LONG-TERM IMPACT OF UNDERGRADUATE SCIENCE REFORM COURSES ON THE PEDAGOGICAL CONTENT KNOWLEDGE OF KINDERGARTEN THROUGH SIXTH GRADE INSERVICE TEACHERS

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ABSTRACT

This study explores the long-term impact of faculty-created reformed undergraduate science courses on the pedagogical content knowledge of kindergarten-6th grade inservice elementary teachers who took these reform courses during their undergraduate programs. On-site case studies were completed with 35 faculty instructors teaching entry-level undergraduate science courses at 20 higher education institutions, and 91 elementary inservice teachers. The sample was selected from a national population of diverse colleges and universities that had undergone reform in one or more of their undergraduate science courses. The data collection protocol involved classroom observations, interviews, artifact analysis, semi-structured interviews, and field notes from multiple instruments and sources. Data were collected during on-site visits from instructors and their graduated students. Quantitative and qualitative analysis identified variations in faculty instructors', as well as inservice teachers', perceptions and observations of the intended and enacted teaching goals, instruction, student difficulties, and rationale for teaching a specific science concept in observed science lessons. These perceptions and observations, identified as science pedagogical content knowledge (PCK), varied significantly among both faculty instructors and inservice elementary teachers who experienced the undergraduate reformed science courses taught by these same faculty instructors.

DEDICATION

This dissertation is dedicated to my daughter, Genesis Gabrielle, who sacrificed time spent with her Mommy so that I could complete school. Thank you for your patience and love as I completed this leg of the journey. I love you forever, Mommy!

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CHAPTER I

INTRODUCTION

Science teaching and learning have been actively researched for decades. Many reports, *National Science Education Standards* (NSES), *Benchmarks for Science Literacy*, and *Shaping the Future*, have outlined the need for research-based pedagogy, curriculum and goals, benchmarks, standards, and assessment criteria to improve science teaching and learning and to encourage a scientific literate society (National Research Council [NRC], 1996, 2000; American Association for the Advancement of Science [AAAS], 1990; National Science Foundation, 1996). The National Science Education Standards suggest that (1) what students learn is greatly influenced by how they are taught, (2) the actions of teachers are deeply influenced by their perceptions of science as an enterprise and as a subject to be taught and learned, (3) student understanding is actively constructed through individual and social processes, and (4) actions of teachers are deeply influenced by their understanding of and relationships with students (NRC, 1996, p. 28). Thus, teachers need knowledge and understanding of science content and pedagogy that will best engender student understanding of science content and assist them in the attainment scientific literacy. The *National Science Education Standards* define scientific literacy as

> the ability to ask, find, or determine answers to questions derived from curiosity about everyday experiences. It means that a person has the ability to describe, explain, and predict natural; phenomena. Scientific literacy entails being able to read with understanding articles about science in the popular press and to engage in social conversation about the validity of the conclusions. Scientific literacy implies that a person can identify scientific issues underlying national and local decisions and express positions that are scientifically and technologically informed. A literate citizen should be able to evaluate the quality of scientific information on the basis of its source and the methods used to generate. Science literacy also implies the capacity to pose and evaluate

> arguments based on evidence and to apply conclusions from such arguments appropriately. (NSES, 1996, p. 22)

National Science Teachers Association (NSTA) standards for science teacher reparation are consistent with the vision of the NSES. According to these standards, "The NSES is a visionary framework for science teaching in precollege education, based upon the assumption that scientific literacy for citizenship should be a primary--if not exclusive--goal of science education at the precollege level" (NSTA, 2003, p. 1). Teachers of science at all grade levels must demonstrate competencies consistent with the achievement of this vision. They should not only demonstrate that they have the necessary knowledge and planning skills to achieve these goals, but also that they are successful in engaging their students in studies of such topics as the relationship of science and technology, nature of science, inquiry in science, and science-related issues (NSTA, 2003). The NSTA standards are intended to serve as the foundation for a performance assessment system through which preservice teachers must satisfactorily demonstrate their knowledge and abilities at stable assessment points in the science teacher preparation program (NSTA, 2003). The standards address the knowledge, skills, and dispositions deemed important by the NSTA for teachers in the field of science and are aligned with the *National Science Education Standards* and consistent with the standards of the *National Board for Professional Teaching Standards* (NBPTS).

Both the *National Science Education Standards* and the *National Science Teachers Association Standards for Science Teacher Preparation* point to the notion that teachers must have content knowledge and pedagogical knowledge for effective science teaching to occur. Under Professional Development Standard B, the NSES posits that effective science teaching requires more than knowledge of science content and possessing a plethora of teaching strategies; rather it is the ability of the teacher to integrate their knowledge of science content, curriculum, learning, teaching, and students to facilitate and deepen student understanding of science content. Such knowledge allows teachers to tailor learning situations to the needs of individuals and groups. This special knowledge, called “pedagogical content knowledge,” distinguishes the science knowledge of teachers from that of scientists.

Standards one and five of the National Science Teachers Association address content and pedagogy. These standards indicate the importance of preservice teachers’ acquisition of the knowledge and skills enabling them to understand and articulate the knowledge and practices of contemporary science as well as interrelate and interpret important concepts, ideas, and applications in their fields of licensure. Preservice teachers should be able to create a community of diverse learners who construct meaning from their science experiences and possess a disposition for further exploration and learning.

The reform efforts of the *National Science Education Standards* and the *National Science Teachers Association* standards for the preparation of science teachers emphasize the importance of inservice teachers gaining the science content knowledge and pedagogical knowledge needed for effective science teaching and learning. However, elementary teachers are not only expected to have expertise in science but they are also expected to have expertise in all of the subjects that they teach (Schwarz & Gess-Newsome, 2008). The 2000 National Survey of Science and Mathematics Education was designed to provide up-to-date information and to identify trends in the areas of teacher background and experience, curriculum and instruction, and the availability and use of instructional resources (Weiss, Banilower, McMahon, & Smith, 2001). A total of 5,728 science and mathematics teachers in schools across the United States participated in this survey, a response rate of 74%.

The survey revealed that 40% of Kindergarten-5th grade elementary teachers have had four or fewer semesters of college level science. In addition, the survey showed that elementary teachers tend to be better prepared in life science than in other science disciplines, with 92% having completed at least one life science course and 83% having completed at least one semester of study in earth/space science (Weiss et al., 2001). In contrast, only 62% of Grades K-5 teachers of science have had coursework in physics/physical science, and 53% have had coursework in chemistry (Weiss et al.). Kindergarten-5th grade elementary teachers' perceptions of their own preparedness reflected their minimal science background, with more than two-thirds of the sample reporting that they did not feel well-prepared to teach science, whereas 77% reported feeling well-prepared to teach language arts and reading.

Regarding pedagogical preparedness, greater than 60% of elementary teachers indicated in the survey that they felt comfortable in implementing practices aligned with the standards but stated that they needed professional development in the following areas: (1) deepening science content knowledge, (2) learning how to use inquiry/investigative teaching strategies, (3) understanding student thinking in science, and (4) learning how to assess student thinking. However, elementary school science teachers also report low levels of participation in professional development specific to science teaching (Weiss et al., 2001).

In the era of the *No Child Left Behind Act* of 2001, greater emphasis has been placed on reading and language rather than science instruction (Griffith & Scharmann, 2008; Schwarz & Gess-Newsome, 2008; Sandler, 2003). Elementary teachers typically spend 25 minutes per day or less on science instruction while spending 114 minutes on language and math (Weiss et al., 2001). Teachers report that the majority of the science lessons involved whole class lecture/discussions, collaborative groups, or hands-on activities where teachers emphasized:

(1) basic science concepts (68%), (2) increasing student interest in science (57%), learning important terms and facts in science (42%), and scientific process (41%).

There seems to be a disconnect between reform efforts, teacher education programs, and elementary classroom practice. The missing ingredient appears to be the lack of emphasis placed on pedagogical content knowledge (PCK). Pedagogical content knowledge seems to be the mediating factor between content and pedagogical knowledge. PCK is expert knowledge that resides within the teacher. It is the teacher’s ability to transform specific science content through the purposeful use of instructional strategies and knowledge of students learning difficulties to making it understandable to those being taught. It is this type of knowledge, pedagogical content knowledge, that best informs effective science teaching practice.

Pedagogical Content Knowledge

The notion of pedagogical content knowledge (PCK) was advanced by Lee S. Shulman (1986). He described PCK as a teacher’s ability to represent and formulate content to make it comprehensible to others. Thus, teachers may use analogies, models, illustrations, examples, and demonstrations to represent content based on what they know about how their students learn in order to ensure student understanding of science concepts. Shulman (1987) suggested that teachers' content knowledge and their pedagogy were being treated as mutually exclusive domains. Such exclusion produces teacher education programs focused on content or pedagogy, not both.

Pedagogical Content Knowledge, as conceptualized by Pamela Grossman (1990), subsumes three knowledge domains that influence a teacher’s PCK. These knowledge domains include the following: (1) subject matter knowledge and beliefs, (2) pedagogical knowledge and beliefs, and (3) knowledge and beliefs about context. According to Grossman (1990), PCK is a type of knowledge transformed by these three knowledge domains and is more powerful than its constituent parts.

Pedagogical Content Knowledge was defined by Magnusson, Krajcik, and Borko (1999) as consisting of five components: (1) orientations toward science teaching, which include a teacher's knowledge of goals for and general approaches to science teaching; (2) knowledge of science curriculum, including national, state, and district standards and specific science curricula; (3) knowledge of assessment for science, including what to assess and how to assess students; (4) knowledge of science instructional strategies including representations, activities, and methods; and (5) knowledge of students' science understanding, which includes common conceptions and areas of difficulty.

Pedagogical content knowledge is an academic construct, according to Loughran, Mulhall, and Berry (2006), rooted in the belief that teaching requires considerably more than delivering subject content knowledge to students, and that student learning is more than absorbing information for later regurgitation, it is the notion that students construct meaning for themselves. Loughran et al. (2006) suggested that PCK is the knowledge that teachers develop over time, and through experience, about how to teach particular content in particular ways in order to lead to enhanced student understanding. The conception of PCK originally developed by Shulman (1986) has been modified, explicated, refined, revised, and extended by a number of science educators over time (Appleton, 2002; Gess-Newsome & Lederman, 1999; Grossman, 1990; Loughran et al., 2003; Magnusson et al., 1999) but has served as the theoretical framework for the vast amount of research on science teacher knowledge. Pedagogical content knowledge today serves as a framework for science teaching and learning in the *National Science Education*

Standards and the *National Science Teachers Association Standards for Science Teacher Preparation*.

My study investigates the impact of faculty-created reformed undergraduate science courses on the pedagogical content knowledge of inservice teachers who took these courses during their undergraduate programs.

Previous Science Reform Movements

Many reform movements in science education have occurred over the past 50 years. National efforts have been made to improve science teaching and learning by concentrating on curriculum, content standards, and assessment and through providing funds for teacher education programs. The launch of Sputnik in 1957 by the Soviet Union served as the impetus for the enactment of the National Defense Education Act (NDEA) of 1958, which helped provide funds for graduate study toward a college teaching career and a wide array of programs to enhance precollege teacher training and public understanding of science and technology (National Defense Education Act, 1958). By the late 1960s and early 1970s, attention in education had moved from concerns about keeping pace with the Soviets to concern about providing an equitable and humane educational environment for all American youth (DeBoer, 1991).

The National Commission on Excellence in Education (NCEE) was established in 1981 to help define the problems afflicting American education and provide solutions to these problems. The report of the Commission, *A Nation at Risk*, was a call to mobilize the efforts of the federal government along with those of states and local school districts to raise the level of competence of American students in all academic areas, but with a special emphasis on science and math. The Commission on Precollege Education in Mathematics, Science, and Technology of the National Science Board issued its report, *Educating Americans for the 21st Century,* which heralded many of the ideas in *A Nation at Risk* and provided additional detail on how the vision improved science education (Science and Technology National Science Board Commission on Precollege Education in Mathematics, 1983). Both of these reports described how the educational system had experienced a period of neglect resulting in low performance levels in mathematics and science.

Science for All Americans provided the first detailed statement of what all adults must know and be able to do in order to be considered scientifically literate through the establishment of Project 2061. Project 2061 was a long-term reform endeavor to define and promote science literacy. With the publication of its 1989 document, *Nation at Risk* and *Educating Americans for the 21st Century*, the American Association for the Advancement of Science (AAAS) brought together the ideas of earlier reports, through a detailed description of science literacy. In the same year, President George H. W. Bush and various state governors agreed to establish national performance goals and strategies to ensure that the United States remain internationally competitive. To accomplish this aim, the President and his constituents agreed that there should be annual reporting on the progress toward meeting those goals and that in turn states would be given greater autonomy in the use of federal funds to meet the goals. In 1991, in his America 2000 report, President Bush said standards would be developed for core subjects. Benchmarks for science literacy were developed by Project 2061 and served as the framework for the *National Science Education Standards* (NSES).

The *National Science Education Standards* (NSES) provided criteria for judging progress toward a national vision of learning and teaching science. The NSES outline standards for science teaching and learning as well as standards for science content. These standards provide a framework for what teachers need to know and skills they need to possess for effective science teaching in Kindergarten-12th grade classrooms. In order to assess and track the achievement of students against state standards, the *No Child Left Behind Act* (2001), promulgated the standards-based accountability movement. The law required state testing of grades 3 and 8 students using statewide tests. The law further required testing of students once between grades 10 and 12 in reading and mathematics beginning in 2005-2006, placing a heavy burden on elementary teachers to prepare students for these assessments. The NCLB also required student testing in science at three grade bands, 4th, 8th, and 12th grades beginning in 1997. Jorgensen and Hoffman (2003) suggested the standards-based accountability movement punctuated the power of assessment in the lives of students and teachers, shifting the focus to testing rather than quality instruction.

In response to these reform movements, teacher education programs attempted to prepare elementary preservice teachers for effective science teaching by requiring them to take a few science content courses and, typically, at most, only one science methods course to shape the development of pedagogy. The former seems to suggest that content is a separate entity from pedagogy. Content and pedagogy are coupled in the doing of science and therefore, should be coupled in the teaching of science (DeBoer, 2006). As stated in the publication, *Benchmarks for Science Literacy*, science teaching that attempts solely to impart to students the accumulated knowledge of a field leads to very little understanding and certainly not to the development of intellectual independence and facility.

As Shulman (1986) described in his earlier thoughts on PCK, there is a “blind spot” in regard to teaching with an emphasis that has been placed on pedagogy with little focus on content. This is true especially with regard to elementary teachers who tend to be a content generalist rather than science content specialist. This blind spot must be accommodated if effective science teaching in kindergarten-sixth grade classrooms is to be realized.

Brief Overview of the NASA Opportunities for Visionary Academics (NOVA)

The NASA for Opportunities for Visionary Academics (NOVA) professional development project was created in response for the need to facilitate change in science teaching in higher education by providing assistance to faculty throughout the U.S. who wanted to change the way they taught science, mathematics, technology, or engineering to their students (Sunal, Wright, & Day, 2004, p. 4). The program's emphasis was on constructing, connecting, and collaborating in order to enhance science, mathematics, and technology literacy of all undergraduate students while focusing on the involvement of education majors in entry-level undergraduate courses.

The NASA/NOVA project described types of professional development activities faculty instructors received over the course of 10 years. These activities helped to inform and shape the pedagogical practices of undergraduate faculty. These practices then were incorporated into science and/or science methods courses with preservice teachers who eventually would graduate and teach science.

One national effort to evaluate the effects the NASA/NOVA project was the National Study of Education in Undergraduate Science (NSEUS). The National Study of Education in Undergraduate Science (NSEUS) examined the critical undergraduate science course characteristics and variations in teaching science content to undergraduates with diverse majors. The goal of the national multi-year study was to investigate the impact of undergraduate course reform on student short-term learning outcomes for all majors while focusing on long-term outcomes of a specific group, those who were preservice, undergraduate, elementary school majors. In an attempt to examine how these reformed undergraduate science courses served to shape the development of Kindergarten-6th grade inservice teacher's PCK, I used a portion of the archived data collected during this multi-year study in which I served as a doctoral student investigator in the collection of data.

Statement of the Problem

Pedagogical content knowledge (PCK) is an academic construct that is rooted in the belief that teaching requires more than delivering subject content knowledge to students (Loughran et al., 2006). It is the knowledge that teachers develop over time, and through experience, about how to teach particular content in particular ways in order to lead to enhanced student understanding (Loughran, et al.). Thus, teachers must have a rich conceptual understanding of the particular subject content that they teach combined with expertise in developing, using, and adapting teaching procedures, strategies, and approaches, for use with particular classes (Loughran et al.). The conceptual understanding of subject matter content coupled with specific teaching procedures, strategies, and/or approaches is linked to what Shulman described over 20 years ago as pedagogical content knowledge (PCK).

Pedagogical content knowledge (PCK), then, describes both the content and pedagogical knowledge that teachers must have in order to provide students with rich experiences in science. It stands to reason that no matter how capable a teacher might be when teaching his or her subject, both skills and ability are immediately challenged when teaching content with which there is little familiarity (Loughran et al., 2006).

The problem is that reform endeavors aimed at improving teacher education programs tend to emphasize either content or pedagogy without examining the influence of these same endeavors on the development of pedagogical content knowledge (PCK). The undergraduate reformed science courses examined in this study are a unique blend of content and pedagogy in which faculty instructors of the reformed science courses used their PCK expertise to represent content in a variety of ways to their students and preservice teachers. Thus, in doing so preservice teachers could develop a meaningful understanding of science content and be able to translate science content to their students in novel situations.

Studies have sought to understand the role of teacher education programs in the development of preservice teachers pedagogical content knowledge (Appleton, 2003, 2002; DeJong, van Driel, & Verloop, 2005; Faikhamta, Coll, & Roadrangka, 2009; Lowery, 2002). Some studies have examined the pedagogical content knowledge of secondary preservice teachers (DeJong, van Driel, & Verloop, 2005; Ozden, 2008) while others have examined the pedagogical content knowledge of elementary inservice teachers (Appleton, 2003, 2002; Appleton & Kindt, 1998). However, these studies have not examined PCK from the aspect of reform. There currently are no large scale studies employing quantitative and qualitative data examining the effects of a standards-based reformed undergraduate science course on the pedagogical content knowledge of inservice elementary teachers who experienced the course during their undergraduate program. This study examined aspects of undergraduate science reform courses and their relationship to science teaching practices and the pedagogical content knowledge of inservice elementary teachers who experienced these science courses during their undergraduate program.

Significance of the Study

Current attempts at reform tend to stress unilaterally either content or pedagogy, often providing teachers with an array of non-contextualized, unconnected activities, concepts and demonstrations (Mason, 1999). This situation is what Shulman (1986) described over 20 years ago as the "missing paradigm" in teacher education. The missing paradigm refers to a blind spot with respect to content that characterized research on teaching. The emphasis was placed on issues such as how teachers manage their classrooms, organize activities, allocate time and turns, structure praise and assignments, plan lessons, and judge student understanding of science concepts without placing emphasis on knowledge of content. This study is unique in that the reformed undergraduate science courses experienced by inservice teachers were a unique blend of content and pedagogy.

There is very little literature, currently, on how reformed undergraduate science courses aid in the development of inservice teacher's pedagogical content knowledge. My research examines common aspects of typical undergraduate science courses as well as reformed science courses based on elements of the *National Science Education Standards* (1996) and how these courses influence the development of the pedagogical content knowledge of inservice teachers who experienced these courses during their undergraduate major programs. Insights gained from this study could add to the existing literature on PCK, as well as inform teacher education programs as to what could be done to equip preservice elementary teachers with the science content knowledge and pedagogical knowledge needed for effective science teaching.

Research Questions

The overarching research question investigated in this study is, "What is the long-term impact of varying models of reformed undergraduate science courses on the science pedagogical content knowledge of inservice elementary teachers? More specifically, the following research questions will be investigated.

1. Are there observed pedagogical differences between faculty teaching reformed and comparison undergraduate science courses?

2. Are there instructional differences between elementary teachers who experienced reformed instruction and those who did not based on observed pedagogical differences?

3. Is the level of pedagogical reform experienced in undergraduate science courses a predictor of the type of science instruction observed at the elementary school level?

4. How is the level of pedagogical reform experienced in undergraduate science courses related to the pedagogical content knowledge of inservice teachers?

Overview of Research Study Design

My study follows that of a mixed-methodological research paradigm. Mixed-methods research represents a social science that encourages the integration of two major methodological approaches: quantitative and qualitative (Symonds & Gorard, 2010). This study will follow the quantitative dominant mixed-methods research paradigm in that the investigator will rely heavily on quantitative data while using qualitative data to corroborate findings from quantitative analysis, a process called triangulation. Data collection will be comprised of structured and semi-structured interviews with faculty, inservice teachers and undergraduate student focus groups; classroom observation; and fieldwork write-ups. I used the following instruments for the data collection phase of the study: (a) *Reformed Teaching Observational Protocol* [RTOP] (b) *Content Representation (CoRe*), (c) *Professional and Pedagogical Experience Repertoires*, and (d) interview protocols.

The quantitative phase of the data collection included the classroom observations of both faculty and inservice elementary teachers. Faculty of reformed and comparison courses were observed at least twice during the week-long site visit using the *Reformed Observation Teaching Protocol,* a criterion referenced test designed to measure the degree of reform in a science classroom. These observations lasted from 60 to 90 minutes and typically consisted of a lecture, laboratory, or a class that had a combined lecture and laboratory. At least two trained observers observed classroom instruction. The RTOPs were individually scored immediately after the classroom observation and then discussed to resolve any discrepancies between researcher ratings. The labs and lecture were combined to give an average RTOP score for each faculty. The elementary teachers were observed once during the site visit from 20-50 minutes.

The qualitative phase of data collection used interviews and *Content Representation* (CoRe) and the *Personal and Professional experience Repertoire* (PaP-eRs) instruments. A CoRe provides an overview of how teachers conceptualize the content of a particular subject matter or topic (Loughran et al., 2006). According to Loughran et al. (2006) whether or not a particular action by a teacher is illustrative of that teacher’s PCK is closely related to the thinking upon which the teacher reasons through and develops the subsequent teaching action.

Pedagogical and Professional experience Repertoires are narrative accounts of a teacher's PCK for a particular piece of science content. Each PaP-eR then "unpacks" the teacher's thinking around an element of PCK for that content, and is based on classroom observations and comments made by teachers during the interviews from which the CoRes were developed. *Pedagogical and Professional experience Repertoires* are intended to represent the teacher's reasoning, that is, the thinking and actions of a successful science teacher in teaching a specific aspect of science content. The function of the narrative is to elaborate and give insight into the interacting elements of the teacher's PCK in ways that are meaningful and accessible to the reader, and that may serve to foster reflection in the reader about the PCK under consideration, and to open the teacher reader to possibilities for change in his/her own practice (Mulhall et al., 2003). Interviews were conducted with the faculty and elementary teachers immediately following classroom observations lasting from 60 -90 minutes.

The population involved undergraduate faculty throughout the nation and their graduated kindergarten-grade 6 inservice elementary teachers. The sample was selected through stratified random sampling from a national population of diverse colleges/universities that had undergone instructional reform.

Operational Definition of Terms

Content knowledge--Content knowledge may be defined as the knowledge of concepts, principles, relationships, processes, and applications a student should know within a given academic structure (Ozden, 2008). It includes both syntactic and substantive knowledge.

Content representation--A CoRe (content representation) provides an overview of how a given group of teachers conceptualize the content of particular subject matter or topic (Loughran et al., 2006, p. 21).

Inquiry--Science inquiry refers to the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work.

Inservice teacher--teachers who have graduated from an undergraduate program with teacher certification and are presently teaching in a school district. Inservice teachers in this study took either the reform or comparison course and were teaching science in their schools.

Instructional differences--will be measured using Reformed Teaching Observational Protocol (RTOP). The Reformed Teaching Observation Protocol (RTOP) is an observational instrument that can be used to assess the degree to which science instruction is "reformed." It embodies the recommendations and standards for the teaching of science that are advocated by the National Research Council (Sawada & Piburn, 2000). The instrument draws on the following sources: (1) National Academy of Science, National Research Council, *National Science Education Standards* (1996); and (2) American Association for the Advancement of Science, Project 2061, *Science for All Americans* (1990), *Benchmarks for Scientific Literacy* (1993).

Orientations toward science teaching--Orientations are generally organized according to the emphasis of the instruction from purely process or content to those that emphasize both and fit the national standard of being inquiry based (Magnussen, Krajcik, & Borko, 1999). Orientations comprise the goals of teaching science that a teacher has and the typical characteristics of the instruction that would be conducted by a teacher (Magnussen et al., 1999). A teacher's orientations are distinguished based on the purpose for employing a particular strategy.

