nature and mission of contemporary educational psychology. *Educational Psychology Review, 8*(4), 397-417.

Sanders, L., Borko, H., & Lockard, J. (1993). Secondary science teachers' knowledge base when teaching science courses in and out of their area of certification. *Journal of Research in Science Teaching, 3*(7), 723-736.

Schoeneberger, M., & Russell, T. (1986). Elementary science as a little added frill: A report of two case studies. *Science Education, 70*, 519-538.

Schön, D. (1983). *The reflective practitioner*. United States: Basic Books.

Schön, D. (2002). From technical rationality to reflection in action. In Harrison, R., Reeve, F., Hanson, A. & Clarke, J. (Eds.), *Supporting Lifelong Learning* (pp. 40-61). New York: Routledge-Falmer.

Schoon, K. & Boone, W. (1998). Self-efficacy and alternative conceptions of science of preservice elementary teachers. Science Education, 82(5), 553-568.

Schwarz, C., Gunckel, K., Smith, E., Covitt, B., Bae, M., Enfield & M., Tsuraski,B. (2008). Helping elementary preservice teachers learn to use curriculum materials for effective science teaching. *Science Education, 92*(2), 345-377.

Settlage, J. (2000). Understanding the learning cycle: Influences on abilities to embrace the approach by preservice elementary school teachers. *Science Education, 84* (1), 43-50.

Shulman, J. (1989). Blue freeways: Traveling the alternate route with big-city teacher trainees. *Journal of Teacher Education, 40*(2), 2-8.

Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher, 15*(2), 4-14.

Shulman, L. (1987). Knowledge and teaching; Foundations of the new reform. *Harvard Educational Review, 57*(1), 1-22.

Smith, D.C. (1999). Changing our teaching: The role of pedagogical content knowledge in elementary science. In J. Gess-Newsome & N. Lederman (Eds.), *Examining pedagogical content knowledge: PCK and science education* (pp. 3-17). Netherlands: Kluwer Academic Publisher.

Smith, D. C., & Neale, D.C. (1989). The construction of subject matter knowledge in primary science teaching. *Teaching and Teacher Education, 5*(1), 1-20.

Smith, L. & Gess-Newsome, J. (2004). Elementary science methods courses and the National Science Education Standards: Are we adequately preparing teachers? *Journal of Science Teacher Education, 15*(2): 91-110.

Smith, L. & Southerland, S. (2007). Reforming practice or modifying reforms?: Elementary teachers' response to the tools of reform. *Journal of Research in Science Teaching, 44*(3), 396-423.

Smylie, M. (1994). Redesigning teachers' work: Connections to the classroom. *Review of Research in Education, 20*, 129-177

Southeast Center for Teaching Quality. (2004). *Teach for America study reports some gains, but obscures failed teaching policies in urban schools*. Retrieved June 30, 2008, from http://www.teachingquality.org/resources/html/TFA_Report.htm

Southerland, S., Smith, L., Sowell, S. & Kittleson, J. (2007). Chapter 2: Resisting unlearning: Understanding science education's response to the United State's national accountability movement. *Review of Research in Education 31*, (1), 45-77.

Stake, R. (1995). *The art of case study research.* Thousand Oaks, CA: Sage Publications.

Strangis, D., Pringle, R. & Knopf, H. (2006). Road map or roadblock? Science lesson planning and preservice teachers. *Action in Teacher Education, 28*(1), 73-84.

Stanulis,R. (1994). Fading to a whisper: One mentor's story of sharing her wisdom without telling answers. *Journal of Teacher Education, 45*(1), 31-38.

Strike, K. and Posner, G. (1982) Conceptual change and science teaching. *International Journal of Science Education, 4* (3), 231 -240.

Strike, K. A., & Posner, G. J. (1992). A revisionist theory of conceptual change. In R. A. Duschl & R. J. Hamilton (Eds.), *Philosophy of science, cognitive psychology, and educational theory and practice* (pp. 147-176). New York: State University of New York Press.