Pedagogical content knowledge (PCK)--Pedagogical content knowledge, or PCK, identifies the distinctive bodies of knowledge for teaching. It represents the blending of content and pedagogy into an understanding of how particular topics, problems, or issues are organized, represented, and adapted to the diverse interests and abilities of learners, and presented for instruction (Shulman, 1987).

Pedagogical knowledge--includes knowledge of learning difficulties and conceptions, and knowledge of instructional strategies (Kaya, 2009).

Pedagogical and Professional Experience Repertoire (PaP-eR)--A PaP-eR is a narrative account of a teacher's PCK that highlights a particular piece, or aspect, of science content to be taught (Loughran et al., 2006). Because PCK is seemingly a broad construct, within the context of this study it will be measured based on the indicators or features of inquiry.

Preservice teachers-- students that are studying the required coursework in pedagogy and science content to receive certification to become elementary teachers.

Science reform--within the context of my study science reform refers to the essential features of inquiry delineated by the National Research Council for effective science teaching and learning. These features include (1) the learner engages in scientifically oriented questions; (2) the learner gives priority to evidence in responding to questions; (3) the learner formulates explanations from evidence; (4) the learner connects explanations to scientific knowledge; and (5) the learner communicates and justifies explanations.

Snapshots of PCK--Because PCK cannot necessarily be gauged from one classroom setting (Loughran et al., 2006), I used the term snapshots to describe instances of specific events of PCK.

Assumptions

Within the context of this study it is assumed that experienced faculty and inservice elementary teachers could articulate their reasons for the specific instructional strategies used to teach a specific science topic. It is also assumed that these same faculty and teachers can provide specific learning goals and objectives for that same science topic. It is assumed that faculty who taught the reform course have participated in or have been provided professional development in the main elements of the original NASA Opportunities for Visionary Academics

(NASA/NOVA) professional development program that was geared toward the enhancement of science, math, and technology literacy for preservice teachers.

Limitations

The following limitations apply to this study:

1. Elementary teachers were observed only one time during the course of a given week, which may not provide an accurate picture of PCK. Loughran et al. (2006) suggested that it is difficult to ascertain a teacher's PCK from just one lesson or teaching experience.

2. The study began with 30 institutions across the nation; however, due to attrition the number of institutions visited is 20.

3. Quantitatively, sample size was a limitation in my study regarding the number of inservice elementary teachers who took the undergraduate reform course and those who did not.

4. The variation in the level of reform observed in faculty instructors of undergraduate reform courses.

Summary

The overarching purpose of this present study is to identify the impact of undergraduate science reform courses on the development of kindergarten-grade 6 elementary teachers' pedagogical content knowledge. This study provides the opportunity to explore the specific aspects of undergraduate science reform on the development of reform teaching at the elementary school level and how it informs pedagogical content knowledge. Insights gained from this study may provide understandings as to what is needed in order to develop and sustain reformed teaching at the kindergarten-6 elementary level through classroom observations and interviews of faculty and inservice teachers as well as contribute to the existing literature on PCK.

Chapter I presented a rationale for this study. Also included in Chapter I are the introduction, purpose of the study, significance of the study, operational definition of terms, overview of research design, and the assumptions and limitations inherent within this study. Chapter II presents a review of related literature. Chapter III contains a description of the methodology and the analyses used in conducting this study. Chapter IV presents the results for each research question emanating from the analysis of data and Chapter V presents the conclusions, discussion, implications, and further recommendations for the data analysis portion of the study.

CHAPTER II

REVIEW OF RELATED LITERATURE

This study attempts to explore and understand the long-term impact of a standards-based undergraduate science reform course on the instructional practices of Grades K-6 elementary teachers who took these science courses during their undergraduate programs and are now inservice elementary teachers. This chapter analyzes the research literature pertinent to science education reform, pedagogical content knowledge, and inquiry teaching and learning. The review of related literature in which this study is situated will examine the following: (a) current state of student science achievement for Kindergarten-6th grade students, (b) undergraduate science education reform, (c) traditional and reform teaching, and (d) pedagogical content knowledge. The chapter closes with a summation.

A brief history is provided of a funded higher education program within the National Aeronautics and Space Administration (NASA), the NASA Opportunities for Visionary Academics (NASA/NOVA) program, because the participants in this study took part in the set of activities associated with the NASA/NOVA project. The NASA/NOVA project was developed to facilitate change in science teaching in higher education by providing assistance to faculty on a national basis (Sunal, Wright, & Day, 2004). The program's emphasis was on constructing, connecting, and collaborating, using the best of what had been learned through research on faculty professional development in order to enhance science, mathematics, and technology literacy of all undergraduate students while focusing on the involvement of education majors enrolled in these entry-level undergraduate courses. The project endeavored to build upon the national science and mathematics education standards in K-12 education (Sunal et al., 2004). The overarching objectives for the project were as follows:

1) Disseminate the NOVA preservice education model nationally to a diverse population of higher education institutions, addressing critical concerns for equity and geographic distribution

2) Continue development of the NOVA preservice education model aligned with NASA's Strategic Enterprises and the national standards and benchmarks for science, mathematics, and technology

3) Sustain the change process by mentoring workshop participants and collaborating with NOVA partner institutions

4) Increase the collaboration among the NOVA partner institutions by providing a forum to exchange innovative ideas for change in preservice education, and

5) Stimulate and conduct research and evaluation on the effectiveness of NOVA's preservice education model. (p. 4)

The NASA/NOVA project offered a variety of research and literature-based activities that the NOVA team faculty members from lead institutions received over the course of 10 years. These activities helped to inform and shape the pedagogical practices of undergraduate science and mathematics faculty. These practices then were incorporated into science with preservice teachers who would eventually graduate and teach science.

Current State of Science Achievement of Kindergarten through Sixth Grade Students

Over the past 50 years, national efforts have been made to improve science teaching and learning by concentrating on curriculum, content standards, assessment, and through providing funds for reform in teacher education programs. The National Commission on Excellence in Education (NCEE) was established in 1981 to help define the problems afflicting American education and to provide solutions to these problems (DeBoer, 2006). The report of the Commission, *A Nation at Risk* (NCEE, 1983), was a call to mobilize the efforts of the federal government along with states and local school districts to raise the level of competence of American students in all academic areas but with special emphasis on science and math. The Commission on Pre-college Education in Mathematics, Science and Technology of the National Science Board issued a related report, *Educating Americans for the 21st Century*, echoing many of the ideas in *A Nation at Risk* and provided additional detail as to how improved science education for all could be realized (DeBoer, 2006). Both of these reports described how the educational system experienced a period of neglect resulting in low performance levels in mathematics and science. The NCEE suggested that in order to accommodate the vision of science reform then increased exposure to science, higher standards of participation and achievement (noting comparisons to Japan's system where students spent more time in school), and a system of objective measurement to monitor progress must be realized (DeBoer, 2006).

The American Association for the Advancement of Science (AAAS) publication of *Science for All Americans* (SFAA, 1990) brought together the ideas of the reports, A *Nation at Risk* and *Educating Americans for the 21st Century*, through a detailed description of what all adults should know in terms of science, math, and technology in order to be considered science literate. According to SFAA (1990),

> Education has no higher purpose than preparing people to lead personally fulfilling and responsible lives. For its part, science education--meaning education in science, mathematics, and technology--should help students to develop the understandings and habits of mind they need to become compassionate human beings able to think for themselves and to face life head on. It should equip them also to participate thoughtfully with fellow citizens in building and protecting a society that is open, decent, and vital. America's future--its ability to create a truly just society, to sustain its economic vitality, and to remain secure in a world torn by hostilities--depends more than ever on the character and quality of the education that the nation provides for all of its children. (p. xiii)

In addition to concerns over content, SFAA (1990) also made recommendations for pedagogy. *Science for All Americans* suggested that in order to teach for understanding, students must have opportunities to engage in activities that allow them to construct meaning by taking into account their prior knowledge in a variety of social contexts (SFAA, 1990).

In direct response to the federal government's insistence for content standards in the five disciplinary areas, the *National Science Education Standards* (NSES) (NRC, 1996) were developed for science content in order to measure progress toward the national goals. In addition to writing content standards, the NRC also wrote standards for science teaching, professional development, assessment, science education programs, and science education systems. The *No Child Left Behind Act* (NCLB, 2001) required that beginning in 2007 states must measure students' progress in science at least once each year in Grades 3-5, 6-9, and 10-12. The U.S. Department of Education (2001) stated, "No Child Left Behind" is designed to change the culture of America's schools by closing the gap, offering more flexibility, giving parents more options, and teaching students based on what works. The overarching goal of Part B Title II is to increase student achievement through increasing content knowledge and pedagogical skills according to the Mathematics and Science Partnership Website. This is accomplished through programs that

1) improve and upgrade the status and stature of mathematics and science teaching by encouraging institutions of higher education to assume greater responsibility for improving mathematics and science teacher education through the establishment of a comprehensive, integrated system of recruiting, training, and advising mathematics and science teachers;

2) focus on the education of mathematics and science teachers as a career-long process that continuously stimulates teachers' intellectual growth and upgrades teachers' knowledge and skills;

3) bring mathematics and science teachers in elementary schools and secondary schools together with scientists, mathematicians, and engineers to increase the subject matter knowledge of mathematics and science teachers and improve such teachers' teaching skills through the use of sophisticated laboratory equipment and work space, computing facilities, libraries, and other resources that institutions of higher

education are better able to provide than the elementary schools and secondary schools;

4) develop more rigorous mathematics and science curricula that are aligned with challenging State and local academic content standards and with the standards expected for postsecondary study in engineering, mathematics, and science; and

5) improve and expand training of mathematics and science teachers, including training such teachers in the effective integration of technology into curricula and instruction.

Despite these reform endeavors, America's students continue to make little progress on national and international assessments. The National Assessment for Educational Progress (NAEP) has assessed the science abilities of students in Grades 4, 8, and 12 on the following scales: basic, proficient, and advanced. Students performing at the *basic* level should be able to describe, measure, and classify familiar objects in the world around them, as well as explain and make predictions about familiar processes, using evidence to support their observations and conclusions. Students performing at the *proficient* level should be able to demonstrate relationships among closely related science concepts and familiar phenomena around them, as well as analyze alternative explanations or predictions, using evidence to support their explanations and predictions; critique observational studies and simple investigations; identify patterns in data and/or explain those patterns in data; and apply scientific ideas to identify and critique alternative designs to problems that personally affect them. Students performing at the *advanced* level should be able to demonstrate relationships among different representations of principles, as well as propose alternative explanations or predictions of familiar phenomena, using evidence to support their explanations and predictions; design observational studies or simple investigations to validate or criticize explanations or predictions and use sampling strategies to obtain evidence; and propose and critique alternative individual and local community responses to design problems (NAEP, 2009). The total score for the National Assessment of Educational Progress (NAEP) for science was 300.

The National Assessment of Educational Progress science achievement score average for 4th grade science increased from 147 in 1996 to 151 in 2005; there has been no measurable change in eighth science scores between 1996 and 2005, with a national average of 149. Disparities continue to exist within racial/ethnic categories of the NAEP. The national average score for White Americans in 2005 was 162 while Blacks had an average of 129 and Hispanics a score of 133.

The NAEP was updated in science in 2009 to keep the content current with key developments in science, curriculum standards, assessments, and research. Because of the recent changes to the assessment, the results from 2009 cannot be compared to those from previous assessment years. Students were assessed on the following categories: physical science, biology, and earth and space science. A proficiency scale was developed to establish a baseline for future assessments. This score was set at 150 out of a possible 300 points. The national average for Grades 4 and 8 students was 149. In addition, 34% of Grade 4 and 30 % of Grade 8 students scored at the proficient level.

The Trends in International Mathematics and Science Study (TIMSS) also reported on the status of U.S. Grades 4 and 8 students in science and mathematics. Students are assessed every three years and compared to Grades 4 and 8 students in other countries. The mean score for TIMSS is 500 out of a possible 1000 points. In 1995, Grade 4 students in the U.S. received a score of 542 while Grade 8 students received a score of 513. In 2007, Grades 4 and 8 students in the U.S.A. earned an average score of 539 (a 3% decrease) and 520 (7% increase), respectively. Although Grade 8 students increased their TIMSS scores by seven points, these gains were not considered statistically significant (NCES, 2009). Students in Grades 4 and 8 in countries such as Japan, Hong Kong, China, England, and Singapore continue to outperform the U.S. students in Grades 4 and 8, with average scores of 548 or better. Although students took the TIMSS test in the spring of 2011, these scores currently are not available.

United States President Barack Obama has recently launched one of the world's most ambitious education reform agendas, "Race to the Top." This federally funded program endeavors to adopt internationally benchmarked state-developed standards and assessments that prepare students for success in college and the workplace; recruiting, developing, rewarding, and retaining effective teachers and principals; building data systems that measure student success and inform teachers and principals how they can improve their practices; and turning around the country's lowest-performing schools.

With the many efforts aimed at reform in science teaching and learning throughout the U.S. there seems to be a disconnect as to what happens in teacher education programs throughout the nation and what actually takes place in Grades Kindergarten-12th science classrooms. The National Science Teachers' Association standards for the preparation of science teachers state that elementary and middle school teachers of general science should,

> be prepared to teach science with a strong emphasis on observation and description of events, manipulation of objects and systems, and identification of patterns in nature across subjects. They should also be prepared to effectively engage students in concrete manipulative activities that will lead to the development of desired concepts through investigation and analysis of experience. (NSTA, 2003, p. 6)

There is a strong emphasis on content with these standards. In addition to this, the NSTA states that elementary and middle school teachers should be able to create a community of diverse learners who construct meaning from their science experiences and possess a disposition for further exploration and learning (NSTA). Content knowledge and pedagogical knowledge, collectively called pedagogical content knowledge, is at the heart of the *National Science Education Standards* and the National Science Teachers' Association standards for the preparation of science teachers. However, this is typically not the case in the preparation of elementary teachers in teacher education programs throughout the U.S.A.

Reform efforts must be aimed at increasing the amount of content courses that preservice teachers are exposed to along with courses that aid in the development of pedagogical skills for science teaching.

Science Education Reform

Many reform efforts have been aimed at improving science teaching and learning in Grades K-8 and in postsecondary institutions over the past two decades. Despite these efforts, teachers continue to embrace traditional approaches to teaching and learning (Weiss, Paisley, Smith, Banilower, & Heck, 2003). Two lessons have been learned concerning reform efforts: first, large-scale reform of science education takes time and second, systemic reforms must include both top-down and bottom-up approaches (Kahle, 2007). The researcher provided insights from her work with systemic reform suggesting that (1) communication about the reform must reach parents, students, and teachers; (2) reform takes time--time to learn new content and skills; (3) capacity building must include individual as well as organizational and systemic needs; (4) teachers and administrators need to be involved in multiple levels; and (5) coherence among state policies and guiding vision is needed. Efforts to reform science teaching and learning have not only been difficult to achieve in Kindergarten-12 institutions but in colleges and universities as well.

Undergraduate Science Reform

As scientific research creates new knowledge and as educational research identifies more effective methods for teaching science to college students, faculty are under tremendous pressure to create increasingly effective science teaching at the university level (Sunal et al., 2004). Research in the areas of inquiry teaching, conceptual development, and preconceptions has led to more innovative strategies for college classroom instruction and to new approaches for creating pedagogical change in science courses (Sunal et al.). According to Sunal et al. large scale change is more difficult at this level than changing school science, where decisions are coordinated at the state level. As stated previously, the faculty population in this study participated in the NASA/NOVA project because they expressed a desire to reform the way they taught science to their students. When examining the extent to which reform practices are actually implemented into classroom practice, it is important to understand some of the factors that serve as barriers to the actual implementation of reform practices in these classrooms.

Several barriers to the implementation of standards-based science reform practices have been identified in the literature (Wainwright, Morrell, Flick, & Schepige, 2004). Lack of administrative support, lack of pedagogical training, and lack of emphasis on instruction were identified as common barriers to implementation (Walczyk Ramsey, & Zha, 2007; Sunal et al., 2004). Internet surveys were used by Walczyk et al. (2007) to explore the obstacles, supports, and incentives for innovation in the classroom in the college of science and mathematics at Louisiana Tech University through funds provided by the Louisiana Collaborative for Excellence in the Preparation of Teachers (LaCEPT). The surveys revealed four issues that provided insight on barriers to instructional innovation: (1) lack of communication from administrators as to the importance of instruction; (2) traditional assessments that still dominate in most of the science and math classrooms; (3) science and math faculty have little pedagogical training; and (4) faculty at institutions that assign greater weight to teaching effectiveness in important personnel decisions, such as tenure and raises, were more likely to consult external authority for instructional innovations. Similarly, Henderson (2005) found that a lack of pedagogical knowledge hindered a physics faculty member's ability to implement reform instruction in his classroom.

Studies conducted by Christopher and Atwood (2004) and Goldston, Clement, and Spears (2004) found that collaboration was key to the effective implementation of reform endeavors. In an earlier study, Christopher and Atwood (2004) described an interdisciplinary collaborative planning approach in the implementation of a standards-based physical science course for preservice elementary teachers. The collaborative planning committee consisted of the physicist, a science educator, two elementary teachers, a chemist, and a geologist. The investigators found that the collaborative efforts of the committee and the support and commitment of the physics department demonstrated that effective change efforts begin with a shared goal to be accomplished through the collaborative efforts of a curriculum planning committee and the support and commitment of the physics department.

Beliefs about teaching were also identified by Henderson (2005) and Gess-Newsome et al. (2003) as a barrier to the implementation of reform practices. Using case studies, Gess-Newsome, Southerland, Johnston, and Woodbury (2003) investigated three faculty members as they designed and implemented an integrated, inquiry-based science course, the Natural World, at a small, private, independent liberal arts college. The investigators used the Teacher-Centered Systemic Reform Model (TCSR), teacher's personal practical theories, and conceptual change as a framework to study the reform efforts of these three faculty members. The TCSR model takes into account teaching context (structural and cultural), teacher characteristics, teacher thinking, and their interactions as factors that influence reform (Gess-Newsome et al., 2003). According to the text, the structural contexts of teaching include the physical, temporal, and psychological characteristics of the setting while the cultural contexts include the beliefs, values, habits, and assumed ways of doing things among communities of teachers. Overall the investigators found that mitigation of structural contexts is a necessary but insufficient precursor to change and that personal practical theories are the most powerful influence on instructional practice (Gess-Newsome et al.).

Lastly, Sunal et al. (2004) identified the following additional barriers to the implementation of reform practices: tenure, merit pay, professional respect, teaching load, curriculum, and certification and accreditation barriers. The researchers suggested these barriers must be accommodated in order for effective implementation of a new innovation and change to occur in a reasonable timeframe. Changing the way science is taught in colleges and universities is more difficult than changing secondary school science where decisions are coordinated in schools, school districts, and at the state level; however, there is a general consensus that reform in undergraduate courses is critical to systemic reform Kindergarten-12 (Sunal et al.). According to the *National Science Education Standards* to college and university science faculty,

> University and college professors of science are an integral part of this educational system because it is, in very large part, from our courses that society will learn its science... The responsibility of science faculty members is to develop not only the science knowledge of our students, but also their understanding of the nature of science, their ability to understand and use scientific ways of thinking, and their ability to make connections and apply what they know to the world outside the classroom. (p. ix)

K-12 Science Reform

In “The New Meaning of Educational Change,” Fullan (2007) suggested that large scale reform involves ongoing accountability and capacity building efforts at three levels: school, district, and the state. Capacity refers to the collective power of all involved in reform efforts to effect change. Within the context of teaching, this refers to the improvement of instruction, student learning, and achievement. Several guidelines have been proposed to achieve large scale reform (Fullan; Newman et al., 2001). All of these guidelines point to school capacity and include the following: (1) shared meaning and program coherence; (2) the attainment of literacy, numeracy, and well-being; (3) a school culture that is built on respect and dignity; (4) professional learning communities and ongoing collaboration; (5) teacher knowledge, skills, and dispositions; (6) principal leadership; (7) accountability; and (8) building confidence. These guidelines are consistent across the literature with schools that have successfully implemented district or school-wide systemic reform in various settings. It is important to understand factors that serve as barrier to the implementation of reform practices in elementary schools. Few studies are found in the literature that delineates the overall impact of undergraduate science reform on inservice elementary teachers who have taken these reformed courses.

The national impact of the Collaboratives for Excellence in Teacher Preparation program (CETP) was investigated by Lawrenz et al. (2007). The National Science Foundation’s (NSF) Collaboratives for Excellence in Teacher Preparation (CETP) program focused on both teacher knowledge and pedagogical skills as a means to improve science and mathematics teachers. The CETP program was designed to better prepare science and mathematics teachers. The purpose of the Lawrenz et al. study was to examine the national impact of the CETP program in two different settings: institutions of higher education, and Kindergarten-12 science and mathematics classrooms. The focus of the study was to examine the impact of the CETP program on the institutional culture and collaborations among and between faculty, and changes in instructional techniques used by higher education faculty and Kindergarten-12 teachers. Instruments included web-based surveys, paper-pencil surveys, and classroom observations.

Nationally, 19 Collaborative for Excellence in Teacher Preparation projects were funded by NSF for 5 years, 1993 through 2000, with the option for an additional 3 years. Participation in this study was voluntary and comprised 12 of the 19 Collaborative for Excellence in Teacher Preparation projects. Overall results from the study revealed that faculty believed that CETP had improved the collaboration within institutions as well as increased the use of standards-based instruction. To examine the impact of the CETP, the investigators sought to examine which aspects of the teacher preparation program were different. Teachers were asked eight different questions about what was included in their teacher preparation programs (i.e., computer-assisted instruction, science methods courses, mathematics methods courses, science or mathematics capstone courses, field experiences in education in addition to student teaching, and field experiences in science and mathematics) and how they would rate it overall. In addition, teachers were asked if their teacher preparation programs included information about the mathematics or science standards. The results for Grades Kindergarten-12 are as follows: (1) in general, more CETP teachers reported their preparation programs as having more computer assisted instruction, more topic specific methods classes, more field experiences, and more information about science standards, while non-CETP teachers reported having more capstone courses; and (2) the instructional practices of teachers prepared by CETP programs were viewed by students and observers as significantly different from the instructional practices of teachers prepared by other programs.

Reformed mathematics and science courses were examined by Judson and Sawada (2001) at community colleges and universities to determine their impact on education majors as they began a teaching career. The study comprised 86 observations of middle and high school teachers (i.e., Grades 5-12) over a 4-month period. These teachers ranged from one to three years of teaching experience and had taken anywhere from zero to four reformed science or math courses at Arizona State University. Teachers were stratified based on years of teaching experience. For example, when comparing ACEPT prepared teachers with non-ACEPT prepared teachers, the sample was stratified into first-year, second-year, and third-year teachers (Judson & Sawada, 2001). Teachers with two to three years of teaching experience were grouped in the same category because few observations were done with teachers with 3 years teaching experience. Of the 86 observations, 53 were teachers who had taken at least one ACEPT course and 33 observations occurred in classrooms of non-ACEPT teachers. The investigators found when comparing ACEPT with non-ACEPT, the investigators found a statistically significant difference between ACEPT and non-ACEPT teachers in the level of reformed instruction based on RTOP scores. When examining subgroups, significant differences did not hold true between ACEPT and non-ACEPT teachers (e.g., second- and third-year middle school teachers). Teachers having no ACEPT courses and those having one course did not differ. However, significant differences were found to exist between non-ACEPT teachers and those ACEPT teachers who had at least two ACEPT courses.

Using self-reported surveys, McGinnis and Parker (2001), in the Maryland Collaborative for Excellence for the Preparation of Teachers, investigated inservice teachers who graduated from an inquiry-based, standards-guided teacher preparation program. The following questions guided this aspect of their study: how do new specialist teachers of mathematics and science who graduate from an inquiry-based, standards-guided innovative teacher preparation program view their subject disciplines; intend to enact their roles as teachers; and compare in their beliefs and intentions concerning mathematics and science to other elementary/middle schools. The survey was administered over a period of three years (1999/2000/2001; $N = 68$). The authors indicated a 60% response rate. Concerning the nature and teaching of science, MCEPT graduates differed significantly ($p < .05$) than the national population.

The MCEPT teachers were less likely to believe that science is primarily a formal representation of the real world, that science is primarily a practical and structured guide to addressing real situations; that a liking for and understanding of students is essential for teaching science; that it is important for teachers to give students prescriptive and sequential directions for science experiments; and that students see a science task as the same task when represented in two different ways. Disaggregated data analysis revealed that MCEPT middle school teachers in comparison to the national sample differed significantly ($p < .05$) on two beliefs: they were less likely to believe that it is important for teachers to give students prescriptive and sequential science experiments; however, they were more likely to believe that science is primarily a practical and structured guide for addressing real situations. Concerning teachers' use of instructional practices, elementary and middle school teachers differed significantly from the national population on the following practices: they were more likely to assist students in achieving high standards; use standards-aligned curricula; use standards-aligned textbooks and materials; and make use of telecommunications-supported practices. In addition, the majority of the elementary and middle school teachers made connections between science and math.

In an earlier study, McGinnis, Parker, and Graeber (2000) used case studies to investigate what happens to new teachers who are prepared to enact reform-based practices in science and math. The focus was on a select number of graduates who were in their first two years of teaching. These graduates had taken reformed-based science courses in their undergraduate programs. Insights were framed based on the following components: the individual's intentions, needs, and capabilities, and institutional demands, supports, and constraints. The researchers found that from the new teachers' perspective, school culture was a major factor as to the implementation of reform-based science practices. Furthermore, in instances where new teachers perceived that their school cultures offered a lack of support for their intent to implement reform-based practices, the new teachers exhibited differing social strategies such as resistance, moving on, or exit. Some teachers adjusted their teaching practices to fit the school culture.

The relationship between science teacher cognition and the program experiences that teachers attribute to their knowledge construction was investigated by Adams and Krockover (1997). Results from their study revealed that of the teacher education program, student-centered learning, cooperative learning, general pedagogical knowledge, and pedagogical content knowledge, were adopted into the schema of beginning teachers. The degree of adoption appeared to be linked to the individual's most significant learning experiences and the constraints of the school situation.

If science reform practices are going to be realized in Kindergarten-16 classrooms then the collective power of all who are involved in reform endeavors must be included. As evidenced in the literature, successful implementation of reform practices requires collaboration, ongoing professional development opportunities, administrative support, a shared vision and goals, and a school culture that supports reform practices. Reform aimed at science teaching and learning has been occurring in higher education in increasing rates. Helping preservice teachers understand science ideas is a complex task and in order to do it well takes a significant amount of pedagogical, curricular, practitioner research knowledge and skills (Sunal & Wright, 2007). Faculty with little to no professional training in teaching must have opportunities to attend professional development workshops geared toward improving science teaching and learning.

Kindergarten-12th grade schools throughout the nation must have (1) high expectations; (2) a clear sense of purpose and commitment among all members of the school community (administrators, teachers, parents, and students); (3) well-defined, agreed-upon standards of performance and behavior for all members of the school community; (4) a personalized, supportive learning environment; (5) a teaching staff with the content knowledge and instructional skills required to teach intellectually rich subject matter; and (6) a strong collegial and collaborative school culture that encourages teachers to work together to improve practice and solve problems (French & Goldberger, 2003). These characteristics must be in place if reform practices will be realized in Kindergarten-12th grade schools.

Traditional versus Reform Science Teaching

There is a national commitment in the United States to the teaching of science as inquiry across the Kindergarten-12th grades. Inquiry teaching of science reflects the investigative approach scientists use to discover and construct new knowledge. Inquiry processes of science range across aspects like observing; posing questions; exploring phenomena; experimenting; interpreting data; seeking relationships; inferring from evidence; suggesting and testing hypotheses; developing concepts, laws and models; and communicating and explaining findings (Schuster, Cobern, Applegate, Schwartz, Vellom, & Undreiu, 2011). Inquiry, then, is an active process of learning--something that students do, not something that is done to them (NRC, 1996).

Despite the emphasis on inquiry in national standards and state curricula, there is continuing debate about desirable and effective approaches to science instruction. There exists a range of approaches across a spectrum from “direct” didactic presentation on the one hand to unguided “discovery” learning on the other (Schuster et al., 2011). Teachers, likewise, have conscious or unconscious orientations toward one part of the instructional spectrum or another. In order to effectively employ inquiry strategies then, teachers must know science content and possess the pedagogical knowledge needed to employ inquiry in the classrooms for student learning.

Both the *National Science Education Standards* and the National Science Teachers Association Standards for the preparation for science teachers point to the notion that teachers must have content knowledge and pedagogical knowledge for effective science teaching. More specifically, elementary and middle school teachers of general science should,

> be prepared to teach science with a strong emphasis on observation and description of events, manipulation of objects and systems, and identification of patterns in nature across subjects, as well as, be prepared to effectively engage students in concrete manipulative activities that will lead to the development of desired concepts through investigation and analysis of experience. (NSTA, 2003, p. 6)

This type of instruction is constructivist in nature in that these sorts of activities allow students to construct meaning for themselves. Pedagogical content knowledge draws upon the constructivist approach to science teaching and learning recognizing that students must be engaged in activities that draw upon and challenge their misconceptions while allowing them to construct meaning through their active engagement in the learning process.

The National Research Council (1996) suggested that novice and experienced teachers may have trouble changing the way science has been taught because they were not taught from a constructivist or inquiry-based approach. The *National Science Education Standards* and the

American Association for the Advancement of Science urge for less emphasis on the memorization of facts and more emphasis on students investigating the everyday world and developing deep understandings from their inquiries. Even though there is a push for inquiry, many teachers still embrace traditional instructional practices.

The Inside the Classroom study was conducted by the Horizon Research, Inc. (HRI) between November 2000 and April 2002. This major undertaking was supported by the National Science Foundation (NSF). The study was designed to provide the education research and policy communities with snapshots of mathematics and science education as they exist in classrooms in a variety of contexts in the United States. These snapshots included both the instruction that took place and the factors that shaped instruction. The study consisted of a subset of 40 middle schools that participated in the 2000 National Survey of Science and Mathematics Education. Once the middle schools agreed to participate, the study coordinators identified the elementary schools and high schools that were in the same feeder pattern and randomly sampled one of each. The investigators of this study incorporated the following instruments: teacher interview protocol, observational protocol, math questionnaire, and science questionnaire. Inside the Classroom observers assessed the quality of four components of each lesson. These components were (a) lesson design, (b) lesson implementation, (c) math/science content addressed, and (d) classroom culture.

Lesson design encompassed the activities, the instructional strategies, the assigned roles, and the resources of the lesson. Indicators in this area include the extent to which the lesson reflected careful planning and organization, the extent to which the available resources contributed to accomplishing the purpose of the lesson, and the extent to which strategies and activities reflected attention to issues of access, equity, and diversity. It was found that the strongest elements of the lesson design was the instructional resources used and planning, *M* = 3.32 and *M* = 3.24, respectively. Among the weakest of the elements for lesson design was the amount of time and structure for sense making and for wrap-up appropriate for the purposes of the lessons, *M* = 2.39 and *M* = 2.16, respectively.

Lesson implementation refers to how the teacher carried out the lesson. Indicators in the implementation of the lesson are (a) pace of the lesson, (b) classroom management, (c) teacher questioning, and the (d) teacher's confidence in his or her ability in teaching the subject (Weiss et al., 2003). In addition, the observers evaluated the extent to which instructional strategies coincided with investigative science. Results indicate that teachers appear to be confident in teaching science (*M* = 3.69) as well as exhibiting effective classroom management (*M* = 2.93). However, teachers receive low scores for questioning and instructional strategies consistent with investigative science, *M* = 2.15 and *M* = 2.41, respectively.

Science content was rated based on the following indicators: (a) its inherent importance in K-12 science and its appropriateness for the particular students observed in the class, (b) the extent to which students were engaged in the content and their ability to make sense of the content, (c) accuracy of the content, (d) teacher understanding of the concepts, and (e) the extent to which there were appropriate connections to other disciplines or other real world phenomenon. Results indicate that science content is significant and worthwhile as well as accurate, *M* = 3.79 and *M* = 3.64, respectively. On the other end of the spectrum, students are not intellectually engaged with important ideas (*M* = 2.52) and science is not portrayed as a dynamic body of knowledge (*M* = 2.25). Lastly, the degree to which sense making is appropriate for the observed lesson was *M* = 2.23.

Classroom culture was rated on the following indicators: (a) extent and nature of the engagement of students in the class; (b) rigor of classroom climate; and (c) equity and diversity issues that may have affected the classroom climate such as the extent to active participation is encouraged and valued, interactions that reflected collaborative working relationships between teacher and students, intellectual rigor, constructive criticism, and the challenging of ideas. Lessons as a whole were weaker to the extent in which their climate encouraged students to generate ideas and questions and intellectual rigor, $M = 2.41$ and 2.13, respectively. However, the climate of respect for student ideas, questions, and contributions was evident ($M = 3.2$), and active participation of all students was encouraged and valued ($M = 3.2$).

Overall, 15% of math and science lessons nationally are estimated to be high quality, 27% medium quality, and 59% low quality. National reform efforts are attempting to reform science teaching and learning at the Kindergarten-12 level.

While there typically has been a lack of agreement among researchers as to the meaning of inquiry-based instruction (Anderson, 2007; Barrow, 2006; Blanchard et al., 2009; Lederman, 2003; Wilson, Taylor, Kowalski, & Carlson, 2009), a general consensus exists about what activities characterize an inquiry classroom as noted in the essential features of inquiry. The success and benefits of inquiry instruction have been established throughout the literature. Research shows that when students practice inquiry, it helps them to develop their critical thinking abilities and scientific reasoning while developing a deeper understanding of science (NRC, 2000). In order for teachers to be successful at implementing inquiry practices, however, they must know science content and they must have the pedagogical skills to facilitate inquiry teaching and learning (Kanter & Konstantopoulos, 2010). The following studies illustrate the impact of inquiry in K-12 schools.

In a study involving 58 students aged 14-16 years, Wilson et al. (2009) examined the effect of an inquiry-based and commonplace science teaching approaches on students' knowledge, reasoning, and argumentation abilities using quantitative methods. The investigators in this study delineated three goals of science education to measure in this study: scientific knowledge, scientific reasoning, and construction and critique of scientific explanations. Students were assigned to one of the two groups--inquiry-based or commonplace science teaching. Wilson et al. (2009) found that students who experienced the inquiry-based program improved achievement on all indicators: student understanding of science content, students' ability to reason and infer patterns and relationships, and students' ability to critique and engage in discourse with their peers. Similar results had been obtained in an earlier by Chang and Mao (1998) with 232 secondary students examining the impact of inquiry-based and traditional instruction on Earth Science students' achievement. A study by Marx, Blumenfield, Krajcik, Fishman, Soloway, Geier, and Tal (2004) examined the effects of an inquiry-based and technology infused curriculum on student learning over a period 3 years. The results showed statistically significant increases in student achievement for each year of participation.

The impact of an inquiry-based laboratory approach on the conceptual knowledge of secondary students enrolled in a chemistry class on molecular diffusion was examined by Van Rens and van der Schee (2009). Five chemistry teachers, expressing concern about the difficulties faced in using inquiry-based instruction, worked with the investigators in this study to design and implement a unit creating a simulated inquiry community of upper-secondary chemistry students to enhance inquiry-based student learning. The inquiry-based approach was based on the Procedural and Concept Knowledge in Science (PACKS) model which (1) extends students prior knowledge and skills to produce new learning, (2) engages with interest in the learning task, (3) interprets the task to be done, (4) selects the appropriate equipment, (5) draws conclusions and evaluates them, (6) uses current understanding to make sense of new material, (7) applies relevant domain-specific concepts, and(8) considers empirical evidence. Overall, researchers found that student learning occurred and conceptual knowledge was enhanced regarding diffusion, dissolution, and precipitation.

The effects of open-inquiry instruction with low-achieving, marginalized high school students to improve their argumentation skills was investigated by Yerrick (2000). Entrance and exit instruction interviews were conducted with five students to track their change over time in scientific discourse. Students posed hypotheses and gathered supporting evidence pertaining to their questions. In addition, once students had proposed their models or explanations, they were required to design and carry out experiments in groups of three to test their claims and then discuss their models and initial claims with the whole class. Results indicated that student arguments shifted toward those more consistent with the nature of the scientific arguments including (1) students' tentativeness of knowledge claims, (2) students' use of evidence, and (3) students' views regarding the source of scientific authority.

Similar to that of Yerrick (2000), Blanchard et al. (2009) employed quantitative methods to compare the efficacy of guided or Level 2 inquiry-based laboratory instruction versus traditional (verification) laboratory instruction in the learning of concepts related to a forensics unit, adding to the growing empirical knowledge base concerning the use of inquiry methodologies in the classroom. The sample comprised 1,700 students placed in the classrooms of 12 middle school and 12 high school science teachers. The investigators used Hierarchical Linear Modeling to examine student scores, teachers, school socioeconomic status, Reformed Teaching Observational Protocol, and level of school (middle and high). Students who participated in the guided inquiry-based laboratory unit showed significantly stronger growth in test scores when compared to the students who participated in a traditional verification laboratory-based unit (Blanchard et al., 2010). The researchers, however, found that when broken down by level, high school students receiving the guided inquiry instruction outperformed students experiencing the verification labs and middle school students who experienced the verification labs outperformed students that received guided inquiry instruction. The researchers were able to delineate the differences in student performances through an analysis of teacher RTOP scores. Teachers with high RTOP scores were found to have more reformed teaching practices and stronger implementation of inquiry methods. Guided inquiry sections at both the high school and middle school levels were found by Blanchard et al. to have the best scores, growth, and long-term retention if the teacher was in the "high" RTOP group. Conversely, the students from both high school and middle school levels in "low" RTOP inquiry sections fared worse than any other group (including the traditional sections).

Similarly, Wolf and Fraser (2007) examined the effects of inquiry and non-inquiry laboratory instruction in terms of students' perceptions of the classroom learning environment, attitudes toward science, and achievement among middle-school physical science students, as well as, whether the use of inquiry-based methods is differentially effective for male and female students in terms of student perceptions of the learning environment, attitudes toward the class, and achievement in physical science. In terms of classroom environment, students in inquiry classes perceived a statistically significant amount of student cohesiveness than did students in the non-inquiry classes, and although not statistically significant, small differences were noted in other indicators of the classroom environment such as task orientation, involvement, and cooperation (Wolf & Fraser, 2007). Situational interest and its sources on students participating in science lessons focused on inquiry skills were examined by Palmer (2008). The researcher found that interest arousal was substantial and that sources of interest were (1) novelty (surprise, suspense), (2) autonomy (choice), and (3) social involvement. In an earlier study, Gibson (1998) found that students participating in an inquiry-based Summer Science Exploration Program (SSEP) maintained a positive attitude toward science and a higher interest in science careers.

The effects of a Project Based Science (PBS) Curriculum on the attitude and achievement of urban students from ethnic and racial groups underrepresented in science careers was examined by Kanter and Konstantopoulos (2010). The investigators described the PBS curriculum as a reform-based pedagogy that places emphasis on students constructing a usable or meaningful understanding of the science they are learning, as opposed to memorizing decontextualized scientific facts. The investigators suggested that teachers must have sufficient content knowledge (CK) and pedagogical knowledge in order to use the PBS curriculum as well as employ the inquiry-based aspects of the curriculum and diagnose student misconceptions. Teachers received professional development in order to improve content knowledge and pedagogical content knowledge. The study revealed that increases in teachers' CK and PCK correlated with the improvements in student science achievement but did not correlate with improvements in student science attitudes or plans; however, the frequency of teachers' use of specific inquiry-based activities did correlate with improvements in students' science attitudes and plans but did not result in an overall increase in student achievement.

Despite the overall impact of inquiry-based teaching there are also some limitations and/or dilemmas (Anderson, 2002) noted in the literature. The impact of high stakes testing on teaching practice was investigated by Barksdale-Ladd and Thomas (2000). They found that teachers feel constrained to teach to the test rather than employ various teaching strategies; feel as though testing de-professionalizes teaching practice; and also reported using instructional practices that were specifically geared toward test preparation rather than activities such as laboratory experiences, collaboration, writing assignments, and small group discussions. Teachers also feel powerless to do anything about it. In a similar study, Anderson described three barriers or dilemmas that influence the implementation of inquiry: (1) *technical dilemmas*, which include the ability to teach constructively; the degree of commitment to the textbook; the challenges presented by state assessments; the challenge of the new teacher role as a facilitator; and inadequate professional development; (2) *political dilemmas*, which refer to short-term or limited professional development programs, parental resistance that science is taught differently than they experienced, unresolved conflicts among science teachers about what and how to teach, and lack of available resources; and (3) *cultural dilemmas*, which include quality of textbooks and support materials, views about purposes of assessment, and view of preparation for the next science class. These barriers must be addressed if inquiry is going to be effectively implemented in K-12 science classrooms. Despite these limitations and/or barriers, research continues to illustrate that science inquiry has the capacity to improve student learning and foster positive attitudes toward science.

Teaching science is a demanding task, requiring teachers to understand not only the science content but also how to translate the content and methods of science into analogous instructional practices (Schuster et al., 2011). Such ability is what Shulman called pedagogical content knowledge or PCK. Pedagogical content knowledge is the knowledge of effective instructional practices pertinent to specific content areas. For science teaching, that emphatically includes the understanding of inquiry as an approach to the subject. It is not enough to know how to employ inquiry strategies but rather teachers must know content and know how and when to use these strategies to transforms that content in a manner that is understandable and accessible to students.

Content Knowledge, Pedagogical Knowledge, and Pedagogical Content Knowledge

Pedagogical content knowledge (PCK) was first posited by Shulman (1986) to describe the transformation of subject-matter knowledge into forms accessible to the students being taught (Abell, 2007). Teachers have been described as having three types of knowledge--content knowledge, pedagogical knowledge, and pedagogical content knowledge--all of which are needed for effective science teaching practices. Shulman (1986), however, suggested that there was a “blind spot” with regard to the content of the lessons taught, the questions asked, and the explanations offered. How do teachers decide what to teach, how to represent the content in which they are teaching, and how do they handle students misunderstandings about content are questions that Schulman posed over 20 years ago.

Schulman’s conception of PCK has been refined, revised, and extended by a number of science educators over time (Appleton, 2002; Gess-Newsome & Lederman, 1999; Grossman, 1990; Loughran et al., 2003; Magnusson et al., 1999). There is a general consensus, however, that PCK is the transformation of content into a form that is understandable and accessible to those being taught. Within the context of this present study the four of the components of PCK found in the Magnussen et al. (1999) model, orientations toward teaching science (OTS), content knowledge, pedagogical knowledge, and pedagogical content knowledge, will be discussed here.

Orientations toward teaching science are typically organized according to the emphasis of instruction from purely processor content to those that emphasize the national standard of being inquiry-based (Magnussen et al., 1999). These orientations are described with regard to the goals of teaching science that a teacher with a particular orientation would have and the typical characteristics of the instruction that would be conducted by a teacher with a particular orientation. Nine orientations toward science teaching and the purposes and characteristics of instruction associated with that orientation were proposed by Magnussen et al. They cautioned that a particular teaching strategy (e.g., use of laboratory investigations) may be characteristic of more than one science teaching orientation: “this similarity indicates 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” (p. 97). The nine orientations were divided into two categories by Friedrichson (2002): (a) teacher-centered orientations (didactic and academic rigor), and (b) orientations based on the reform efforts of the 1960s (process, activity-driven, discovery) and those based on contemporary reform efforts and associated curriculum projects (conceptual change, project-based, inquiry, and guided inquiry). A teacher’s orientation will then guide how they approach the teaching of specific content.

Content knowledge may be defined as the concepts, principles, relationships, processes, and applications a student should know within a given academic subject, appropriate for his/her organization of the knowledge (Ozden, 2008). Earlier, Schulman drew upon Joseph Schwab in his definition of content knowledge. For Schwab, the structures of the content include both the substantive and syntactic structures. The substantive structure of the content is the organization of concepts, facts, principles, and theories, whereas syntactic structures are the rules of evidence and proof used to generate and justify knowledge claims in the discipline (Abell, 2007). Although content knowledge is an essential component of pedagogical content knowledge, it is not a stand-alone for effective teaching. It must be coupled with pedagogy for effective teaching practice.

Pedagogy has been used a variety of ways in education. Pedagogy was described by Van Manen (1999) as:

> As a practice, pedagogy describes the relational values, the personal engagement, the pedagogical climate, the total life-worlds and especially the normativity of life with children at school, at home, and in the community. And as an academic discipline, pedagogy problematizes the conditions of appropriateness of educational practices and aims to provide a knowledge base for professionals. . . . Central to the idea of pedagogy is the normativity of distinguishing between what is appropriate and what is less appropriate for children and what are appropriate ways of teaching and giving assistance to children and young people. (p. 14)

Pedagogical knowledge includes the general aspects of teacher knowledge about teaching such as learning theory, instructional principles, and classroom discipline (Abell, 2007). Mishra and Koehler (2006) stated,

> Pedagogical knowledge is deep knowledge about the processes and practices of teaching and learning, encompassing educational purposes, goals, values, strategies, and more. This is a generic form of knowledge that applies to student learning, classroom management, instructional planning and implementation, and student assessment. It includes knowledge about techniques or methods used in the classroom, the nature of the learners' needs and preferences, and strategies for assessing student understanding. A teacher with deep pedagogical knowledge understands how students construct knowledge and acquire skills in differentiated ways, as well as how they develop habits of mind and dispositions toward learning. As such, pedagogical knowledge requires an understanding of cognitive, social, and developmental theories of learning and how they apply to students in the classroom (p. 1026).

Thus, content knowledge and pedagogical knowledge are essential components of pedagogical content knowledge. There are many models implicating the various components of PCK; however, only orientations toward teaching science, content knowledge, and pedagogical knowledge are considered in this study.

Pedagogical content knowledge (PCK) is a combination of content knowledge and pedagogical knowledge. It was first hypothesized by Shulman (1986) to describe the transformation of subject-matter knowledge into forms accessible to the students being taught (Abell, 2007). Shulman suggested that PCK goes beyond knowledge of subject to the dimension of subject matter knowledge for teaching. It includes the most useful forms of representation of those ideas, the most powerful analogies, illustrations, examples, explanations, and demonstrations--in a word, the ways of representing and formulating the subject that make it comprehensible to others (Shulman). Pedagogical content knowledge also includes an understanding of what makes the learning of specific topics easy or difficult: the conceptions and preconceptions that students of different ages and backgrounds bring with them to the learning of those most frequently taught topics and lessons (Shulman). If those preconceptions are misconceptions, which they so often are, then teachers need knowledge of the most effective strategies that are most likely capable of reorganizing the understanding of learners while ensuring meaningful learning.

Pedagogical content knowledge was described by Loughran et al. (2006) as an academic construct that is rooted in the belief that teaching requires more than delivering subject content knowledge to students, and that student learning is considerably more than absorbing information for later accurate regurgitation. They suggested that PCK is the knowledge that teachers develop over time, and through experience, about how to teach particular content in particular ways that will lead to enhanced student understanding (Loughran et al.). Successful teachers then have a special knowledge that informs their teaching of particular content and that special knowledge is encapsulated in PCK. Teachers not only know content but they have a variety of teaching strategies that they use to teach that content for specific reasons. Effective teachers are deliberate in their selection of strategies to be used with particular content. They may draw upon student alternative conceptions/misconceptions and their prior knowledge and experiences in order to shape their teaching.

Several issues have been proposed by Loughran et al. (2006) regarding the of PCK: (1) PCK is a notion invented by academics to describe an aspect of the professional knowledge and expertise developed by teachers; (2)PCK refers to the knowledge that teachers develop about how to teach particular content/subject matter in ways that lead to enhanced student understanding of that content; (3) PCK is not the same for all teachers within a given content area despite the fact that there are many commonly shared elements of teachers' PCK within that content area; and (4) understanding teachers' practice in terms of PCK may be helpful in making explicit and refining teachers' professional learning about practice.

Although there is no universal model of PCK, many would agree that at the heart of PCK is content knowledge and the teacher's ability to translate that knowledge into forms understandable and accessible to students being taught. Both the *National Science Education Standards* and the National Science Teachers Association Standards for the preparation for science teachers point to the notion that teachers must have content knowledge and pedagogical knowledge for effective science teaching. Throughout the literature, science educators investigating topic-specific PCK point to the importance of content and pedagogical knowledge for effective science teaching. The studies that follow provide insight as to the importance of CK and PK in science teaching and learning.

Research on Pedagogical Content Knowledge

The following studies examine the relationships between undergraduate science reform and the pedagogical content knowledge of pre- and in- service teachers. Studies conducted by

Kaya (2009), Ozden (2008), Halim and Meerah (2002), Van Driel, De Jong, and Verloop (2002) and Van Driel, Verloop, and De Vos (1998) demonstrated that content knowledge influenced pedagogical content knowledge.