Strong, M. (2005). *Mentoring new teachers to increase retention: A look at the research.* Santa Cruz, CA: University of California, Santa Cruz, New Teacher Center.

Strong, M. & Baron, W. (2004). An analysis of mentoring conversations with beginning teachers: suggestions and responses. *Teaching and Teacher Education, 20*(1), 47-57.

Tabachnick, B.R., Zeichner, K., Densmore, K., Adler, S. & Egan, K. (March, 1982). The impact of the student teaching experience on the development of teacher perspectives. Paper presented at the annual meeting of the American Educational Research Association, New York City.

Tatto, M.T. (1998). The influence of teacher education on teachers' beliefs about purposes of education, roles, and practice. *Journal of Teacher Education*, 49 (1), 66-77.

Taylor, S. J., & Bogdan, R. (1984). *Introduction to qualitative research methods: The search for meanings.* New York: John Wiley and Sons.

Teach for America (n.d., a) *Training.* Retrieved June 23, 2008 from http://www.teachforamerica.org/corps/training.htm.

Teach for America (n.d., b) *Ongoing professional development.* Retrieved June 23, 2008 from http://www.teachforamerica.org/corps/ongoing_professional_development/professional_development.htm.

Teach for America, (2007a). *Classroom management & culture.* Teach for America: Author.

Teach for America, (2007b). *Diversity, community, & achievement.* Teach for America: Author.

Teach for America, (2007c). *Elementary literacy.* Teach for America: Author.

Teach for America, (2007d). *Instructional planning & delivery.* Teach for America: Author.

Teach for America, (2007e). *Learning theory.* Teach for America: Author.

Teach for America, (2007f). *Teaching as leadership.* Teach for America: Author.

Thorndike, E. (1913). *An introduction to the theory of mental and social measurements.* New York: Teachers College Press.

Tobin, K. (Ed.) (1993). *The practice of constructivism in science education.* Washington, DC: AAAS Press.

Tobin, K., Briscoe, C., & Holman, J. R. (1990). Overcoming constraints to effective elementary science teaching. *Science Education, 74*,409-420.

United States Department of Education (n.d.) Guide to U.S. department of education programs. Retrieved August 14, 2007, form http://www.ed.gov/programs/mathsci/index.html.

van Driel, J., Beijaard, D., & Verloop, N. (2001). Professional development and reform in science education: The role of teachers' practical knowledge. *Journal of Research in Science Education, 38*(2), 137-158.

van Driel, J., Verloop, N., & deVos, W. (1988). Developing science teachers' pedagogical content knowledge. *Journal of Research in Science Teaching, 35*(6), 673-695.

Vygotsky, L. (1987) *The collected works of L.S. Vygotsky.* New York: Plenum Press.

Vygotsky, L. (1991). *Thought and language.* Cambridge: MIT Press.

Wallace, J. & Louden, W. (2002). *Dilemmas of science teaching: Perspectives on problems of practice.* New York: Routledge/Falmer.

Wang, J. (2001).Contexts of mentoring and opportunities for learning to teach: a comparative study of mentoring practice. *Teaching and Teacher Education 17*, 51-73.

Wang, J. (2002) Learning to teach with mentors in contrived contexts of curriculum and teaching organization: experiences of two Chinese novice teachers and their mentors. *Journal of In-Service Education, 28* (2), 339-374.

Wang, J. & Odell, S. (2002). Mentored learning to teach according to standards-based reform: A critical review. *Reveiw of Educational Research , 72* (3), 481-546.

Wang, J. & Odell, S. (2007). An alternative conception of mentor–novice relationships: Learning to teach in reform-minded ways as a context. *Teaching and Teacher Education, 43*, (4), 473-489.

Wang, J. & Paine, L. (2001) Mentoring as assisted performance: a pair of Chinese teachers working together, *Elementary School Journal, 102(2)*, 157-182.

Wang, J., Strong, M. & Odell, S. (2004). Mentor-novice conversations about teaching: A comparison of two U.S. and two Chinese cases. *Teachers College Record* 106 (4), 775-813.