The relationship among the components of preservice science teachers' (PSTs) pedagogical content knowledge (PCK) involving the topic ozone layer depletion was examined by Kaya (2009). Within the context of the study, Shulman's model of PCK was used. PCK consisted of content knowledge and pedagogical knowledge. Pedagogical knowledge encompassed the following four components: (1) knowledge of curriculum, (2) knowledge of student learning difficulties, (3) knowledge of instructional strategies, and (4) knowledge of assessments. The subjects were 216 students (118 females and 98 males, aged 21-23 years) in their final year (fourth year of their undergraduate degree) enrolled in science teacher education programs at two universities in Turkey. Seventy-five students (40 females and 35 males) were randomly selected from these 216 students, based on the level of their subject matter knowledge in order to explore possible relationships among the PSTs' PCK. More specifically, Kaya (2009) sought to examine the relationship between subject matter knowledge and pedagogical knowledge. Data collection involved a five-item open-ended survey for subject matter knowledge and semi-structured interviews for pedagogical knowledge.

The open-ended survey comprised five main areas concerning ozone layer depletion: (1) nature of the ozone layer; (2) causes of ozone layer depletion; (3) consequences of ozone layer depletion; (4) functions of ozone in the stratosphere; and (5) relationships among ozone layer depletion, global warming, and acid rain. The structure of the interviews was composed of four main sections that make up the pedagogical knowledge for teaching the topic of ozone layer depletion. Each section of the interview individually dealt with each component of pedagogical knowledge. In choosing the PSTs for the interview portion of the study, all 216 PSTs were first placed into one of three ability groups based on the level of their subject matter knowledge as determined by their responses to the open-ended survey. These groups were as follows:

- High-ability group: PSTs giving the appropriate answers to four or all of the five questions.
- Average-ability group: PSTs giving the appropriate answers to two or three of the five questions.
- Low-ability group: PSTs giving the appropriate answer to only one of the five questions at most.

The open-ended survey comprised five topics: nature of the ozone layer; causes of ozone layer depletion; consequences of ozone layer depletion; functions of ozone in the atmosphere; and relationships among ozone layer depletion, global warming, and acid rains.

The PSTs' responses to the open-ended survey and interview questions were assessed based on the same three knowledge categories (appropriate, plausible, and naïve). A scoring outline for the three knowledge categories (3.5/1/0) was used to evaluate the PSTs' responses to the survey and interview questions. This rubric was designed to assess the respondents' answers according to their proximity to the category scheme that judges derived from current scientific knowledge of ozone layer depletion and current understanding in reform documents such as the *National Science Education Standards*. The three knowledge categories are described here:

- Appropriate (3.5 points): PST's response expresses an appropriate view.
- Plausible (1 point): While not completely appropriate, PST's response expresses some plausible points.
- Naïve (0 point): PST's response expresses a view that is inappropriate or not plausible.

The results from the study revealed the following:

1) Most PSTs did not have enough knowledge to be able to teach the topic of ozone layer depletion;
2) PSTs' subject matter and pedagogical knowledge, including all of its components, are significantly related. PSTs with strong subject matter knowledge exhibited more appropriate pedagogical knowledge, whereas there was more naïve pedagogical knowledge for those with low subject matter knowledge;
3) Significant correlations were found to exist among the components of the PSTs' pedagogical knowledge. This meant that the PSTs who had more appropriate knowledge in one of the components of pedagogical knowledge had a better understanding of other components of pedagogical knowledge; and
4) Results of qualitative analysis of the interview data reveal that PSTs in the high ability group had either appropriate or plausible knowledge rather than naïve knowledge in terms of all of the components of the pedagogical knowledge, while PSTs in the low ability group had either plausible or naïve knowledge rather than appropriate knowledge with respect to all components of the pedagogical knowledge.

Using open-ended surveys with preservice teachers, Kaya (2009) explored the relationship between content knowledge and the components of pedagogical knowledge. These teachers had no teaching experience but rather were in the last year of their teacher education program. This current study involves inservice Grades K-6 elementary teachers who had previous teaching experience.

Using the lesson preparation task, content knowledge test, and semi-structured interviews, Ozden (2008) examined the amount and quality of content knowledge on pedagogical content knowledge regarding phases of matter with 28 science student teachers enrolled in the Department of Primary Science Education in Adryaman University. Prospective teachers were invited to write individual lesson plans for a 2-hour teaching period on the topic of phases of matter for Grade 5. Following the lesson plan, prospective teachers were asked to take the content knowledge test. The test was placed after the lesson plan task so that it did not affect the lesson plan (Ozden). Prospective teachers were then interviewed to ascertain their content knowledge, pedagogical content knowledge and difficulties in lesson planning, and anticipated problems in teaching and perceived educational needs to perform successfully as a teacher. Results from the study indicated that content knowledge had a positive influence on pedagogical content knowledge and effective teaching. In addition, prospective teachers mentioned that the knowledge of teaching methods and knowledge about students' understanding of science as the most important educational needs (Ozden). Similarly, Ogletree (2007) found that elementary teachers teaching the concept of chemical change lack the appropriate content and pedagogical knowledge for teaching this topic. In addition, she found that teachers also lacked curricular knowledge for this concept.

Preservice teachers were found to expand their pedagogical content knowledge by deepening demonstrated that preservice teachers expanded their PCK by deepening their understanding of learning difficulties and student misconceptions after learning from teaching as they experienced a postgraduate teacher education program (De Jong, Van Driel, & Verloop, 2005; De Jong & Van Driel, 2004; Van Driel, De Jong, & Verloop, 2002).

The science pedagogical content knowledge of preservice chemistry teachers (PTs) as they experienced a postgraduate teacher education program was studied by DeJong, Van Driel, and Verloop (2005). The results of this qualitative study using discussions and written reports showed that an extensive, 1-year, training course on teaching chemistry topics, which used particle models for matter, successfully contributed to the development of PCK of the preservice teachers (DeJong et al.). The participants in this study were a group of 12 (3 female, 9 male) preservice teachers who had completed a Master's degree in chemistry. Eight PTs followed the institutional program at Utrecht University, while the other four participated in the program at Leiden University. Research data were obtained from answers to written assignments, transcripts of workshop discussions, and reflective lesson reports, written by the participants.

The program comprised a course module that focused mainly on learning from teaching rather than learning of teaching. DeJong et al. (2005) suggested that the latter approach assumes that preservice teachers learn in a mainly passive way how to teach, whereas learning from teaching means that preservice teachers learn in an active way involving real practice situations, to make their learning more meaningful. The first part of the module aimed at making the PTs more aware of their existing PCK, especially with respect to difficulties in understanding the relationship between corpuscular entities, and substances or processes. The PTs were required to respond to the following question:

(a) Assignment 1: What difficulties in learning the relationship between corpuscular entities and substances or processes do you remember from your earlier experiences as a schoolboy or schoolgirl and as a university student, or from your previous teaching practice?

The second part of the module required PTs to select and read relevant parts of school textbooks. Specifically, PTs read and discussed three sections of a chapter on molecules and atoms, and their relationship with substances and processes, taken from a chemistry textbook for ninth grade. After discussions, PTs were required to complete the following assignment:

(a) Assignment 2: (a) What students' difficulties in understanding these issues do you expect? and (b) Give some examples of instructional strategies that you may use to promote students' understanding of these issues.

The third part of the module required PTs to design and teach a series of lessons on a topic focusing on the use of particle models to understand the relationship between phenomena and corpuscular entities. Each preservice teacher taught three to six lessons on the chosen topic at his or her practice school, using the current textbook, and made audio recordings of these lessons. The fourth part of the course module endeavored to make PTs aware of the PCK that they had developed through reflection. They were asked to write an individual reflective report about difficulties in teaching and learning, and about new teaching intentions, using the following guidelines:

(a) Assignment 3: Write a concise report about the most remarkable episodes and events during the lessons, including the analysis of the students' mistakes in a test at the end of the lessons. Address the following issues: (a) What difficulties of students did you identify; (b) What difficulties did you experience in your teaching; and (c) What changes would you make in these lessons next time?

The outcomes of the study revealed that at the outset of the study, PTs were able to describe specific learning difficulties, such as problems secondary school students have in relating the properties of substances to characteristics of the constituent particles. In addition, all of the preservice teachers acknowledged the potential importance of using models of molecules and atoms to promote secondary school students' understanding of the relationship between phenomena and corpuscular entities (DeJong et al., 2005). After their teaching experiences, all preservice teachers demonstrated a deeper understanding of their students' problems with the use of particle models. In addition, about half of the participants had become more aware of the possibilities and limitations of using particle models in specific teaching situations. The authors found that from learning from teaching, the preservice teachers further developed their PCK of using particle models, although the development of PCK varied from preservice teacher to preservice teacher (DeJong et al.). In an earlier study, DeJong and Van Driel (2004) examined the development of eight preservice teachers' PCK of the multiple meanings of chemistry topics: that is, the macroscopic, microscopic, and symbolic meaning. The preservice teachers were asked to choose and teach a chemistry curriculum topic with a focus on the macro-micro-symbolic issue. The result of the study obtained from the individual interviews demonstrated an increase in most of the preservice teachers' PCK (De Jong & Van Driel,). Preservice teachers not only elaborated but also added new teaching and students' learning difficulties at the end the study. Similarly, Hsiao-lin and others (1995) investigated the development of pedagogical content knowledge of three preservice chemistry teachers in Taiwan during 1 year of a practicum course. Data collection included semi-structured interviews before and after each teaching experience, classroom observations, and collecting artifacts. Results indicate that after experiencing 1 year of the practicum course, preservice chemistry teachers' views of chemistry became simplified but their knowledge of teaching became more complicated and focused more on students' characteristics and learning styles than before. During the year, the preservice teachers gained an awareness of the importance of pedagogical content knowledge in improving their future science teaching.

In a similar study involving interpretive case studies that drew upon classroom observations, semi-structured interviews, chemistry content knowledge surveys, beliefs surveys, and documents as data sources, Faikhamta, Coll, and Roadrangka (2009) examined the impact of a PCK-based methods course on preservice chemistry teachers' PCK, and investigated how they developed and brought their PCK into teaching practice during their teaching field experience. The participants were four preservice chemistry teachers participating in the Graduate Diploma Programme in Teaching Profession at a university in the Northeast of Thailand. In the Thai Science Teachers Standards, Thai science teachers must acquire science content knowledge, understand the nature of science, have knowledge of different pedagogies, and use this knowledge appropriately in the teaching of particular content. Thai teachers are also expected to implement constructivist-based teaching practices and integrate these practices with their PCK. The questions driving this study were as follows:

1) How does a PCK-based chemistry methods course influence the development of PCK for Thai preservice chemistry teachers?
2) How do Thai preservice chemistry teachers develop their PCK during their field experience?

Data collection involved classroom observations, interviews, a chemistry concept survey, a beliefs survey, and examination of documents to include weekly journal entries, portfolios, lesson plans, worksheets, and reports. Results revealed that the preservice teachers broadened their views about the nature of science and learner-centered views of teaching and learning and gradually developed their PCK as a result of the methods course. At the beginning of the course, the preservice teachers had opportunities to read, analyze, and discuss guidelines and principles about teaching and learning from the National Education Act, the Basic Education Curriculum, and the Science Curriculum Framework. They also considered the goals of teaching and learning of science, teacher and student roles in the science classroom, science curriculum, emphasis on student conception and learning, learner-centered teaching approaches, and assessment modes.

From this, preservice teachers were able to develop components of PCK in relation to fundamental ideas discussed in the methods course. According to the investigators, the preservice teachers became aware of conceptual understanding, science process skills, and cooperative group work as learning outcomes, the significance of students' prior knowledge and individual differences in learning activities, and a variety of assessment methods and broadened their beliefs to be more constructivist in nature. Lastly, the preservice teachers were able to transfer their PCK from their methods course into classroom practice. The preservice teachers thought that experience in planning chemistry lessons and micro-teaching enhanced their teaching ability. Preservice teachers felt as though an understanding of lesson planning and organizing learning activities appropriate with chemistry content and student-centered learning could be applied in a real situation.

Similarly results were obtained by Bozkurt and Kaya (2008) with third- and fourth-year prospective science teachers enrolled in the department of primary science education at Gazi University in 2003-2004. The researchers found that third- and fourth-year teachers did not acquire meaningful learning about the concept of the ozone layer. The study revealed that prospective science teachers have not had appropriate pedagogical knowledge consisting of the following three components: the curriculum knowledge, the knowledge of students' learning difficulties, and the knowledge of instructional strategies involving the topic of ozone layer depletion. Likewise, using case studies, Loughran, Mulhall, and Berry (2008) showed that purposeful use of PCK in a preservice science teacher program, student teachers' thinking about their teaching and about their development as science teachers is shaped.

Elementary education majors from a large university were investigated by Lowery (2002) to examine how preservice teachers develop pedagogical content knowledge. The purpose of the study was to further the understanding of how preservice teachers construct teacher knowledge and pedagogical content knowledge of elementary mathematics and science in a school-based setting and the extent of knowledge construction. The participants in this study were 31 junior and senior elementary education majors at a large university enrolled in a required methods course, which fulfilled certification for elementary mathematics and science instruction. The site for the methods course was located on a suburban public elementary school campus (Kindergarten-5) in a central Texas school district with an enrollment of 338 students. A portable building designated as the mathematics and science lab was the site of methods course instruction. Although called a professional development school, this experience was content-specific in that the methods course involved only mathematics and science instruction. This allowed a more in-depth experience in these content areas for the preservice teachers (Lowery, 2002).

The preservice teachers experienced a standards-based rather than textbook-based math and science curriculum. The goal of the method's course was designed to make preservice teachers aware of state and national standards as well as encourage them to become reflective practitioners. A constructivist approach to learning and teaching was modeled, observed, discussed, and implemented. Site-specific tasks included teaching and tutoring mathematics and science to elementary students; designing instructional materials; and creating family involvement nights. This was a qualitative case study that involved participant observations, random individual interviews and focus group exit interviews, methods course artifacts, and school artifacts were used to develop a thick description of the learning context from multiple perspectives (Lowery, 2002). Required products from coursework used as data sources were written assignments, anonymous weekly evaluations, a midterm assessment project, reflective journals, summative portfolios, and a final assessment document (Lowery). Various course tasks included evaluation, synthesis, and implementation of teaching strategies and national standards; participation in inquiry and discovery activities; and participation in professional development activities with inservice teachers (Lowery). The use of constructivist instructional strategies and authentic assessment were integral components of the experience. The methods course included topic contents and methods instruction in mathematics, science, and the integration of mathematics and science (Lowery).

Overall, findings from the study revealed an extensive acquisition of teacher knowledge and pedagogical content knowledge. Learning venues were discovered to be the conduits of learning in a situated learning context. Learning venues comprised (1) learning through collaboration, (2) learning through reflection, (3) learning through exemplary models, and (4) learning through situated context. These venues, along with specific learning components, were found to assist in the development of teacher knowledge and pedagogical content knowledge. In a similar study, Zembal-Saul, Krajcik, and Blumenfield (2002) found that when prospective teachers are provided with opportunities to apply and reflect substantively on their developing considerations for supporting children's science learning, they are able to maintain a subject matter emphasis. However, in the absence of such opportunities, student teachers abandon their subject matter emphasis, even when they have had extensive background and experiences addressing subject-specific considerations for teaching and learning

Two first-year inservice teachers were investigated by Avraamidou and Zembal-Saul (2010) to explore what aspects of teacher practices were most consistent with an inquiry-based approach, what PCK served as a mechanism for facilitating these practices, and what experiences have mediated the nature and development of these teachers' PCK. This study followed a qualitative case study research approach.

The two first-year elementary teachers were purposefully selected, for several reasons, to participate in this study. Both teachers went through a year-long, highly mentored internship in a professional development school setting. Their university coursework differed in that one teacher, Jean, took three undergraduate science courses (Teaching with Insects, Using Applications of Technology to Support Learning Science as Inquiry; Fundamentals of Science, Technology, and Engineering Design) that were specifically designed for prospective elementary teachers, while, the other teacher, Andrea, took three standard introductory science courses. Multiple sources of data were used in order to capture and characterize the teacher's instructional practices and knowledge about science teaching. For each of them, data included three audio-recorded interviews that lasted for about 1 hour each, six video recorded classroom observations that also lasted about 1 hour each, lesson plans and samples of student work associated with the observed lessons.

The collection of data lasted for 6 months (January-June) and it consisted of two phases. The first phase of data collection involved an interview with the participants in order to gain insight into their knowledge about science teaching and identify the K-16 experiences that influenced the development of their knowledge. In addition, a second interview was conducted in which information was obtained on the participants' pedagogical and content knowledge. The second phase entailed classroom observations and video recording of the participants' teaching the science units and a third interview at the end of the unit where the participants were asked to reflect on their teaching practices and provide evidence on teacher learning (Avaarimidou & Zembal-Saul, 2010).

Overall, findings revealed that an inquiry-based approach to science teaching was evident in both of the participants' instructional practices as they engaged their students in question-driven investigations, the use of observational data, making connections between evidence and claims, and communicating those claims to others (Avaarimidou & Zembal-Saul, 2010). Both teachers were able to move beyond hands-on activities and make connections between students' engagement in activities and conceptual aspects of learning. Lastly, the investigators of the study found that Jean spoke explicitly of engaging students in constructing and communicating claims resulting from inquiry-based investigations in the form of an argument. In addition, she used the language of claims and evidence in the classroom discourse. Also, Jean not only asked her students to talk about their claims using the evidence they collected through classroom activities, but at the end of each lesson she also asked them to write in the form of claims and evidence.

The authors noted that Jean's PCK for scientific inquiry emphasized evidence and explanation and could be traced back to the content courses that were specifically designed for preservice teachers. No evidence in the data related to Andrea's PCK for scientific inquiry regarding her knowledge about the nature of scientific discourse (Avaarimidou & Zembaul-Saul, 2009). They obtained similar results in an earlier case study with first-year elementary teachers (Avaarimidou & Zembaul-Saul, 2005). Similar results were obtained by Mulholland and Wallace (2005) when they studied an elementary teacher through the career stages as a student teacher, beginning teacher, and an established teacher over a 10-year time period. General results of the study showed that as the general knowledge base grew, she began to teach new areas of science and develop ways to use manipulatives and cooperative groups. Lastly, Appleton (2002) found that many primary teachers tend to be reluctant to teach science because they lack the content knowledge and confidence to teach science. As a result, they tend to substitute "activities that work” for science PCK. The researcher found that teachers considered activities that work as (a) hands-on activities; (b) interesting and motivating for students; (c) manageable in the classroom; (d) activities that draw upon resources that are readily available; and (e) lend themselves to integration.

There is no general consensus in the literature as to how to measure teachers’ PCK (Friedrichsen, Van Driel, & Abell, 2011) nor is there a universally accepted model for PCK. With the attempts to reform science education in K-16 classrooms through a standards-based curriculum emphasizing inquiry-embedded instruction, it is not enough to push for standards or inquiry teaching and learning. Teachers must make the connection between content and pedagogy. Loughran et al (2007) suggested that

> PCK is not simply using a teaching procedure because it works and it is not just breaking down knowledge of content into manageable chunks but it is the combination of the rich knowledge of pedagogy and content together, each shaping and interacting with the other so that what is taught and how it is constructed is purposefully created to ensure that that particular content is better understood by students in a given context because of the way the teaching has been organized, planned, analyzed, and presented. (p. 10)

Summary

This chapter focused on several key issues related to the potential impact of undergraduate science courses on the current state of science achievement in K-8 classrooms in the U.S., science reform at the undergraduate and elementary level, science inquiry, pedagogical knowledge, content knowledge, pedagogical content knowledge, and current research on pedagogical content knowledge.

The recurring theme in the literature base, whether in secondary or elementary school science, is the notion that effective science teaching requires knowledge of content and pedagogy in order to represent topic specific content in a manner that is understandable to students being taught. Although the *National Science Educational Standards* and the *National Science Teachers Association* for the preparation for science teachers state what teachers know and should be able to do in order to teach science to students in K-6 classrooms, many elementary teachers have not had enough content courses to feel confident in teaching science to their students (Appleton, 1999, 2003; Ogletree, 2007). Because PCK is concept specific and is developed over time, it is not surprising that there are few studies that report on the pedagogical knowledge of elementary teachers. Those reported here echo the notion that elementary teachers tend to lack the content knowledge needed to teach science to their elementary students. When this is the case, elementary teachers may avoid teaching science content or substitute hands-on activities for PCK (Appleton, 2003). However, when elementary teachers have the content and pedagogical knowledge needed to teach science, then expansive PCK is found (Avaarimidou & Zembaul-Saul, 2009; Mulholland & Wallace, 2005).

It is a common theme in the studies examined that a combination of content and pedagogical knowledge is needed in order to effectively teach science. Teachers need to know content in order for transformation to occur as well as teachers need knowledge of student learning difficulties, prior knowledge, and the most appropriate instructional strategies associated with the teaching of specific content in order to facilitate meaningful student learning. Pedagogical content knowledge is developed over time as a teacher teaches a particular subject and becomes familiar with student misconceptions associated with the teaching of that content. This is typically not the case with elementary teachers who have to teach a number of courses in addition to science and are typically generalist (Avaarimidou & Zembal-Saul, 2010). This study focused on the long-term impact of a standards-based reform undergraduate science course on the development of pedagogical content knowledge as well as characteristics of reform courses that contribute to sustained reform science at the elementary level.

Both the *No Child Left Behind* (*NCLB*) *Act of 2001* and the *Race to the Top* initiative have brought evidence-based research front and center in education by requiring federal programs under each act to use their allocations on evidence-based strategies for the purposes of improving science teaching and learning in K-12 institutions across our nation. In conjunction with this vision of the NCLB, both the *National Science Education Standards* and the National Science Teachers Association Standards for the preparation for science teachers point to the notion that teachers must have content knowledge and pedagogical knowledge for effective science teaching. Very few studies discuss the impact of undergraduate science courses on the pedagogical content knowledge of elementary teachers

This study is unique in that it will involve the investigation of a sample of undergraduate courses throughout the nation that have been involved in reforming traditional courses for over 10 years and those teachers who have taken these courses. The research questions in this study were designed to capture "snapshots of PCK" faculty and their graduated students' PCK as it relates to science reform practices, content, instructional strategies, and, more importantly, their rationale for strategies used to teach that specific content. Teaching is a complex activity. Good teaching is not the implementation of a number of steps or protocols that can be passed from one teacher to another (Loughran et al., 2007). Understanding the complex nature of teaching by uncovering the sophisticated thinking that informs teachers' actions and decision making in particular situations is essential. Therefore, how, when, and why teachers think about what they do becomes an important aspect of making the tacit explicit in attempting to capture and portray PCK (Loughran et al., 2006). As suggested in the literature, science courses may influence the development of PCK. My study attempted to show that the way in which undergraduate science reform courses are taught can influence the development of the pedagogical content knowledge of inservice elementary teachers who experienced these courses in their undergraduate program by influencing how they think about science content and how they approach the teaching and learning of that content. Table 1 provides an overview of the key studies presented in chapter II.

Table 1

Overview of Key Studies

Sources	Purpose	Sample	Methods/Instruments	Findings
Avaarimidou, L. and Zembaul-Saul, C. (2010). In search of Well-Started Beginning Science Teachers: Insights From Two First-Year Elementary Teachers. *Journal of Research in Science Teaching*, 47(6), 661-686.	The purpose of this qualitative case study was to explore what aspects of two first- year elementary teachers' practices were most consistent with an inquiry-based approach, what PCK served as a mechanism for facilitating these practices, and what experiences have mediated the nature and development of these teachers' PCK. For each of the participants data included audio-recorded interviews, video-recorded classroom observations, lesson plans, and samples of student work.	This study comprised two first year elementary teachers.	Multiple sources of data were used in order to capture and characterize Jean's and Andrea's instructional practices and knowledge about science teaching. For each of them data included three audio-recorded interviews that lasted for about 1 hour each, six video recorded classroom observations that also lasted about 1 hour each, lesson plans and samples of student work. The first phase of data collection involved an interview with the participants in order to gain insight into their knowledge about science teaching and identify the K-16 experiences that influenced the development of their knowledge. This phase of data collection also involved a second interview through which we obtained information on the participants' pedagogical and content knowledge. The second phase involved classroom observations.	Although both teachers PCK for scientific inquiry was found, only Jean's PCK for scientific inquiry emphasizes evidence and explanation and could be traced back to the content courses that were specifically designed for preservice teachers.

(*table continues*)

Sources	Purpose	Sample	Methods/Instruments	Findings
Faikhamta, C., Coll, R.K., and Roadrangka, V. (2009). The Development of Thai Preservice Chemistry Teachers' Pedagogical Content Knowledge: From a Methods Course to Field Experience. Journal of Science and Mathematics, 32(1), 18-35.	The purpose of this study was to examine the impact of a PCK-based methods course on preservice chemistry teachers' PCK and to investigate how they developed and brought their PCK into teaching practice during their teaching field experience.	The participants in this study were four preservice chemistry teachers participating in a Graduate Diploma Programme in Teaching Profession. Each participant had completed a Bachelor of Science degree in chemistry.	In order to understand teacher's PCK in three ways (planning, actions, and reasons), multi-method evaluations were used. The methods included classroom observation, interviews, a chemistry concept survey, a beliefs survey and examination of documents including journal entries, portfolios, lesson plans, worksheets.	Findings revealed that upon experiencing the PCK-based chemistry methods course, all of the preservice teachers gradually developed their PCK. Preservice teachers had a better understanding of student learning difficulties and took into account student prior knowledge when planning lessons. Content Knowledge was found to serve as a barrier to implementing to science teaching.
Kaya, O.N. (2009). The Nature of Relationships among the Components of Pedagogical Content Knowledge of Preservice Science Teachers: 'Ozone layer depletion' as an example. *International Journal of Science Education*, 7(1), 961-988.	To investigate the inter-relationships and intra-relation among the components of preservice science teachers' (PSTs') PCK involving the topic 'ozone layer depletion'.	The study involved 216 students were surveyed to ascertain their subject matter knowledge. From the 216, 75 students were randomly selected to explore relationships between components of PCK.	Five Item Open-ended survey to ascertain subject matter knowledge of PSTs' on ozone layer depletions and Interviews to ascertain their pedagogical knowledge.	There was a significant inter-relationship between the subject matter and pedagogical knowledge of the PSTs. There were significant intra-relationships among the components of the PSTs pedagogical knowledge except for knowledge of assessment.

(*table continues*)

Sources	Purpose	Sample	Methods/Instruments	Findings
Ozden, M. (2008). The Effect of Content Knowledge on Pedagogical Content Knowledge: The Case of Teaching Phases of Matters. *Educational Sciences: Theory & Practice*, 8(2), 633-645.	To investigate the effect of the amount and quality of content knowledge on pedagogical content knowledge involving the topic phases of matter.	The study involved 28 Science Student Teachers enrolled in the Department of Primary Science Education.	The instruments used in this study were the Lesson Preparation Task, Content Knowledge Test and Interviews. The lesson preparation task involved writing individual lesson plans for a 2-hour teaching period on the topic of phases of matter for Grade 5 students. Student teachers then took a content knowledge test on the phases of matter. In order to ascertain CK and PCK student teachers participated in a structured interview within 3 weeks of the writing the lesson plans.	Findings revealed that content knowledge positively influences pedagogical content knowledge. In addition, interviews revealed the following educational needs of student teachers: content knowledge; teaching methods; knowledge of curriculum; and experience of teaching in primary school.
Ogletree, G.L. (2007). The effect of Fifth Grade Science Teachers' Pedagogical Content Knowledge on Their Decision Making and Student Learning Outcomes on the Concept of Chemical Change. Unpublished doctoral dissertation, The University of Alabama	The purpose of this study was to examine the pedagogical content knowledge of fifth grade teachers as they planned and taught chemical change as a part of property changes in matter.	The sample comprised 7 fifth grade teachers who taught science to 350 students.	The instruments employed in this study were the Reformed Observation Teaching Protocol, Content Representation and Personal and Professional experience Repertoire, Interviews, and Rubrics	Findings revealed that a) teachers lack content knowledge for the concept of chemical change; b) teachers had low to moderate understanding about teaching the concept of chemical change; c) the teachers did not use the state course of study to determine what should be taught about chemical change; and d) years of experience were not related to PCK.

(*table continues*)

Sources	Purpose	Sample	Methods/Instruments	Findings
Halim, L. and Meerah, M.S. (2002). Science Trainee Teacher's Pedagogical Content Knowledge and its Influence on Physics Teaching. *Research in Science & Technological Education*, 20(2), 215-225.	The purpose of this study was to explore trainee teachers' awareness of pupils' likely misconceptions and their suggestions of ways of explaining the scientific ideas to pupils.	12 trainee teachers enrolled in a one-year post graduate course leading to teacher certification	Survey questionnaire comprising topic areas around concepts of physics to ascertain CK. Interviews to ascertain Content knowledge and pedagogical knowledge.	Findings revealed that teacher trainees' knowledge of student misconceptions and teaching strategies to accommodate misconceptions depends their understanding of the content knowledge.
DeJong, O., Van Driel, J.H., and Verloop, N. (2005). Preservice Teachers' Pedagogical Content Knowledge of Using Particle Models in Teaching Chemistry. Journal of Research in Science Teaching, 42(8), 947-964.	The purpose of the study was to investigate the development of pedagogical content knowledge using particle models to understand the relationship between phenomena and corpuscular entities. Preservice teachers took part in an experimental introductory course that emphasized learning from teaching.	12 preservice teachers of chemistry in a 1-year post-graduate teacher education program who completed a Master's degree in chemistry prior to their participation in the teacher education program.	Data was collected through the modules which contained: a) Written answers of each individual preservice teacher to the questions and assignments included in the four parts of the module; b) reflective lesson reports; c) audio-recordings	Findings reveal that all of the preservice teachers initially were able to describe specific learning difficulties such as problems secondary school students have in relating the properties of substances to characteristics of constituent particles however after teaching all preservice teachers demonstrated a deeper understanding of their students' problems with the use of particle models. Findings also reveal that that preservice had become more aware of the possibilities and limitations of using particle models in specific teaching situations.

(*table continues*)

Sources	Purpose	Sample	Methods/Instruments	Findings
Van Driel, J.H., De Jong, O. and Verloop, N. (2002). The Development of Preservice Chemistry Teacher's Pedagogical Content Knowledge. *Science Teacher Education*, 86, 572-590.	The purpose of this study was to investigate the development of pedagogical content knowledge within a group of 12 preservice chemistry teachers during the first semester of their one-year post-graduate teacher education program.	12 preservice teacher of chemistry who had obtained a Master's degree in chemistry prior to enrollment in the teacher education program.	Questionnaire focusing on subject matter knowledge, workshop sessions on macroscopic-microscopic phenomenon in chemistry, interviews, and final or post Questionnaire that focused on pedagogical content knowledge only.	Findings from the study revealed that 10 of the 12 preservice teachers expanded their PCK in their awareness of student learning difficulties and misconceptions associated with the macro-micro phenomenon; gave a precise description of a teaching strategy to be used with the teaching of this concept (6/12); and increased their subject matter knowledge in this area (5/6).
Loughran, J., Mulhall, P., and Berry, A. (2008). Exploring Pedagogical Content in Teacher Education. International Journal of Science Education, 30(10), 1301-1320.	The purpose of the research discussed in this study was to explore the use of the idea of PCK in preservice science teacher education by examining the question: How does knowing about PCK as a construct influence teacher thinking about teaching science, and about one's development as a science teacher?	The participants in this study were a science teacher educator and his student teachers, comprising five who were in their final year of a Bachelor of Education degree and 22 who were doing a one year Post-Graduate Diploma in Education (a one-year add-on programme to their undergraduate degree so they could qualify as teachers).	Instruments used for data in this study included CoRes and PaP-eRs developed by the student-teachers, interviews, field notes, and audio-tape recordings of discussions.	From use of the CoRes and PaP-eRs student teachers move beyond the more traditional approach of gathering a range of 'tips and tricks' about how to teach and to delve into deeper understandings of practice based on better linking of teaching and learning purposes.
Appleton, K. (2002). Science Activities That Work: Perceptions of Primary School Teachers. *Research in Science Education*, 32, 393-410.	The purpose of this study was to investigate elementary teachers' conception of activities that work.	Twenty elementary teachers from local elementary schools in Australia.	Audio-taped interviews were conducted with twenty elementary teachers to determine their understandings of activities that work.	Appleton (2003) found that many of the elementary lacked the confidence and background science knowledge to teach science but suggested that using "activities that work" enabled them to teach science with confidence. Appleton (2003) suggests that teachers typically incorporate activities that work as a substitute for science PCK.

CHAPTER III

METHOD

This study examined the long-term impact of standards-based undergraduate science reform courses on the pedagogical content knowledge of inservice teachers. More specifically, this study attempted to address the following questions:

1. Are there observed pedagogical differences between the reformed and comparison course?

2. Are there instructional differences between elementary teachers who experienced the undergraduate science reform course and those who did not based on observed pedagogical differences?

3. Is the level of pedagogical reform experienced in undergraduate science courses a predictor of the type of science instruction at the elementary level?

4. How is the level of reform experienced in the undergraduate science course related to the pedagogical content knowledge of elementary inservice teachers?

According to Loughran et al. (2006), PCK is not easily captured, recognized, or articulated. In their initial attempt to capture PCK, the investigators envisioned case methodologies as a means of capturing teacher’s PCK but found that over time, the form of knowledge and information that they were gathering and attempting to portray extended beyond that which could reasonably be described as being case-based (Loughran, Milroy, Berry, Gunstone, & Mulhall, 2001). They found that interviews with teachers tended to move across a content area without focusing on any particular concepts, thus offering summative views of classroom practice rather than rich pictures of content-related pedagogy (Loughran et al., 2001). They identified the following reasons that pose a problem to measuring a teacher's PCK: (1) PCK may not be evident within the confines of one lesson because that lesson may extend over a considerable period of time; (2) science teachers typically do not use a language that includes the PCK construct; (3) science teachers typically have little time, opportunity, or obvious reason to engage in discussions that help them to develop the tacit knowledge of their professional experience into explicit, articulable forms to share across the profession; (4) the development of PCK is closely tied to the changes in one's understanding of content, and how teaching that content has influenced this development; and (5) science teachers have difficulty articulating their knowledge about their teaching practice.

For this reason, I chose a mixed methods research design for this study in order to capture instances of PCK through classroom observations and interviews. Mixed methods research is a class of research that combines quantitative and qualitative research techniques, methods, approaches, concepts, or language into a single study (Johnson & Onwuegbuzie, 2004, p. 17). This approach will give credence to this study and provide a more accurate picture as to the realities of instructional practice. The data collected do not characterize a cause and effect relationship but possibly a predictive one that provides insights as to the behaviors of faculty instructors of reform and comparison courses as well as behaviors of inservice teachers who graduated from these institutions.

My study was designed to use a portion of the archived data from a completed longitudinal study, the *National Study of Education in Undergraduate Science* (NSEUS) that has taken place over the course of 5 years. NSEUS was funded under the National Science Foundation in 2006 with data collection being completed in June 2011.The overarching goal of

NSEUS was to investigate the impact of standards-based, reform science courses on short-term learning outcomes of students in the courses and the long-term outcomes or graduated students who became inservice elementary teachers.

Setting

The setting comprised a diverse population of institutions throughout the U.S. These institutions included Historically Black Colleges and Universities (HBCU), master's level (MA) colleges and universities, Hispanic Serving Institutions (HSI), Native American Institutions, and doctoral/research universities based on the Carnegie classification (see Figure 1) (Sunal, Sunal, Mason, & Zollman, 2008).

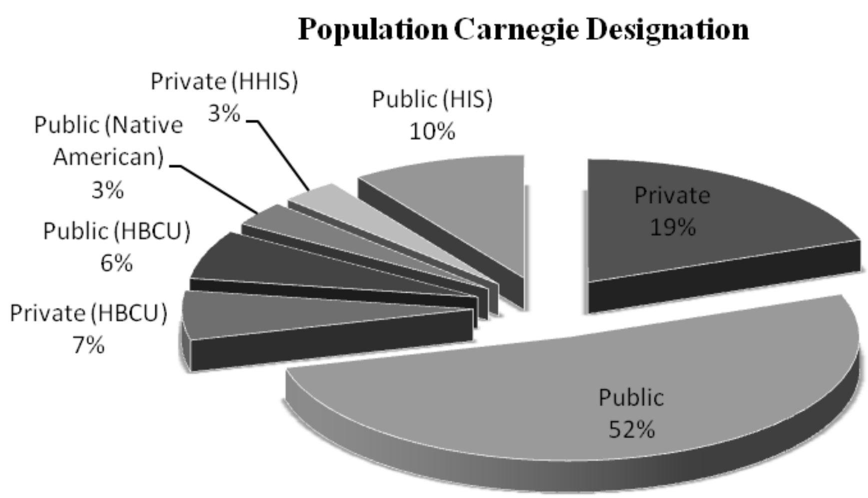

Figure 1. Population Carnegie designation.

Although the undergraduate reformed science courses varied along a continuum based on the level of reform, the courses shared the following features: 1) all of the students were involved in inquiry/investigative processes of science, 2) all of the students were involved in small collaborative and cooperative groups during course activities, and 3) all of the students were involved in alternative assessments rather than traditional forms of assessment. The reform courses were the product of the NASA Opportunities for Visionary Academics (NASA/NOVA) professional development program that spanned from 1995-2006. The NASA/NOVA project was developed to facilitate change in higher education to enhance science, mathematics, and technology literacy of preservice teachers. The faculty of the comparison courses did not participate in the NASA/NOVA professional development training for the enhancement of their courses.

Population

The population for this study comprised 103 higher education institutions throughout the United States in which undergraduate reform courses were taught as a direct result of participation in the NASA Opportunities for Visionary Academics (NASA/NOVA) professional development project (Sunal et al., 2008). In the 1990s, faculty of science, technology, engineering, and mathematics expressed a need for professional development that focused on “inquiry oriented” undergraduate teaching. As a result of these expressed needs, guidelines were established that were incorporated into a national undergraduate faculty science professional development program that made use of standards-based reform practices (Sunal et al., 2008). These guidelines focused on the National Science Education Standards for science teaching and learning with emphasis on science content and pedagogical reform.

Sample

A purposeful, stratified sample of 30 institutions was drawn from the NASA/NOVA national population of 103 institutions. The selection was based on several selection variables. The variables included the following: (1) the reformed course was a science undergraduate course still being offered in an academic science department, (2) faculty at each institution agreed to participate in the study, (3) the variety of Carnegie levels that was representative of the population, and (4) the geographic diversity that was representative of the population. Purposeful, stratified sampling allowed the investigator to purposefully select a sample in which the phenomenon of interest could be studied. The phenomenon of interest in this study was the undergraduate reformed science courses and inservice elementary teacher pedagogical content knowledge. The population of 103 institutions comprised faculty who taught science, math, engineering, or technology (see Figure 2).

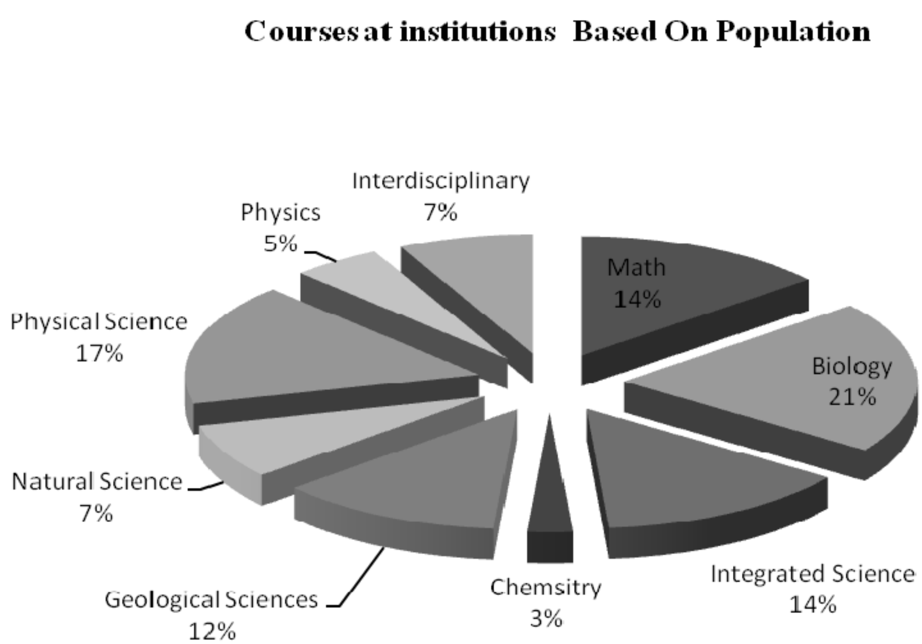

Figure 2. Courses at institutions based on population.

From this national population, faculty at institutions who had participated in the NASA/NOVA professional development project and who taught undergraduate science were invited to participate in the NSEUS study. Faculty were called and emailed to solicit their participation. A sample of 30 institutions was finally selected. Due to attrition and/or the dissolving of courses at some of the institutions, the final sample size resulted in 19 higher education institutions being used for data collection. The institutions that participated in this study were located throughout the nation (see Figure 3 for geographical distribution of population institutions).

Geographical Distribution of Population Institutions that Participated in Study

Figure 3. Geographical distribution of population institutions that participated in the study.

At each of these institutions, one reform course was matched with one comparison undergraduate science course. Data were collected from faculty in both reformed and comparison courses, and their former students who were now kindergarten through sixth grade elementary teachers. The reformed courses were patterned on the goals of the *National Science Education Standards* (NRC, 1996) and the National Science Foundation's guidelines for undergraduate courses as provided in the 1996 document *Shaping the Future* for science teaching and learning (NSF, 1996). The comparison course was of comparable subject and academic level that was not developed through NASA/NOVA. Both courses were either required or served as an elective in the elementary education program at the institution. Students signed up for these courses as a part of their undergraduate program and not because the course was considered a reformed science course. Science courses included: biology, chemistry, integrated science; natural science; geological sciences, and physics (see Figure 4).

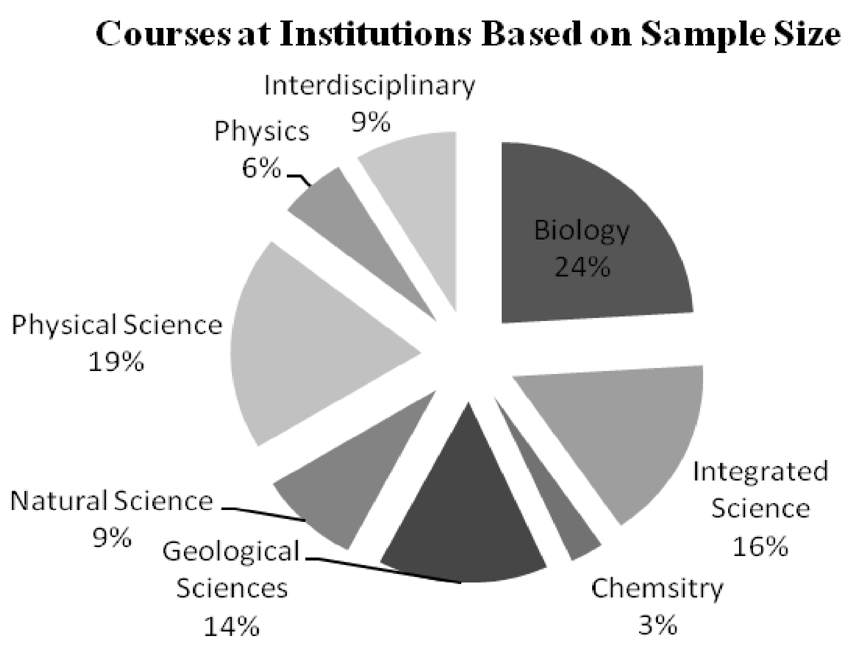

Figure 4. Courses at institutions based on sample size.

The participants included 35 faculty instructors and 91 Kindergarten-6th grade elementary teachers. The faculty instructors of the reformed courses participated directly or indirectly in the NASA/NOVA program and were implementing reform practices in their respective undergraduate classrooms. Some faculty instructors inherited the reform course from a previous instructor who had participated in the project; thus, the course was a reformed course but the faculty had not participated directly in the NASA/NOVA project and did not necessarily implement standards-based reform practices.

A faculty liaison was identified to help facilitate the site visit at each campus locality. The liaison was responsible for ensuring that the investigator had contact information and schedules for the faculty instructors and inservice elementary teachers as to the times available to conduct the classroom observations and interviews. The liaison contacted the faculty instructors of reformed and comparison courses to set up a time for the classroom observations and interviews. Permission was secured from each institution to conduct the observations and interviews as required by the *Institutional Review Board* (IRB). Once permission was secured, faculty instructors identified former students who were now inservice elementary teachers for participation in the study. The liaison provided the dates and times as to when site visits to the University and the elementary schools could take place.

Campus site visits lasted for a minimum of 1 week in duration. These were intense site visits that involved a minimum of two classroom observations and one interview for each faculty instructor, one classroom observation and interview for six elementary inservice teachers, and an undergraduate student focus group interview for each faculty instructors. Thirty-five faculty instructors were observed teaching in all lectures, discussion groups, other sessions, and labs during that week for each course. Faculty instructors were also interviewed using a set of predetermined questions. The Reformed Observation Teaching Protocol (RTOP) was used to conduct the classroom observations. The RTOP was designed by Sawada, Piburn, Turley, Falconer, Benford, Bloom, and Judson (2000) for the Arizona Collaborative for Excellence in the Preparation of Teachers (ACEPT) to assess the degree to which math or science instruction is reformed. Inservice elementary teachers who had experienced and completed the reformed or comparison courses were contacted by the liaison from the University to see if they would be willing to participate in the study. Once teachers agreed to participate in the study, the liaison acquired permission from the school was located or school district to conduct observations and interviews as required by the IRB. Once the IRBs were completed and secured by the liaison, teachers provided a date as to the time most convenient for the classroom observation of a science lesson and personal interviews.

Ninety-one inservice elementary teachers were observed using the RTOP instrument and interviewed using semi-structured interview questions, to assess the amount of reform instruction and to capture snapshots of PCK. Teachers were observed once teaching a science lesson. Loughran and Berry (2004) considered this a limitation because of the difficulties in trying to capture PCK in just one setting since PCK may across a number of lessons or one unit. Prior to the classroom observation, teachers participated in a structured interview. Table 2 provides a general overview of the schedule of events occurring during the course of one week for each site visit.

Initial quantitative analysis of classroom observations with faculty instructors and using SPSS 19 enabled me to determine whether there were indeed observed pedagogical differences between faculty instructors of the reformed courses and faculty instructors of the comparison course. Also, initial quantitative analysis of classroom observations with inservice elementary teachers enabled me to determine whether observed pedagogical differences existed between inservice elementary teachers who took the reformed science course during their undergraduate programs and those who did not. After initial quantitative analysis of classroom observations with faculty instructors, the faculty instructors were divided into three groups based on their RTOP scores to investigate the level of reform practices on the pedagogical practices of inservice elementary who took these courses.

Faculty instructors were placed into high, medium, and low RTOP groups based on their RTOP scores and regardless of their reform or comparison status. Low RTOP scores ranged between 0 and 33, medium RTOP scores ranged between 34 and 67, and high RTOP scores ranged between 68 and 100. The RTOP scores of faculty placed in the high RTOP group were used to predict reformed instruction in kindergarten-6th grade elementary classrooms using the RTOP scores of the elementary teachers who took their courses during their undergraduate program. A total of 17 faculty instructors comprised the high RTOP group along with their 46 inservice elementary teachers. Once the investigator was able to determine if the level of reform instruction predicted the type of classroom instruction seen in the elementary classroom, then additional analysis was conducted.

Pedagogical content knowledge analyses were conducted with the faculty instructors in the high RTOP group and their inservice elementary teachers. Typically, each faculty instructor, reform and comparison, had three inservice elementary teachers that were observed and interviewed. However, in some cases faculty instructors had less than or greater than three teachers. Pedagogical content analysis was only conducted with the faculty instructors who had three inservice elementary teachers. Pedagogical content analysis was conducted with seven faculty instructors and 21 inservice elementary teachers (see Figure 5 for selection sample).

Observations and Interviews conducted with faculty instructors of reformed course (N=21) and comparison course (N=14)

Faculty divided into low, medium, and high RTOP groups based on RTOP scores

RTOP scores of Faculty in high RTOP (N=17) group used as a predictor of reformed pedagogical instruction in elementary

PCK analysis conducted with faculty instructors (N=7) with three inservice teachers

Observations and interviews conducted with graduated inservice elementary teachers who took the reform course (N=56) and those who did not (N=35)

Inservice elementary teachers teachers of faculty instructors designated to high RTOP group (N=47) analyzed for reformed pedagogical instruction

PCK analysis was done with 21 inservice elementary teachers to develop PCK snapshots

Figure 5. Sample selection process.