Watts, M., & Jofili, Z. (1998). Towards critical constructivist teaching. *International Journal of Science Education 20*(2), 173-185.

Wenner, G. (1993). Relationship between science knowledge levels and beliefs toward science instruction held by preservice elementary teachers. *Journal of Science Education and Technology, 2* (3), 461-468.

Wenner, G. (1995). Science knowledge and efficacy beliefs among preservice elementary teachers: A follow-up study. *Journal of Science Education and Technology, 4* (4), 307-315.

Wideen, M., Mayer-Smith, J. & Moon, B. (1998). A critical analysis of the research on learning to teach: Making the case for an ecological perspective on inquiry. *Review of Educational Research, 68*(2), 130-178.

Wildman, T., Magliero, S., Niles, R. & Niles, J. (1992). Teacher mentoring: An analysis of roles, activities and conditions. *Journal of Teacher Education , 43*, 205-213.

Wilson, S., Floden, R. & Ferrini-Mundy, J. (2001).*Teacher preparation research: Current knowledge, gaps, and recommendations.* Seattle: University of Washington, Center for the Study of Teaching and Policy.

Windschitl, M. (1999). The challenges of sustaining a constructivist classroom culture.

Phi Delta Kappan, 80 (10), 751-756.

Yin, R. (2003) *Case study research: Design and methods* (3rd edition). Thousand Oaks, CA: Sage Publications.

Zeichner, K. & Conklin, H. (2005). Teacher education programs. In Cochran-Smith, M. & Zeichner, K. (Eds.), *Studying teacher education* (pp 645-736). Mahwah, NJ: Erlbaum.

Zeichner, K. & Gore, J. (1990). Teacher socialization. In W. R. Houston, M. Haberman, & J. Sikula (Eds.), *Handbook of research on teacher education.* New York: Macmillan.

Zeichner, K. & Shulte. (2001). What we know and don't know from peer-reviewed research about alternative teacher certification programs. *Journal of Teacher Education*, *52* (4), 266-282.

Zembal-Saul, C., Blumenfeld, P. & Krajcik, J. (2000). Influence of guided cycles of planning, teaching, and reflection on prospective elementary teachers' science content representations. *Journal of Research in Science Teaching, 37* (4), 318-339.

Zembal-Saul, C., Starr, M., & Krajcik, J. (1999). Constructing a framework for elementary science teaching using pedagogical content knowledge. In J. Gess-Newsome & N. Lederman (Eds.), *Examining pedagogical content knowledge: PCK and science education* (pp. 3-17). Netherlands: Kluwer Academic Publisher.

Zey, M. (1984). *The mentor connection.* Homewood, IL: Dow Jones-Irwin.

VITA

Graduate College
University of Nevada, Las Vegas

Mary Sowder

Local Address:
2720 Strathmoor Dr.
Henderson, NV 89074

Home Address:
740 N 600 W
Orem, UT 84057

Degrees:
Bachelor of Arts, Music, 1974
Chapman University, Orange, California

Master of Science, Computer Education, 1989
NOVA Southeastern University, Ft. Lauderdale, FL

Publications:

Sowder, M. (2005). Mentoring for understanding challenges in mathematics instruction. *New England Mathematics Journal. 37*(2), pp. 57-73.

Sowder, M. (in press). Site-based teacher educators. In Klecka, C., Odell, S. J., Houston, R. & McBee, R. (Eds.), *Standards for teacher educators: establishing a vision for the profession.* Alexandria: Association of Teacher Educators.

Dissertation Title: Mentoring Novice Elementary Teachers in Teaching Science

Dissertation Examination Committee:
Co-Chairperson, Dr. Sandra J. Odell, Ph. D.
Co-Chairperson, Dr. Jian Wang, Ph.D.
Committee Member: Dr. Emily Lin, Ph. D.
Graduate Faculty Representative, Dr. Leann Putney, Ph.D.