Sample Timeline for a Campus On-site Visit

Table 2

Timeline of Site Visit

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday
	Faculty Interview (60 to 90 minutes)	Teacher Interview (30 to 45 minutes)	Faculty classroom observation (60 -90 min)	Teacher Interview (30 to 45 minutes)	Additional Interviews/ Observations
	Faculty Classroom Observation (90 minutes)	Teacher Observation (30 to 45 minutes)	Teacher Interview (30 to 45 minutes)	Teacher Observation (30 to 45 minutes)	Wrap-Up
			Teacher classroom observation (30-60 min)		
	Break	Break	Break	Break	
Meeting with Liaison for Dinner to discuss week's events.	Teacher Interview (30-45 min)	Teacher interview (30 to 45 minutes)	Teacher interview (30 to 45 minutes)	Teacher interview (30 to 45 minutes)	
	Teacher classroom observation (30-60min)	Teacher classroom observation (30-60min)	Teacher classroom observation (30-60min)	Teacher classroom observation (30-60min)	
	Faculty Interview (60 to 90 minutes)	Faculty lab observation (60 – 90 min)	Debrief	Faculty lab observation (60 – 90 min)	
	Debrief	Undergraduate Student Focus Group Interviews		Undergraduate Student Focus Group Interviews	
		Debrief		Debrief	

Description of Reformed Classroom Instruction

Within the context of this study reform is based on the *National Science Education Standards* (National Research Council, 2000)*, and Inquiry and* the *National Science Education Standards* (National Academy Press, 2000). When conducting the classroom observations, the investigator looked for the following characteristics that were emphasized during the NASA/NOVA professional development workshop and those that coincided with the NSEUS study (Sunal et al., 2008). These characteristics included the following: (1) student-centered instruction, (2) engaging students' prior knowledge, (3) use of structured and guided inquiry as a regular part of instruction, (4) integrated learning formats (i.e. combination of lecture and lab), (5) use of cooperative student groups that focused on interactive and collaborative learning, (6) emphasis on the processes of science, and (7) emphasis on content that is relevant to student lives. When conducting classroom observations with kindergarten-6th grade elementary teachers, the investigator looked for characteristics that are based on the National Science Education Standards for science teaching and learning. These characteristics include the following: (1) student-centered instruction, (2) emphasis on the processes of science, (3) use of structured and guided inquiry emphasizing the five essential features of inquiry, (4) use of cooperative student groups that focus on interactive and collaborative learning, and (5) engaging students' prior knowledge.

Interviews were used to inform the use of reform practices of faculty and inservice elementary teachers. When conducting interviews with the faculty, the investigator looked for words or phrases to understand faculty use of and rationale for reform practices. The investigator listened for words or phrases such as (1) less is more, (2) science literacy or students will need to know this information for use in their daily lives, (3) student prior knowledge or learning difficulties, (4) content should be relevant or practical to students' lives, (5) activities or experiments that aid in student understanding of content, and (6) activities that help students understand science as a process. When conducting interviews with the inservice elementary teachers the investigator looked for words or phrases such as (1) engaging students' prior knowledge or experiences, (2) hands-on activities, (3) student misconceptions, (4) cooperative learning, (5) content must be practical, and (6) students having to know information because of state assessments.

Instrumentation

The research instruments for this study comprised structured interviews for the Content Representation (CoRe) (see Appendix A), PaP-eRs derived from classroom observations, the Reformed Teaching Observational Protocol (RTOP) (see Appendix B), and PCK rubrics (see Appendix G). These instruments were vetted with the research literature on conducting classroom observations using the RTOP and examining pedagogical content knowledge using the CoRe and PaP-eR.

Content Representation

A Content Representation (CoRe) provides an overview of how teachers conceptualize the content of a particular subject matter or topic (Loughran et al., 2007). Loughran et al. suggested that whether or not a particular action by a teacher is illustrative of that teacher's PCK is closely related to the thinking upon which the teacher reasons through and develops the subsequent teaching action. Thus, the representations of topic specific PCK delineated in this study serve specifically to make explicit the nature of teachers' pedagogical reasoning and the associated decision making within the context of the teaching of that particular science content. The CoRe, then, links the how, why, and what of science content to be taught with what they agree to be important in shaping students' learning and teachers' teaching. For the CoRe, I draw upon the framework of Mulhall, Berry, and Loughran (2003). Using this framework, the CoRe is constructed based on how each faculty and teacher develops knowledge about science content and learners that enable them to make decisions about (1) curriculum and (2) instructional decisions. The CoRe draws upon questions derived from the interview and comprises these major categories:

Grade Level--It is important to emphasize that a CoRe refers to a particular type of class.

Big Ideas--The "big ideas" refers to the science ideas that the teacher sees as crucial for students to develop their understanding of a specific topic.

What you intend the student to learn about these ideas?--This is the starting point for unpacking the big ideas. This question informs the investigator as to the science teachers' understanding of what matters in a particular content area and why it is important.

Why it is important for students to know this?--In making decisions about what to teach, successful teachers draw on their knowledge of what science content is relevant to students' everyday lives and how the content links with other areas that students study.

What else you might know about this idea that you don't intend students to know yet--When selecting what to teach, teachers often make difficult decisions about which content should be omitted. Indeed, as noted earlier, constructivist perspectives of learning recognize that teaching for understanding takes time, which places limits on the range of what can be taught.

What do you anticipate will be some of the difficulties and/or limitations connected with teaching this idea?--Involves teachers' insights into the potential difficulties when teaching a particular topic to the class in question was an important aspect of teachers' PCK.

What knowledge about students' thinking influences your teaching of this idea? This part of the CoRe makes explicit the influence on their decision-making of teachers' experience in teaching this topic. When planning lessons, teachers draw on their knowledge about commonly held ideas about the topic that students bring to class (the importance of which is highlighted by the "alternative conceptions" literature mentioned earlier) and also the usual responses (including level of interest) of students to specific teaching and learning situations.

What are other factors that influence your teaching of this idea? Contextual knowledge about students and general pedagogical knowledge that influences the teaching approach are indicated in this part of the CoRe.

Describe how you will teach the main ideas in this lesson? Why will you be using this procedure to teach these main ideas? The term "procedures" acknowledges that from a constructivist perspective, student change in terms of learning is gradual and involves the students' active engagement with the science ideas under consideration. Teaching procedures cannot guarantee learning: rather their purpose from a constructivist perspective is to influence student thinking in ways that promote better understanding of science ideas.

What are the specific ways you will use to determine students' understanding or confusion around this idea? Teachers need to constantly monitor the progress of students' understanding so that they can determine the effectiveness of their teaching of the topic and plan future lessons. While summative assessment is usually explicit, teachers' formative assessment is often unacknowledged and implicit, and probably more specific to the topic being studied.

The CoRe questions were developed by Loughran et al. (2000) after extensive revisions. They wanted to find a way to make PCK accessible to science teachers. They found from working with various science teachers that PCK in not a “individual item but a mixture of items” that varied with the “context of the teaching and learning situation.” They suggested that several interacting elements inform PCK. These elements include (1) views of learning, (2) views of teaching, (3) understanding of content, (4) knowledge of students’ science alternative conceptions, (5) context (school, classroom), (6) understanding of students, (7) views of scientific knowledge, (8) decision making, (9) pedagogical practice, (10) reflection, and (11) explicit vs. tacit knowledge of practice/beliefs/ideas.

Loughran et al. (2000) spent several hours discussing what was emerging from working with science teachers on PCK. They also developed a workshop activity to be used with expert science teachers at the annual Science Teacher’s Association of Victoria Conference to obtain information about their knowledge of how to teach a particular science concept well. The teachers used the questions that comprise the CoRe to discuss what aspects of science teaching are important to know when teaching a particular science concept. The teacher’s affirmation of the questions validated the items that Loughran and his colleagues deemed important in representing PCK (Ogletree, 2007).

Pedagogical and Professional Experience Repertoire

Classrooms observations comprised the Pedagogical and Professional experience Repertoire (PaP-eR). PaP-eRs are narrative accounts of a teacher’s PCK for a particular piece of science content. Each PaP-eR then “unpacks” the teacher’s thinking around an element of PCK for that content, and is based on classroom observations and comments made by teachers during the interviews from which the CoRes were developed (Mulhall et al., 2003). PaP-eRs are intended to represent the teacher's reasoning, that is, the thinking and actions of a successful science teacher in teaching a specific aspect of science content. The function of the narrative is to elaborate and give insight into the interacting elements of the teacher's PCK in ways that are meaningful and accessible to the reader, and that may serve to foster reflection in the reader about the PCK under consideration, and to open the teacher reader to possibilities for change in his/her own practice (Mulhall et al.). The voice of a Pap-eR then will vary depending on that which is being portrayed. PaP-eRs bring the CoRe to life and offer one way of capturing the holistic nature and complexity of PCK in ways that are not possible with the CoRe alone (Loughran et al., 2006).

The CoRe and PaP-eR were developed and revised by Loughran et al. (2001, 2004; 2008) in order to examine the nature of teacher's pedagogical content knowledge and found to have inter-rater reliability.

Reformed Teaching Observational Protocol

The *Reformed Teaching Observation Protocol* (RTOP) is a classroom observation protocol designed to measure quantitative characterization of the degree to which a science classroom is "reformed" (Sawada & Piburn, 2000). For this instrument, the characteristics of reformed teaching practices are based on the national standards for science education. The instrument draws on the following sources:

1) National Council for the Teaching of Mathematics. *Curriculum and Evaluation Standards* (1989);

2) *Professional Teaching Standards* (1991) and Assessment Standards (1995). National Academy of Science, National Research Council. *National Science Education Standards* (1995); and
3) American Association for the Advancement of Science, Project 2061. *Science for All Americans* (1990), *Benchmarks for Scientific Literacy* (1993).

The RTOP is criterion-referenced, and observers' judgments should not reflect a comparison with any other instructional setting than the one being evaluated (Sawada & Piburn, 2000). It can be used at all levels, from primary school through university. The instrument contains 25 items, with each rated on a scale from 0 (*not observed*) to 4 (*very descriptive*). Possible scores range from 0 to 100 points, with higher scores reflecting a greater degree of reform. The RTOP is divided into the following three categories: (1) *Lesson Design and Implementation* (5), (2) *Content* (10), and (3) *Classroom Culture* (10). The second and third categories are divided into subcategories of five items each. That is, Content comprises Propositional and Procedural knowledge and Classroom Culture comprises Communicative Interactions and Student Teacher Relationships.

The first category, *Lesson Design and Implementation*, describes a lesson that (1) begins with recognition of students' prior knowledge and preconceptions, (2) attempts to engage students as members of a learning community, (3) values a variety of solutions to problems, and (4) takes its direction from ideas generated by students (Sawada & Piburn, 2000). The second category, *Content*, was divided into the following sub-categories: (1) *Propositional Knowledge*; and (2) *Procedural Knowledge*. The first subcategory assessed the quality of the content of the lesson while the second assessed the process of inquiry. The third category is a measure of students being fully engaged and working in groups in the solution of complex problems, student-to-student interactions, and the idea of teacher as facilitator of student learning.

The RTOP has been used in different settings to assess the degree of reformed instruction (Judson & Sawada, 2001; MacIsaac & Falconer, 2002; Ogletree, 2007) and was found to have a reliability score of 0.954. In terms of construct validity, the RTOP is based on the following two principles of reform: (1) standards-based and (2) inquiry-based. Sawada and Piburn (2000) note that the standards are diverse, with well over 100 individual content specifications in science while the inquiry-orientation component is more of a coherent approach to all subject matter. With this in mind, the RTOP was designed to span a range of standards within the breadth of the five subscales while acknowledging the priority of inquiry orientation. The authors found that the each subscale was a good predictor of the total RTOP score: *Lesson Design & Implementation*, r^2= 0.956; *Propositional Knowledge*, r^2= 769; *Procedural Knowledge*, r^2= .971; *Communicative Interactions*, r^2= .967; and *Student/Teacher Interactions*, r^2= .941. Inquiry orientation was found to be a strong integrative force in the RTOP.

Pedagogical Content Knowledge Rubric

Researcher designed rubrics were used to evaluate “snapshots” of pedagogical content knowledge for faculty instructors and inservice Kindergarten-6th grade elementary teachers. Because PCK is expert knowledge that resides within the individual and specific to that individual, then each faculty instructor and inservice teacher was evaluated on an individual basis. Rubrics are tools of evaluation that lists criteria using gradation of quality to evaluate work. They are flexible, easy to explain, and easy to use (Anderson & Puckett, 2003). Part of the initial design for the rubrics used in my study came from a careful examination of the rubrics designed by Ogletree (2007) in her examination of 5th grade elementary teacher's pedagogical content knowledge for states of matter. Ogletree's four rubrics included (1) content knowledge, (2) student thinking, (3) science teacher knowledge, and (4) professional development. The PCK rubric used in this study assesses PCK holistically, rather than assessing the individual components, by providing an overall PCK rating based on a combination of their content and pedagogical knowledge as evidenced in their interviews, CoRe & PaP-eR, and classroom observations.

There is no universally accepted means by which PCK has been measured (Friedrichsen et al., 2011). Thus, the researcher designed rubric used in this study is based on Schulman's (1986), Grossman's (1990), and Magnussen et al.'s (1999) notion of PCK, which comprised (1) orientations toward science teaching, (2) content knowledge, and (3) pedagogical knowledge. This rubric was used to evaluate teacher interviews, CoRe and PaP-eRs, and RTOPs in order to determine orientations, content, and pedagogical knowledge relative to a specific topic. (See Appendix A for the PCK rubric.) This rubric was used qualitatively to ascertain snapshots of individual inservice elementary teachers' PCK. Because PCK cannot necessarily be gauged from one classroom observation, I use the term snapshots to describe instances of specific events characteristic of PCK.

Inter-rater reliability and validity for the PCK rubric was achieved through consultation with Science Educator Specialists with teaching experience in Kindergarten-Grade16 classrooms. These individuals were experts in their respective fields and had expert knowledge in physics, physical science, biology, and chemistry. Each specialist evaluated the interviews, CoRe and PaP-eRs, and RTOPS of two teachers using the PCK framework, PCK checklist, and PCK rubric to come up with an overall PCK rating for the two teachers. The scores and comments of the specialists were the same as that of the investigator. I believe that the researcher designed framework and rubric are a powerful tool that can be used to assess the level of pedagogical content knowledge with Kindergarten-6th grade elementary teachers.

Table 3 presents an overview of the research methodology corresponding to each research question for this study. Included are the research questions and the researcher's intent behind asking those specific questions. In addition, the table provides the instruments that will be used to analyze each research question and the quantitative and qualitative analysis that will be performed in order to answer each question.

Table 3

Overview of Research Methodology Corresponding to Each Research Question

Research Question	Intent	Instruments	Rating Scale	Method of Analysis
1. Are there pedagogical differences between reform and comparison undergraduate courses?	To determine if there are differences in the type of instruction in both reform and comparison courses	Reformed Teaching Observational Protocol (RTOP)	0=the behavior never occurred 1= the behavior occurred at least once 2=occurred more than once; very loosely describes the lesson 3=a frequent behavior or fairly descriptive of the lesson 4= pervasive or extremely descriptive of the lesson	Multivariate Analysis of Variance (MANOVA)
2. Are there instructional differences between elementary teachers who experienced reformed instruction during their undergraduate programs and those who did not as based on observed pedagogical differences?	To determine if there are differences in the type of instruction exhibited by teachers who experienced the reform courses during their programs and those who did not.	Reformed Teaching Observational Protocol (RTOP)	0=the behavior never occurred 1= the behavior occurred at least once 2=occurred more than once; very loosely describes the lesson 3=a frequent behavior or fairly descriptive of the lesson 4= pervasive or extremely descriptive of the lesson	Multivariate Analysis of Variance (MANOVA)

(*table continues*)

Research Question	Intent	Instruments	Rating Scale	Method of Analysis
3. Is the level of pedagogical reform experienced in an undergraduate science course a predictor of the type of science teaching at the elementary level?	To determine if the undergraduate science reform courses are significant predictors of reform instruction of inservice elementary teachers	Reformed Teaching Observational Protocol (RTOP)	0=the behavior never occurred 1= the behavior occurred at least once 2=occurred more than once; very loosely describes the lesson 3=a frequent behavior or fairly descriptive of the lesson 4= pervasive or extremely descriptive of the lesson	Regression Analysis
4. How is the level of pedagogical reform experienced in undergraduate science courses related to the Pedagogical Content Knowledge kindergarten-6th grade inservice teachers?	To delineate the components of the reform courses that shapes the pedagogical content knowledge of the inservice teachers.	Content Representation (CoRe) and the Pedagogical and Professional experience Repertoire (PaP-eR) Interviews		Pedagogical Content Knowledge Rubrics

Procedures for Data Collection Utilized

Data collection involved an intense week-long site visit to each of the 20 institutions and the elementary schools where the inservice teachers, who graduated from these institutions, were now teaching. As stated earlier, this study was a part of a larger longitudinal study that was conducted over a period of 5 years, 2006-2011. The overarching research question investigated in my study was, “what is the long-term impact of varying models of undergraduate science courses on the pedagogical content knowledge of inservice teachers? The use of both quantitative and qualitative methods strengthened my research design and allowed for the triangulation of the data. The researcher was able to triangulate data from the literature, the interviews, and the classroom observations. At the outset of the study, I along with each data collector received online and on-site training as to how to use the RTOP. In addition, the researchers met face to face to conduct classroom observations in which we individually scored the RTOPs and discussed our ratings immediately after the RTOPs were scored to resolve any discrepancies between researcher ratings thereby ensuring inter-rater reliability.

Each site visit was typically 1 week in length. The research team arrived on Sunday to meet with the liaison for dinner to discuss the week’s itinerary. At this time, we secured any documents that had not already been mailed prior to the visit. We met with the faculty instructors on the following Monday. Faculty instructors were visited twice during the week to observe a classroom lecture and lab or an integrated course. Each observation typically lasted between 60 to 90 minutes. An RTOP was completed for each classroom observation for each faculty instructor to yield an average overall RTOP score (see Appendix B for complete RTOP). The RTOP instrument was individually scored immediately during and after the classroom observation and then discussed to resolve any discrepancies between observer ratings. Each faculty instructor was also interviewed regarding the lesson observed. Faculty interviews lasted anywhere from 45-60 minutes (see Appendix C for complete faculty instructor interview). Questions asked during the faculty interview, followed by probing questions to expand on the response, included the following: (a) How long have you been teaching at the undergraduate level? (b) Please describe the extent of this experience. (c) What was the important knowledge and skills you needed to develop and teach this course? (d) Describe how you will teach these main ideas or concepts, and explain why you chose to use these strategies. and (e) What knowledge about students' thinking and/or learning influences the teaching of these ideas or concepts?

After the classroom observations and interviews were completed for each faculty instructor, a CoRe was constructed from the interviews and a PaP-eR was constructed from the classroom observation. Prior to the classroom observations and interview, I or one of my colleagues discussed the purpose of the project and the means by which privacy and confidentiality would be established. Once the faculty instructor agreed to continue with participation in the study, a consent formed was signed and stored in a secure location in which the primary investigator of the study had the only access. The faculty instructor secured student volunteers to participate in the undergraduate student focus groups. The undergraduate student focus groups were interviewed after the classroom observation of the faculty instructor. I or one of my colleagues explained the nature of the study and the means by which privacy and confidentiality would be established to the undergraduate students. We also informed them that their participation in the interview was completely voluntary. Once the students agreed to continue with participation in the study, consent forms were received from each student.

Classroom observations and interviews were conducted with Kindergarten-6th grade inservice elementary teachers. There were typically three teachers who took the reform course and three teachers that took the comparison course that participated in the study. In some cases however, greater than or less than three teachers for each faculty instructors were observed and interviewed. The elementary teachers were observed once during the week using the *Reformed Teaching Observational Protocol* (RTOP). The classroom observations conducted with the elementary teachers typically lasted between 20-50 minutes. An RTOP was completed for each classroom observation conducted with each elementary teacher. Immediately following the classroom observation, the elementary teacher was interviewed.

Interviews were conducted with elementary teachers immediately before or after their classroom observations, for about 30 to 50 minutes, depending on their schedule (see Appendix D for complete inservice elementary teacher interview). Questions from the elementary teacher interviews, followed by probing questions to expand on their responses, include the following: (a) How would you define the nature of science? (b) What do you feel is the best way to teach science in elementary classrooms and why? (c) Which instructional strategies (activities, assignments, etc.) did you experience as most beneficial to your learning science at the university? and (d) Describe how you will teach these main ideas. After the classroom observation and interviews were completed for each elementary teacher, a CoRe was constructed from the interviews. Using field notes from the classroom observations and additional artifacts, a PaP-eR was constructed and added to the CoRe. The italicized comments on the CoRe represent the PaP-eR (See Appendix F for an example of the CoRe and PaP-eR).

CoRe and PaP-eRs were evaluated using the PCK rubric to capture “Snapshots” of PCK for each faculty instructor and each inservice elementary teacher regarding their orientation toward science teaching, content knowledge, and pedagogical knowledge. Prior to classroom observations and interviews, I or one of my colleagues discussed with each teacher the nature of the study and the means by which privacy and confidentiality would be established. Once the elementary teachers agreed to continue with participation in the study a consent form was secured.

The quantitative phase of the data collection comprised the classroom observations of faculty instructors and inservice elementary teachers. The qualitative phase of the data collection was comprised of the interviews and the completion the CoRe and PaP-eRs. The RTOPs were also used to corroborate statements made concerning the teaching of a particular topic in the interview. Careful examination of the interviews, CoRe and PaP-eRs, and RTOPs using the PCK rubric yielded "snapshots" of PCK for faculty instructors and inservice elementary teachers. The science instruction observed, as well as the information provided in the interviews, provided insight as to the faculty instructors and the inservice elementary teacher's orientation toward teaching science, topic specific content knowledge, and their rationale for the instructional strategy used to teach that particular science topic.

Data Analysis

Data analysis comprised the use of various quantitative computational procedures as well as the qualitative evaluation of categories from the interviews along with the CoRes and PaP-eRs. Faculty were divided into those who taught the reform course and those who taught the comparison course. Faculty of the reform course participated in the NASA/NOVA professional development project or inherited the course from someone who had previously participated in the project. Characteristics of the reform course related to the *National Science Education*

Standards appropriate for science teaching and learning at the undergraduate level. The comparison course was a course of comparable subject and academic level that was not developed through NASA/NOVA professional development workshop. The comparison course was a science course that included a lecture and a lab. In order to determine if there were statistically significant differences between the reform and the comparison course, a Multivariate Analysis of Variance (MANOVA) was performed. The Statistical Package for the Social Sciences version 19 (SPSS 19) was used for all statistical procedures. In order to determine if there were statistically significant differences in the classroom instruction of those inservice elementary teachers who had taken the reform courses and those who had taken the comparison courses during their undergraduate program, a MANOVA was also performed.

Regression analysis was used to determine whether the level of reform experienced in these undergraduate science courses was a predictor of observed pedagogical instruction in the elementary classrooms. Faculty instructors were divided into high, medium, and low RTOP groups regardless of whether or not they taught the reform or comparison course based on their overall RTOP scores. The RTOP scores ranged between 0 and 100. Faculty instructors who scored between 0 and 33 were placed in the low RTOP group; faculty instructors who scored between 34 and 67 were placed in the medium RTOP group; and faculty instructors with RTOP scores of 68 or better were placed in the high RTOP group. The RTOP subscale scores were then used to predict reform instruction in elementary classrooms based on the overall RTOP scores of their graduated, inservice elementary teachers.

Interviews were coded using a set of predetermined categories to capture “snapshots” of the pedagogical content knowledge of faculty instructors and their inservice elementary teachers. Salient themes emerging from the interviews were also noted. From the interviews and classroom observations, CoRes and PaP-eRs were constructed and evaluated on each faculty instructor and inservice elementary teacher to yield a snapshot of PCK. The interview and the CoRe and PaP-eR were analyzed using the PCK framework (see Appendix F). The PCK framework was vetted with the literature on PCK and is based upon Shulman's (1986); Grossman's (1990); and, Magnussen, Borko, and Krajcik's (1999) work with PCK. The PCK framework focused on *Orientations toward Science Teaching (OST)*; *Content Knowledge*; and *Pedagogical Knowledge*. The PCK framework was used to develop a PCK checklist for each faculty instructor and each of the inservice elementary teachers (see Appendix F for the PCK checklist). Based on the components of the checklist, the PCK rubric was used to provide an overall PCK rating for each faculty instructor and each inservice elementary teacher (see Appendix G for PCK rubric) (see Table 4 for an example of the PCK checklist for an inservice elementary teacher). Using the PCK checklist and the overall PCK rating, a snapshot was written for seven of the faculty instructors and 21 inservice elementary teachers (see Table 4 for PCK checklist example).

Orientations toward science teaching are generally organized according to the emphasis of instruction. These orientations are described with regard to the goals of teaching science that a teacher with a particular orientation would have and the typical characteristics of the instruction that would be conducted by a teacher with a particular orientation (Magnussen et al., 1999). Questions from the interview and the CoRe and PaP-eR informed the OST category and include (1) Has your understanding of science teaching (i.e. pedagogy, methods, implementing curriculum) and the ways in which you teach science changed as a result of a single university course or set of courses? If so, in what ways? (2) What do you feel is the best way to teach science in elementary classrooms? Why? Do you feel as though this is the way that you teach science in your classroom? Why or why not. These questions allowed the investigator to understand the inservice elementary teacher's beliefs about how science should be taught and the rationale for that belief. (3) Which instructional strategies (activities, assignments, etc.) did you experience as most beneficial to your learning science at the university? and (4) What do you feel is the best way to teach science in elementary classrooms? Why? Do you feel as though this is the way that you teach science in your classroom? Why or why not.

Understanding the teacher's orientation toward science teaching allowed me to understand the teacher's purpose behind particular strategies that they use in teaching a specific science concept. Content knowledge is defined as the concepts, principles, relationships, processes, and applications a student should know within a given academic subject, appropriate for his/her and organization of the knowledge (Ozden, 2008). Questions that informed the teacher's content knowledge were taken from the interview and the CoRe and PaP-eR: (1) How many university level science courses have you taken? (2) How would you define the nature of science? (3) What will be the main ideas of the lesson? (4) What do you intend students to learn about these ideas? and (5) What content courses do you feel most comfortable teaching. Elementary teachers tend to be generalist and not science specialist (Schwartz & Gess-Newsome, 2008). These questions provided the researcher with data as to the level of content knowledge of the inservice elementary teachers in this study; however, the data did not serve as an exhaustive means by which content knowledge was measured.

Pedagogical knowledge includes knowledge about student learning difficulties, prior knowledge, alternative conceptions, topic- specific instructional strategies, and knowledge of curriculum. Questions from the CoRe and PaP-eR and the interviews inform the pedagogical knowledge category. Some of the questions that inform this include (1) Have you taken any university level science education courses (i.e. teaching methods or content courses for education majors)? How many? What courses? (2) Describe how you will teach the main ideas in this lesson. (3) What do you anticipate will be some difficulties and/or limitations connected with teaching this idea? and (4) What knowledge about students' thinking influences your teaching of this idea?

Table 4

PCK Checklist for an Inservice Elementary Teacher

Teacher	PCK Rating	RTOP Score	CK	PK	OST	Sources of PCK
Adrienne	Novice	54	Teacher has very little content knowledge on the topic of density; took 1 or possibly 2 undergraduate science courses (including the NOVA course); familiar with curriculum and state standards especially since testing drives instruction (Teachers teach the test); she was a special education major and admits that her lack of content knowledge affects her students learning; Also the teacher had several misconceptions as noted during her classroom observation. "*The particles are real close together but it is more dense this reflects a solid*" (*but some liquids are more dense can introduce misconceptions as observed by investigator*)	Teacher has not had any pedagogical training; says that hands-on activities and videos are the best way to teach science because most students are visual learners; does not consider the student prior knowledge or misconceptions concerning the concept of density (covers only material that will be tested); she says that the state objectives are also of least important because of the way they are structured within the curriculum (holes in student learning b/c of the need to cover so much material); concepts are taught in isolation b/c of mandate to cover a lot of material	Very traditional in her approach to science teaching; although teacher says that hands-on activities and videos are the best approach to science teaching she has no basis for this belief; seems to equate hands-on learning with student doing something regardless of whether it facilitates student understanding of topic	Little science content courses taken during her undergraduate program; Little PD for enhancing science teaching ; Most of her PD geared toward literacy; 1-2 content courses

Currently, there is no standard mean by which to capture or measure an individual’s PCK (Friedrichson, Van Driel, & Abell, 2011); however, the investigator used both quantitative and qualitative data from classroom observations, field notes, and interviews in an attempt to capture “snapshots” of PCK. The quantitative analysis of the RTOPs and its corresponding subscales provided insight as to the amount of reform instruction observed during the classroom observations of both faculty and inservice teachers. The RTOP alone did not provide insight as to the teacher’s rationale for choosing a particular teaching strategy to teach the science concept observed during a lesson. The essential component of PCK is the ability of the teacher to transform subject matter into a form that is understandable and accessible to students. This component is based upon their knowledge of the prerequisite skills students need for the learning of a particular topic as well as their prior knowledge and experiences. The interviews, along with the CoRe and PaP-eR, allowed the investigator to examine the decision making aspect of teaching practice. That is, why faculty instructors and inservice elementary teachers chose certain strategies to teach specific science concepts and what they knew about their students that inform these choices.

From the quantitative and qualitative analysis of data, snapshots were developed with a select group of faculty instructors and inservice elementary teachers.

Summary

In chapter III, a detailed account of the methods used to facilitate this study are presented. The setting, participants, instrumentation, data collection and procedures, and data analysis is discussed. A total of 20 institutions including 35 faculty and 91 inservice elementary teachers participated in the study. A mixed-methods approach was employed for the purposes of data triangulation to strengthen the research design. The data collected included classroom observations, interviews, and field notes collected from both faculty and inservice teachers.

CHAPTER IV

ANALYSIS OF DATA

The purpose of this study was to investigate the long-term impact of faculty created undergraduate science reform courses on the pedagogical content knowledge of inservice teachers who took these courses as part of their undergraduate programs. The research design involved a combination of quantitative procedures complimented by qualitative data. The quantitative portion of this study involved classroom observations of 35 faculty and 91 elementary teachers throughout the United States. The classroom observations were measured by the Reformed Teaching Observation Protocol (RTOP) to measure the degree of reform instruction. The qualitative phase of this study involved structured interviews of these same faculty and elementary inservice teachers. The secondary data used in this study was collected over a five year period, 2006-2011. Demographic information is presented for the participants along with the quantitative and qualitative results for each research question in the sections to follow.

Subjects

Thirty-five faculty instructors participated in this study. The participants included representatives from both genders: male (65.7%) and female (34.3%). The teaching experience of the faculty instructors ranged from 4 to 20-plus years of experience. In addition to the faculty instructors, 91 inservice elementary teachers participated in this study. The participants included representatives from both genders: male (15%) and female (85%). The teaching experience of the inservice elementary teach ranged from 0 to 10 or more years of experience.

Analysis of Results

Research Question 1

In order to answer research question number 1, “Are there pedagogical differences between reform and comparison undergraduate science courses,” an independent *t* test was used to compare the overall means of the reformed and comparison course for the total RTOP score and a multivariate analysis of variance was performed based on the subscales of the RTOP. Each faculty was observed using the RTOP instrument at least two times during the site visit. Two research team members were present to conduct the classroom visitations. The RTOPs were individually scored immediately after the classroom observation and then discussed to resolve any discrepancies between observer ratings. The labs and lecture were combined to give an average RTOP score for each faculty instructor. The RTOP instrument comprised 5 subscales: (a) Lesson Design and Implementation, (b) Propositional Knowledge, (c) Procedural Knowledge, (d) Communicative Interactions, and (5) Student Teacher Relationships. A total of 20 points can be accrued in each subscale with a maximum RTOP score on 100.

Results from the quantitative analysis of the data found a statistically significant difference in the total RTOP score between faculty who were instructors of reform and comparison undergraduate science courses, t (33, 2.997), p =.005. The means and standard deviations are presented in Table 5. Analysis of classroom observations on RTOP subscale scores between reformed and comparison courses found statistically significant group effects (Wilks = .028, $F[5, 29] = 3.756$, $p = .010$). Univariate analyses indicate no significant group effects on the Propositional Knowledge subscale [$F(1, 33) = 2.729$, $p = .108$]. However, Univariate analyses indicated significant group effects did occur on the Lesson Design and Implementation subscale [$F(1, 33) = 6.242$, $p = .018$], Procedural Knowledge subscale [$F(1, 33) = 6.978$, $p = .029$], Communicative Interactions subscale [$F(1, 33) = 13.298$, $p = .013$], and Student Teacher Relationships subscale [$F(1, 33) = 8.143$, $p = .007$]. Results of the MANOVA are presented in Tables 6 and 7. These results suggests that the level of reformed teaching in entry-level reformed undergraduate science courses is different from the comparison courses on all RTOP subscales other than the Propositional Knowledge subscale.

Table 5

Means and Standard Deviations for the Reform and Comparison Course

Course	N	Mean	Std. Deviation
Reform	21	70.8105	16.38429
Comparison	14	49.2879	26.20029

Table 6

Means and Standard Deviations for the Reform and Comparison Courses

	Course	Mean	Std. Deviation	N
Lesson Design & Implementation	Reform	12.651	4.053	21
	Comparison	8.3807	6.086	14
	Total	10.943	5.323	35
Propositional Knowledge	Reform	15.690	2.504	21
	Comparison	13.922	3.844	14
	Total	14.983	3.180	35
Procedural Knowledge	Reform	12.623	4.426	21
	Comparison	8.165	5.530	14
	Total	10.840	5.303	35
Communicative Interactions	Reform	14.573	3.675	21
	Comparison	8.707	5.865	14
	Total	12.227	5.440	35
Student Teacher Relationships	Reform	15.270	4.441	21
	Comparison	10.112	6.269	14
	Total	13.206	5.762	35

Table 7

MANOVA Results by RTOP Subscales

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
Course	Lesson Design & Implementation	153.242	1	153.242	6.242	.018
	Propositional Knowledge	26.267	1	26.267	2.729	.108
	Procedural Knowledge	166.947	1	166.947	6.978	.013
	Communicative Interactions	289.109	1	289.109	13.298	.001
	Student Teacher Relationships	223.469	1	223.469	8.143	.007
Error	Lesson Design & Implementation	810.196	33	24.551		
	Propositional Knowledge	317.592	33	9.624		
	Procedural Knowledge	789.536	33	23.925		
	Communicative Interactions	717.440	33	21.741		
	Student Teacher Relationships	905.602	33	27.442		
Total	Lesson Design & Implementation	5154.990	35			
	Propositional Knowledge	8201.168	35			
	Procedural Knowledge	5069.612	35			
	Communicative Interactions	6239.155	35			
	Student Teacher Relationships	7233.809	35			
Corrected Total	Lesson Design & Implementation	963.438	34			
	Propositional Knowledge	343.858	34			
	Procedural Knowledge	956.483	34			
	Communicative Interactions	1006.550	34			
	Student Teacher Relationships	1129.071	34			

The quantitative results of question one were enhanced by qualitative findings. Faculty instructors that taught the reformed course, taught in a more reformed manner. These faculty instructors were more inclined to suggest that a constructivist approach to classroom practice was the best approach to science teaching and learning. In addition, they were able to provide a rationale as to why constructivist practices were the best approach to science teaching and learning.

Frank had taught Physics for over 25 years and was a part of the original NASA/NOVA team. His RTOP score was 77.5, indicating that 77% of his observed and rated classroom instruction indicators were reformed. He said that the particular physics course that he taught to preservice elementary teachers was a content course but was aligned with inquiry practices. His other physics courses were geared toward physics majors and were more lecture-based. He believed that inquiry is the best approach to teaching science.

> I teach this course differently than I teach my regular physics courses. Physics courses are lecture based. . . . Physics (reformed course) is inquiry based. . . . Elicitation addresses prior knowledge and misconceptions. . . . Exploration is the discovery portion. . . . Explanation--students give presentations. . . . In the end they go over all the information discussed during the information discussed on a particular unit (instructor Frank).

The comments made by the undergraduate student focus group of this faculty instructor corroborated the instructional strategies employed by this faculty,

> At beginning of each unit, do brainstorm of all we know or don’t know . . . does demos for us . . . they are reinforced by us doing activities . . . occasionally about 20 min of lecture. (Student in focus group from instructor Frank’s course)

A second example of a faculty instructor was Eleanor who had been teaching science for over 15 years. Eleanor was also a part of the original NASA/NOVA team. She also adhered to a constructivist’s approach to teaching. She varied instruction to meet the diverse needs of her students. She believed that the teacher should serve as a coach in science teaching and learning. She stated the following in her interview,

> What do you recall about the circulatory system. . . . Taking a look at blood flow. . . . Case study on heart attack (what does heart attack have to do with blood flow--you have to know how something works--take fundamental concepts about circulatory and apply it to this disease). . . . Physiology--blood pressure (how does it tie it into circulatory system). Take a look at model of heart. . . . For each topic that I do there is some type of inquiry lesson and case studies along with viewing models. . . . (Faculty instructor Eleanor)

The comments made by the undergraduate student focus group of this faculty instructor supported the statement as to the type of instructional practice used during classroom instruction,

> Case studies really help. Because they are actual people and they tell about the background . . . tell you what's wrong. . . . I like the lab when she let us choose our own lab. We had a topic of homeostasis and we had to come up with our own lab but it was all centered around the same thing but we could pick what we wanted to do but it was not like a standard thing like "you do this and this or here are the directions" (*Referring to cookbook or traditional labs*) . . . it was kind of up to you to do what you want (*How does it make you feel)?* Empowered. . . . We have more options. . . . We do a lot of group work too. . . . If you are not very strong in one area it is not like you are copying from your teammates but you are learning it with them at the same time. (Students in focus group from instructor Eleanor's course)

James was an Adjunct Professor and had over 10 years teaching experience. James was also a part of the original NASA/NOVA faculty professional development project. He believed that science should be taught in a manner that is practical and relevant to students' lives and used activities that demonstrated this belief.

> I teach about the process of science. . . . To broaden their sense as to what science really is practicality of science . . . making connections between other disciplines and science . . . connections between what they may be interested in and science . . . part of the course involves a semester long project which involves studying the muddy river which is across the street. At the very beginning of the course I take them out and let them explore to develop their own interest in the muddy river and I am hoping that they will find something . . . a very, very simple question. . . . The reason that I do that is that I want them to find something that is theirs so throughout the whole semester they have something that is theirs. . . . Then I relate this to the process of science in the way that I described to you by discussing the process of science and characteristics of science. (Faculty instructor James)

The comments of James's undergraduate student focus group relate closely to some of these same statements about this faculty instructor's instructional practices.

> We're doing stuff . . . we are not just sitting there getting lectures . . . using the computer . . . like what we are doing with the virtual river working in small groups . . . interactive stuff rather than sitting there listening to the professor talk to us . . . even the virtual river isn't as hands-on as we get . . . we go outside and do our own project, it is really independent. . . . (*James*) is just overseeing it but we are really doing everything . . . I feel that the experiment that we do with the muddy river is much higher than what we are learning in the classroom to actually be able to do a bank profile up there is much more difficult than all sorts of other elements factor in . . . as much as I feel as though there is no fluidity in science I feel like it is much easier for me to learn when it's there and it is constant as far as going on in doing these hands on activities I feel like there is always so many more variables that are accounted for that could factor into things that all of sudden that throw my mind into a different space of what I thought. (Faculty instructor James)

Faculty instructor Bonnie had been teaching for 6 years. Although she was not a part of the original NASA/NOVA team, she attended several professional development workshops geared toward science education reform. She stated in her interview, "I learn a lot from talking with colleagues and attending meetings that discuss science education reform." Bonnie also participated in extensive ongoing professional development that provided training in reform pedagogical practices. Bonnie stated in her interview that the reform course had been developed about 10 years ago. She stated that prior to her teaching the class it was a traditional quantitative physics course. Her professional development experiences enabled to teach the course in a more reformed manner.

She believed that the teacher's role in science teaching should be that of a facilitator. She used modeling as an instructional strategy to teach the concept of circuits to her class. Students developed focus questions, made predictions and claims, and provided evidence about the model credibility. Students were able to explain circuits as well as troubleshoot as to why circuits may or may not work.

> Students explored circuits both series and parallel (more or less light); what runs down a battery faster. They also used a science notebook (focus questions, predictions, data collection, results, claims, and evidence and conclusions). . . . I have them experience the hands-on exploration and discuss how this can be transferred to an elementary classroom. We have a discussion to seek student input and clarification that ensues after the hands-on experience. Often, there is also a discussion beforehand to make predictions. (Faculty instructor Bonnie)

The undergraduate student focus group corroborated the statements put forth by this faculty instructor. The students reported that the instructional strategies employed by this faculty instructor helped them to understand the practicality of science concepts, the scientific process, and the mechanism by which circuits work in the manner that they do,

> I never thought of electricity and magnetism as science before this course. Yeah. I never made the link that those things were part of science. They seemed just mechanical. . . . I'll remember about circuits from working with them today . . . I know it works, but now I'm starting to get a grasp on how and why it works . . . I'm thinking more about the scientific process. In lab we always go through the process. . . . (Student in focus group from instructor's Bonnie's course)

Comments from the undergraduate student focus group of this faculty instructor also corroborated the idea that the faculty was more inclined to a constructivist approach to science teaching and learning whereby students learn by doing.

> When we get into class we talk a little bit about the activities and then we do it. . . . Then there is a little bit of lecture. . . . If you combined the whole class (this semester) he has lectured maybe 3 class periods. . . . We always do activities. . . . We learn through activities. (Student in focus group from instructor's Bonnie's course)

Faculty instructors of the comparison course taught in a more traditional manner. These faculty instructors were more inclined to spend the majority of the class time lecturing to their students. Laboratory instruction involved the use of "cookbook" labs that were separate from the lecture. In addition, faculty instructors of the comparison course did not attend professional development workshops for improving their science teaching and they did not collaborate with other colleagues about science education reform. Many of the faculty instructors stated that there was no administrative support for improving science instruction for their undergraduate students.

Adam had been teaching the comparison course, physical science, for 5 years. He stated in his interview that the majority of the professional development workshops that he had participated in were geared toward scientific research. He also stated that the administrative personnel did not support professional development workshops that are geared toward science teaching. Adam lectured for the entire class period with no student interaction.

> I try to engage students as much as I can. I use Blackboard to post my notes so that they can spend class time concentrating on what I am saying rather than copying down information. . . . There is a lack of administrative support for faculty to collaborate with one another, and to have pedagogical professional development rather than just research support. (Faculty instructor Adam)

The undergraduate student focus group corroborated the statements put forth by this faculty instructor. The students stated that Adam’s observed lesson was typical for this class and that the laboratory activities seemed to have nothing to do with the science concept taught during the lecture.

> It is kind of the same. We lecture over the chapter. I don’t think the labs have anything to do with what we have in lecture. . . . Simpler concepts are presented in a more complicated way. . . . I can work the problem in one step and he wants us to do many steps. (Student in focus group from instructor’s Adam’s course)

Gertrude had been teaching for over 30 years. She had not participated in any professional development workshops for improving science instruction and did not collaborate with any of her colleagues regarding science education reform. She considered herself to be an expert science faculty. Her predominant method of instruction was “lecture” and “lab.” When asked what knowledge about students’ thinking and/or learning influenced her teaching, she stated, “Who the heck knows.”

Karen had taught the comparison course for 10 years. She had participated in workshops for homework, clickers, and student learning. Karen knew that science teaching and learning should be hands-on and engaging; however, she said that she did not have the time to set up laboratory or hands-on activities because of her part-time status as an adjunct faculty. When asked about how she approached teaching science, she stated,

> 10% of the time you can make it relevant; the remainder has to be memorized . . . use of the board and overheads . . . on-line simulations and cartoons are very helpful. . . . I want to do group work but I don't have time. . . . I mainly straight lecture . . . I use the on-line homework from the publisher that is self-correcting . . . students like it now that it is in-line with the lectures. (Faculty instructor Karen)

The comments of the Karen's student focus group relate closely some of these same statements about this faculty instructor's instructional practices.

> She makes us memorize stuff, which is actually helpful. It gives us a good foundation. If we didn't have to memorize some of this stuff we wouldn't do as well in upper-division chemistry. . . . She always reviews what we did the class before . . . and she gives us her notes, so we can put our own notes in and don't have to spend a lot of time just copying. . . . The packets are really helpful. . . . I hardly touch the book because everything I need is in my notes. (Student in focus group from instructor's Adam's course)

Research Question 1 provides evidence that faculty instructors of the reformed undergraduate science course who participated in the NASA/NOVA professional development workshop or some equivalent taught in a reformed manner. The faculty instructors of the reformed undergraduate science course shared the following characteristics: possessed strong content and pedagogical knowledge, attended ongoing professional development geared toward reformed pedagogical practices, collaborated with their colleagues, and reflected on teaching practice.

Research Question 2

In order to answer Research Question 2, “Are there instructional differences between elementary teachers who experienced reformed instruction and those who did not based observed pedagogical differences,” an independent *t* test was performed to compare the overall means of the inservice teachers who experienced the reformed course during their undergraduate programs and those who did not. In addition, a multivariate analysis of variance (MANOVA) was performed to analyze the subscales of the RTOP. Results from the quantitative analysis of the data did not reveal significant differences in the total RTOP score between inservice elementary teachers who took the reform course during their undergraduate program and those who did not, t (89, .274), p = .785. The means and standard deviations are presented in Table 8. Results from the quantitative analysis of classroom observations using RTOP subscale scores between reformed and comparison courses revealed no statistically significant group effect (Wilks = .061, F[5, 85] = 1.514, p = .194). The results of the MANOVA are presented in Tables 9 and 10. The level of reformed teaching in the elementary classroom, based on observations using the RTOP instrument among graduated inservice teachers is statistically similar for both groups.

Table 8

Means and Standard Deviations for Inservice Elementary Teachers

	Course	N	Mean	Std. Deviation
Sum	Reform	56	61.1275	18.34317
	Comparison	35	60.0286	18.99301

Table 9

Means and Standard Deviations for Teachers

	Course	N	Mean	Std. Deviation
Lesson Design & Implementation	Reform	56	11.525	4.007
	Comparison	35	12.071	4.534
Propositional Knowledge	Reform	56	12.939	3.843
	Comparison	35	12.300	2.908
Procedural Knowledge	Reform	56	10.080	4.363
	Comparison	35	9.371	4.438
Communicative Interactions	Reform	56	12.154	3.776
	Comparison	35	12.085	4.288
Student Teacher Relationships	Reform	56	13.633	4.272
	Comparison	35	14.200	4.689

Table 10

Multivariate Analysis of Variance for Inservice Elementary Teachers

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
ID	Lesson Design	6.431	1	6.431	.362	.549
	Propositional Knowledge	8.798	1	8.798	.712	.401
	Procedural Knowledge	10.836	1	10.836	.562	.456
	Communicative Interactions	.102	1	.102	.006	.936
	Student Teacher Relationships	6.915	1	6.915	.351	.555
Error	Lesson Design	1582.570	89	17.782		
	Propositional Knowledge	1100.231	89	12.362		
	Procedural Knowledge	1717.063	89	19.293		
	Communicative Interactions	1409.619	89	15.838		
	Student Teacher Relationships	1751.458	89	19.679		
Total	Lesson Design	14120.984	91			
	Propositional Knowledge	15770.928	91			
	Procedural Knowledge	10481.656	91			
	Communicative Interactions	14795.056	91			
	Student Teacher Relationships	19217.545	91			
Corrected Total	Lesson Design	1589.001	90			
	Propositional Knowledge	1109.028	90			
	Procedural Knowledge	1727.899	90			
	Communicative Interactions	1409.722	90			
	Student Teacher Relationships	1758.373	90			

The quantitative results of Research Question 2 were enhanced by qualitative analyses of inservice elementary teacher's interviews and field notes from classroom observations. The inservice elementary teachers reported in this section had experienced the undergraduate reform course or the comparison course. Pre-selected categories from the PCK framework developed by the researcher were used to code teacher interviews and field notes from classroom observations. These categories were *Orientations toward Science Teaching* (OTS), *Content Knowledge* (CK), *and Pedagogical Knowledge* (PK). See Appendix H for the PCK framework used to code interviews. The most predominant theme throughout the interviews was the notion that hands-on activities were the best approach to teaching science with elementary students.

Beverly taught first grade for 4 years. She took three science content courses during her undergraduate program including the reform course. Beverly stated in her interview that a hands-on approach was the best approach to science teaching and learning. The lesson observed during her classroom visit was on the concept of air. She provided baggies for students working in cooperative groups. Baggies contained objects that allowed the students to "explore" the concept of air. Each baggie contained a feather, straw, balloon, Styrofoam balls, and cotton balls. The teacher asked students to explore the characteristics of air using the objects found in their baggies. Students were free to explore the characteristics of air using the objects found in their baggies without any direction from the teacher. While students explored, the teacher walked around and posed questions to students as to what they were doing and how it was related to air. Once student groups finished exploring, she had them to come together for a whole class discussion about what they found when they explored the concept of air with their objects. Each group was responsible for presenting something they learned about air. The lesson was student centered with the teacher serving as a facilitator. During her interview, the teacher stated that hands-on activities are the best way to teach science.

> Hands-on whenever possible. . . . Let them see and touch the real item so that they can explore. . . . (Elementary teacher Beverly)

Mary had taught second grade for 9 years. She did not experience the undergraduate science reform course during her science program but took the comparison course. She attributed much of her instructional practice to inservice professional development workshops and years of teaching experience. The observed lesson for this teacher was centered on an activity with liquids to discuss the concept of density. She told the class that they were going to work with liquids and explore them. The teacher started with a demonstration and then told the students exactly what to do for the activity. The students made predictions as to what will happen when you mix certain liquids together and discussed their rationales for their predictions in their student groups. The teacher used the discussion on liquids to introduce the term density. During the interview, Mary explained that a hands-on approach was the best approach to use for science teaching and student learning but admitted that it was difficult doing hands-on activity with this group of kids because they were typically not focused and had short attention spans. She said that she is more apt to do hands-on activities with “better behaved” students.

Illise had taught second grade for 3 years at a private school. Illise served in the capacity of co-teacher for fourth grade during her first year of teaching. Her second year, she taught Kindergarten. She was currently teaching second grade to all boys. Illise took several science content courses including the reformed undergraduate science course. She was a proponent of hands-on activities where exploration and discovery were encouraged.

> I think hands-on. . . . Give them that freedom of experimenting with it and then draw it into the lesson. I think that’s a great way. And that’s how I learned, so I’m partial to that,

> but I feel like that’s a great way for them to actually see it and sense it and feel it. They can try it and if it fails, why. (Elementary teacher Illise)

During her classroom observation, the teacher began the lesson with a discussion about pollution. She asked students what they knew about pollution, which began a rich discussion. She told students that they would work in groups to make lakes to understand the concept of water pollution. The following excerpt was taken from the classroom observation.

> Ask students questions as to what will happen when you mix certain substances (oil, dish detergent) with water. . . . Students give their predictions . . . discuss in their groups and write down their observations. . . . Teacher asks students is the water as clear after adding the oil . . . what happened. . . . Students give a variety of answers . . . what will happen if you mix oil, soap, and water. . . . Students make their predictions. . . . Students make comparisons between bottle with oil, bottle with soap, and bottle with soap, oil and water . . . students discuss their observations. (Elementary teacher Illise)

Lori, Lana, Lisa, and Leanne all took the reformed undergraduate science course during their undergraduate program along with environmental, physical, and life science. All of these teachers had attended professional development workshops for science teaching. Each of these teachers said that the best approach to science teaching was a hands-on approach. Lori used a teacher-guided activity to teach students about volcanoes. The lesson was a prescripted lesson detailing the exact steps of the activity. The activity did not allow for student exploration since the students were told exactly what to do. The teacher had students to draw what they saw. The teacher and students fill out a KWL chart to complete the activity.

Inservice elementary teachers that experienced the comparison course as a part of their undergraduate program employed a hands-on approach to science teaching and learning. Many of them stated that the comparison course did not have an impact on their views regarding science teaching and learning. They stated in their interviews that their views on science teaching and learning had been influenced by their teaching experiences and by professional development workshops geared toward science teaching.

> I saw that when my students simply read the book the information didn’t stick. Students actually need to do it to make it stick so that they can form that synaptic loop and learn from that. . . . My university courses mostly involved memorizing stuff from books with a little bit of hands-on. It was more of my teaching experience that made me see that science was more hands-on. . . . I had the framework of scientific inquiry; I just didn’t really experience it as an undergraduate. I gained knowledge about the concepts when I had to teach them. . . . I wanted to make sure to tie in today’s lesson to what they did in the lab on Friday so that they had a framework to go by. I wanted to tie it to their prior knowledge. On the past Friday, the students had gone to a hands-on lab . . . and had done an activity where they measured the distance an object traveled after going down a steep ramp versus one that was closer to the ground. . . . I expanded on that activity by doing the same experiment on the smooth floor in the hallway and the rough surface of the carpet in the classroom . . . I wanted to base the activity on something they had already done, but to expand on that and give them something new. (Inservice elementary teacher from the comparison course)

> My university courses did not impact my understanding of science teaching. That’s been more impacted by my teaching experiences and inservice workshops. . . . I chose this activity based on what’s worked in the past. . . . I didn’t show them how to do it because that wouldn’t be good. Discovery is the best way for the students to learn. They’re not interested if I show them . . . you learn by discovery. (Inservice elementary teacher from the comparison course)

> The science that I learned in college was much more regimented than what I teach. In high school, science was introduced to me through a lot of different topics with a lot of exploration, but in college it was a lot more regimented and not as fun. Things might have been different if I took science education courses. Science in college was more dry. We weren’t allowed to play with science in college. (Inservice elementary teacher from the comparison course)

> I gained knowledge about the concepts when I had to teach them. That’s when I learned them. . . . Some inservice workshops have helped me understand the concepts better but not my university courses.

Research Question 2 provides evidence that inservice elementary teachers who experienced the reformed undergraduate science course during their undergraduate programs and those who did not taught in a similar manner. One of the main themes that emerged from qualitative analysis of data was that professional development geared toward science content and pedagogy enabled inservice teachers who experienced the comparison course to implement reformed pedagogical practices.

Research Question 3

Research Question 3 asked whether the level of pedagogical reform experienced in undergraduate science courses was a predictor of the type of science instruction observed with graduated teachers at the elementary level; multiple linear regression was performed. All faculty instructors in the sample were considered, both those in the reform and comparison groups. Faculty instructors were divided into high, medium, and low groups based on their RTOP scores. The highest total composite score that could be obtained on the RTOP was 100. Faculty instructors achieving RTOP scores ranging between 0 and 33 were placed in the low RTOP group (N = 5), faculty instructors achieving a RTOP score ranging between 34 and 67 were placed in the medium RTOP group (N = 12), and faculty instructors who achieved a RTOP score ranging between 68 and 100 were placed in the high RTOP group (N = 18). At the time of this study, an RTOP benchmark had not been established. In measuring physics PCK, MacIsaac and Falconer (2002) suggested that an RTOP score of 50 indicates considerable presence of reformed teaching in a lesson.

Initially, regression analysis was used with faculty instructors with RTOP scores ranging between 0 to 50 to predict the reform instruction observed in the elementary classrooms; however, this model was not a good predictor, [$F(5, 26) = 1.224$, $p = .326$]. This model produced an adjusted R^2 of .035 for the prediction of reformed instruction in elementary classrooms. Regression analysis was also conducted with faculty instructors who had RTOP scores ranging from 51 through 100 and this model was also found not to be a predictor of reformed instruction. Based upon the results from initial analysis, the investigator decided to divide the faculty instructors into the three groups, low, medium, and high, to determine whether the level of pedagogical reform would predict reformed instruction in elementary classrooms.

Faculty instructors with high RTOP scores were used to predict the type of instruction exhibited by inservice elementary teachers who took their science discipline courses during their undergraduate program. Overall, the model was not a significant predictor of reformed instruction in elementary classrooms [$F(5, 40) = 1.023$, $p = .417$]. The model produced an adjusted R^2 of .003 for the prediction of reformed instruction in elementary classrooms. The results of the regression analyses are shown in Tables 11 and 12. Together, the RTOP subscales shared only .3 % of the variance in reformed instruction in elementary classrooms. The histogram and the normality plots revealed that the assumptions for this data set had been met. Tables 11 and 12 display the results for this regression analysis.

Table 11

Regression Analysis: Model Summary for Reformed Instruction

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.337[a]	.113	.003	17.71155

Table 12

ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1604.094	5	320.819	1.023	.417[a]
	Residual	12547.959	40	313.699		
	Total	14152.053	45			

Research Question 4

Research Question 4, asked how the level of pedagogical reform experienced in undergraduate science courses related to the pedagogical content knowledge of inservice elementary teachers. Qualitative analyses conducted for Research Question 4 provides evidence regarding the extent of the pedagogical content knowledge of faculty instructors and their inservice elementary teachers.

Qualitative analyses allowed the researcher to delineate characteristics of faculty instructors with expansive topic-specific PCK and examine whether the inservice elementary teachers who took their courses had similar characteristics regarding PCK for the science concept taught. Seven faculty instructors and 21 elementary teachers were analyzed regarding topic specific PCK. Faculty instructors were not compared to each other regarding PCK nor were the elementary inservice teachers who took their courses. Each faculty instructor had three or more inservice teachers on which data was collected. To reduce bias, the only faculty instructors where observational data was collected on three elementary teachers were used for further analyses regarding elementary teacher PCK. Snapshots were developed for the faculty instructors and their inservice elementary teachers with the highest and lowest RTOP scores in each group of three elementary teachers per faculty instructor (see Tables 13 and 14 for PCK checklists for faculty instructors and inservice elementary teachers). Interviews, CoRes and Pap-eRs, and field notes from classroom observations from the faculty instructors and inservice elementary teachers were analyzed using a researcher developed PCK framework based on pre-selected categories. The categories comprising the PCK framework were *Orientations toward Science Teaching* (OST), *Content Knowledge* (CK), and *Pedagogical Knowledge* (PK). Once the interviews, CoRes and Pap-eRs, and field notes of faculty instructor's and inservice elementary teachers had been analyzed, a PCK checklist was completed for each faculty instructor and their inservice elementary teacher (see Appendix H and I for the PCK framework and PCK rubric). Once the PCK checklist was completed, a PCK rating was given for the faculty instructors and the inservice elementary teachers using the researcher developed PCK rubric (See Appendix J for PCK rubric). Snapshots were developed for the faculty instructors and inservice elementary teachers using the completed PCK checklist to determine the extent of their pedagogical content knowledge (see Appendix K for the faculty instructors and inservice elementary teachers PCK checklists). Seven snapshots of faculty instructors and 14 snapshots of their inservice elementary teachers are described in the following section (see Appendix I and J for expanded snapshots of faculty instructors and inservice elementary teachers). Each Snapshot comprised the faculty instructor and their inservice elementary teacher who had the highest and lowest RTOP scores. Again, the purpose of these snapshots is to provide an overall description as to the pedagogical content knowledge of the faculty instructors and the inservice teachers who took their courses during their undergraduate program.

Table 13

Faculty Checklist

Faculty	NOVA	PCK Rating	CK	PK	Constructivist	Sources of PCK
Bonnie	NO	Advanced	X	X	X	Extensive PD, Reflective Practitioner; Collaboration
Calvin	YES	Advanced	X	X	X	Extensive PD, Reflective Practitioner; Collaboration
Denise	NO	Advanced	X	X	X	Extensive PD, Reflective Practitioner; Collaboration
Gerald	YES	Proficient	X	X	X	Only PD was NOVA; Collaboration
Hilda	NO	Emerging	X	--	--	Extensive PD
Eleanor	YES	Advanced	X	X	X	PD, Reflective Practitioner, Collaboration
James	YES	Advanced	X	X	X	PD, Reflective Practitioner, Collaboration

Table 14

Teacher PCK Checklist

Teacher	PCK Rating	CK	PK	Constructivist	Sources of PCK
Beverly	Proficient	X	X	X	Extensive PD, Reform Course, Teaching Experience
Callie	Proficient	X	X	X	Extensive PD, several science content courses, teaching experience, reform course
Dawn	Proficient	X	X	X	Extensive PD, science content courses, teaching experience
Gloria	Proficient	X	X	X	Extensive PD; science content courses; teaching experience
Harvey	Novice	--	X	--	Extensive PD
Illise	Proficient	X	X	X	Extensive PD, Collaboration
Jan	Advanced	X	X	X	PD, Reflective Practitioner, Collaboration

Snapshot One

Bonnie

Bonnie had 10 years teaching experience. She had been teaching the reform course for 2 years. Although she had not been a part of the original NASA/NOVA team she had participated in several professional development workshops that were geared toward science content and pedagogy. She also attended several workshops provided by the local school districts in which some of her former students taught. These workshops were geared toward using science notebooks for interactive note-taking and inquiry. The lesson observed in Bonnie's class was on circuits. Her students worked in small groups to build a model of a circuit. She said that the models would enable her students to conceptualize how circuits work. She stated in her interview that, "They need to know how to explain circuits, and to trouble shoot why things go wrong." She believed that an inquiry-oriented approach was the best approach to science teaching and learning with emphasis on the scientific process.

During her observed lesson, students explored circuits both series and parallel; what runs down a battery faster. Bonnie's students also used a science notebook to write down their focus questions, predictions, data collection, results, claims, and evidence and conclusions. She encouraged her preservice teachers to use these notebooks in their elementary classrooms.

Bonnie received a PCK rating of *Advanced*. Her RTOP score was an 83, indicating that 83% of the classroom instruction observed was reformed. Bonnie participated in ongoing professional development, possessed strong content knowledge, collaborated with peers, colleagues, and science teachers, and was a reflective practitioner. Bonnie's former students, Beverly, Bettye, and Bailey, were inservice elementary teachers at the time of this study. Beverly had the highest RTOP score out of three teachers and Bettye had the lowest RTOP score.

Beverly

Beverly has taught first grade for 4 years. She took two science content courses, including the reformed course, during her undergraduate program. She did not take any science education or methods courses during her undergraduate years. Beverly stated in her interview that a hands-on approach was the best approach to science teaching. She equated hands-on activities as those that allowed students to "see and touch the real item" through exploration. In addition she said that hands-on activities allowed her to "tap their [her students] prior knowledge." Beverly taught about the concept of "air." She wanted her students to know that air is everywhere and takes up space and that air can move things. In order to teach this concept, Beverly used a balloon, a Styrofoam ball, a red feather, and a cotton ball to allow students to explore the characteristics of air. These items were placed in a baggie for each student group. Students were placed in groups of two to three students. Beverly asked the student groups to explore the characteristics of air using the objects contained in their baggies. She did not provide them with a standard means by which to explore the characteristics of air but allowed her students to choose whatever approach they wished to use in exploring this concept. At the completion of the activity, students had to present what new characteristics they learned about air using the contents of their baggies. Beverly said that she specifically chose this strategy to teach the concept of air so that students can think more “deeply” about the characteristics of air. She does not state, however, that this activity helped students to understand the characteristics of air because air is an abstract concept. She stated in her interview that she uses a variety of teaching strategies to teach the concept of air. When planning the lesson, Beverly chose activities that were relevant to students’ lives. She also considered the different learning styles of her students and took into account their prior knowledge. Beverly’s purpose and goals for using hands-on activities with her students was evident during her classroom observation.

Beverly’s PCK rating regarding the concept of air was *Proficient*. The strategies chosen to teach the characteristics of air enabled students to deepen their understanding of this abstract concept through exploring objects familiar to the students. Although she employed a constructivist approach to science teaching and learning, her rationale for using hands-on activities was generic. She knows that hands-on activities allow for student exploration of the characteristics of air but does not state how exploration may deepen students’ understanding of this concept. She also does not seem to do a great deal of reflecting on her teaching practice. She has taught this topic for 4 years but does not discuss the difficulties or misconceptions associated with the teaching and learning of this topic.

The sources of PCK for Beverly seem to stem from her 4 years of teaching experience, and the reform course that she experienced during her undergraduate program. The professional development workshops that Beverly attended were geared toward using science notebooks with her students. Science notebooks help students in their note-taking ability. The instructional strategies that had the greatest impact on this teacher were hands-on activities, collaborative group work that allowed her to learn from others, and visual demonstrations that she experienced from faculty of reformed courses. These experiences were also evident during her classroom observation. Beverly's RTOP score was 85, indicating that 85% of the classroom instruction was reformed.

Bettye

Bettye had 7 years teaching experience during which time she had taught Kindergarten through eighth grade. She had taught fifth grade for the last 2 years. She believed that a hands-on approach was the best approach to science teaching as stated in her interview. She also stated that prior to the year in which this interview was conducted science was not an emphasis at her school until it became a part of state testing.

Bettye said that hands-on activities helped to facilitate the scientific process. Bettye also said that using science notebooks is key to science teaching and learning because notebooks allow students to focus their thinking and explain their thoughts through written communication. Bettye only took two science content courses, including the reform course, during her undergraduate program and one methods course that focused on a variety of subjects. She said in her interview that she did not remember much of the science content taught in her science content courses because the content did not seem to be relevant. She said that the faculty instructor seemed to cover a lot of content without much depth. She attributed her understanding of science content and teaching to professional development workshops that focused on science and literacy and her years of teaching experience.

The science topic covered during the observed lesson was matter. Bettye said that she wanted her students to know that matter is made up of atoms and takes up space. She also wanted her students to know "how hydrogen and oxygen fit."

Bettye said that she used a reading lesson and the science notebook to teach the concept of matter. Her rationale for these specific strategies is that students will work together to share their ideas and understandings about matter. When planning the lesson, Bettye considered the various learning styles of her students but not their prior knowledge regarding matter. She also said that these objectives will be tested so they must be covered. The only aspect of her teaching practice that she reflected on from the previous year in conjunction with this topic is her method of assessment. Bettye suggested that after teaching this lesson last year she gave a test to her students. She indicated that her students did not "carry as much thinking over to the test" so she will not give them a test this year. She said that she will assess based on their notebooks rather than a formal test. Bettye adjusted her method of assessment but not her teaching strategies regarding the concept of matter.

During Bettye's observed lesson, the students were engaged in a reading lesson in which the teacher and the students spent 25 minutes reading a scenario. The teacher assisted the students in picking out the important information and then wrote these key terms on the board. Although this was an introductory lesson, the teacher did not take into account the students' prior knowledge nor were they engaged in any hands-on activities that facilitated the scientific process as she stated in her interview. The following segment was noted during Bettye's observation:

> Teacher gives students new scenario. Students cut out and glue into science notebooks. Students and teacher then read the scenario out loud together and pick out the important

> information. Teacher writes key words on board. Teacher puts paper “molecules” on doc cam (really atoms) and calls on students to show where the “gears” and the “teeth” are.

Bettye’s PCK rating was *Novice*. Her RTOP score was 26, indicating that only 26% of the classroom instruction observed related to reform characteristics. Although Bettye believed that hands-on activities that facilitate the scientific process are the best approach to science teaching, this was not evident in her observed lesson. This was a teacher-centered reading lesson that did not focus on the science content of the lesson, which was matter. The lesson focused on finding the problem in the scenario. The activity did not respect the students’ prior knowledge and did not engage their critical thinking skills. Based on the interview, the teacher thinks that it is the students’ lack of ability to “think” or “reason” that hinders their ability to learn concept of matter and not the specific strategies used to teach the lesson. Bettye’s sources of PCK seemed to stem from her professional development and her years of teaching experience. The professional development that Bettye attended focused on science and literacy. She says that she does not remember much from her undergraduate science courses, including the reform course. Although, she says that her methods course was engaging she cannot specifically remember the activities that she experienced during the course.

The faculty instructor and the inservice elementary teachers believed that a hands-on approach was the best approach to science teaching and learning. They all participated in ongoing professional development and collaborated with other colleagues and science specialists throughout the district. However, Bettye’s focus seemed to be on covering the standards for state testing. She relied on the Foss Kits provided by the district and the science notebooks emphasized in the professional development workshop. The focus of the workshop was science and literacy. Bettye’s lesson was a reading lesson in which the students extrapolated the problem and recorded the information in their science notebooks.

Snapshot Two

Calvin

Calvin had 30 years teaching experience and was a part of the original NASA/NOVA team. Calvin stated in his interview that he believed that an inquiry-oriented approach was the best approach to science teaching and learning. He stressed the importance of science content that is relevant and instruction that facilitates scientific literacy.

Calvin's observed lesson was about isomers and nomenclature. Calvin used models to represent isomers so that students could conceptualize this abstract concept. He stated in his interview that his students' understanding of isomers and nomenclature would dictate the direction he would take for the next lesson. In reflecting on his previous experience in teaching this topic, he knew that students had difficulties in understanding isomers in terms of molecular and structural formulas and knew that models would assist in facilitating student understanding of this topic. Calvin participated in extensive professional development workshops geared toward science content and pedagogy. He maintained collaboration with his colleagues and other science specialists and he was a reflective practitioner. Calvin achieved a PCK rating of *Advanced*. His RTOP score was 89, indicating that 89% of his observed classroom instruction was reformed. Calvin's former students, Carrington, Chris, and Callie, were now inservice elementary teachers. Of the three, Callie had the highest RTOP score and Chris had the lowest RTOP score. Their snapshots are given below.

Callie

Callie had been teaching for 9 years during which time she has taught the fifth and sixth grades. She taught fifth grade for 5 years and sixth grade for 4 years. She was currently teaching the fifth grade. Although she was a Liberal Arts major, she took several science content courses including the reform course. She did not take a methods course but rather two science content courses, chemistry and earth science, which were geared toward science teachers.

Callie believed that a hands-on approach using experiments was the best approach to science teaching. She believed that hands-on learning activities provided students with opportunities "to see and feel [science concepts] . . . that's the only way for them to remember it." The lesson observed was the water cycle. Callie stated that the big ideas of the lesson were the states of water and the notion that water is recycled throughout the environment. She had taught this lesson the previous year. Callie said that students do not understand that water is everywhere nor do they understand condensation. She used a simulated activity, "The Water Model," to simulate the water cycle. She said that this activity enabled her students to see that water is everywhere as well as understand that it is recycled throughout the environment. She emphasized that it is important that the water cycle be connected to the lives of her students. She began the lesson with a short review of the states of water and writes the main points on the board. Students work in groups to complete the water cycle activity. Students made predictions as to what happens to the water during each stage of the cycle. While student groups waited on their models to work, the teacher had them draw the water cycle because she knew that her students loved art. When the activities were completed, the teacher concluded with a whole class discussion to see if student predictions were accurate. To assess student understanding of the lesson, Callie said that she will evaluate her students' lab write-ups, models, and give a formal test.

Callie received a PCK rating of *Proficient*. Her RTOP score was 71, indicating that 71% of the classroom instruction observed was reformed. Callie knew that her students did not understand condensation and had a difficult time understanding that water is in the air, so she chose to use the simulated water cycle activity from the textbook to model the water cycle. Callie has taught this topic for 5 years but does not reflect on her teaching practice. She makes no mention of how she has changed her approach to teaching the stages of the water cycle based on her experience with teaching this concept in previous years. Callie also did not discuss how her students' misconceptions or prior knowledge were taken into account when planning this lesson. The instructional strategies used were based on how she was taught in high school and during her undergraduate program. When asked what knowledge about students' thinking and/or learning influenced how she taught the main ideas or concepts, she replied, "I teach science the way I learned it."

Callie's sources of PCK were the science content courses taken during her undergraduate program, the reform course, and professional development.

Carrington

Carrington had been teaching for 9 years. She has been teaching sixth grade for the past 6 years. She minored in Geology and had taken several geology courses along with biology, physics, and chemistry (reform course) and an elementary science methods course to satisfy her teaching requirements. Carrington stated that she had been greatly influenced by the reform course because it was a combination of science content and pedagogy. She said that her other science content courses were content which only focused on the memorization of facts. She stated that,

> [The reform class] was more hands-on than my other science classes, which made science more about memorization. [The reform class] made science about doing and participating for me. . . . [The reform class] helped me understand a lot of the concepts in chemistry

> that I never felt like I understood before, like ions. The instructor broke things down and had us do things that were more hands-on. It wasn't just about reading a book.

Her orientation toward science teaching was hands-on, as noted throughout her interview. She stated that hands-on activities helped her students to conceptualize difficult concepts or concepts that students cannot see. The lesson observed was convection currents. Carrington wanted her students to understand what causes lithospheric plates to move. She said that students know that the plates move but they don't know why. Carrington began the lesson with a review of lithospheric maps (small 3-D models of the Earth's tectonic plates) that they made in an earlier lesson to recall what they remembered about continents and faults. The review on plate tectonics served as a segue into the lesson on convection currents.

Carrington used a 4-minute video segment on convection currents and plate tectonics boundaries. In addition, she used a simulated activity called "Mantle Motion" that would allow her students to generate and observe convection currents. She guided students in making predictions as to what will happen with the currents. Carrington says that she chose those specific strategies to teach the concept of convection currents to help students deepen their understanding of tectonic plates because it is difficult to conceptualize. When planning the lesson, Carrington took into account students' prior knowledge regarding convection currents. She says, "Since the students don't have a lot of science background knowledge, the pre-lab is really important to go over." Carrington also knows that convection currents is an abstract concept and therefore difficult to grasp because students cannot see it so she knew that if students had the opportunity to simulate the convection currents they would possibly be able to grasp it. Carrington said that the activity that she used to teach the concept was a part of the science kits provided by the district so she does not have prior experience with this particular activity. In her transformation of the concept of convection currents, she uses videos and activities that will allow students to conceptualize their understandings of what causes the movement of the earth's plates.

Carrington's PCK rating is *Proficient*. She uses accurate scientific language regarding convection currents. She understands that her students have a difficult time understanding abstract concepts such as convection currents and knows that her students typically have poor background knowledge regarding this concept and plans her lessons accordingly. Although Carrington knows that students have a difficult time understanding the concept of convection currents because they cannot see it, she does not mention specific learning difficulties that she knows students may have based on her previous experience in teaching this topic. She believes that hands-on activities is the best approach to science teaching and learning because it helps students conceptualize difficult to understand topics but seems to think that hands-on activities should be used in teaching all science concepts. Carrington received an RTOP score of 71, indicating that 71% of the instruction observed was reformed. The source of her PCK is the number of content courses taken during her undergraduate program, the reform course, professional development, and continued collaboration with the instructor who taught the reform course during her undergraduate program.

The faculty instructor and the inservice elementary teachers believed that a hands-on approach was the best approach to science teaching and learning. Like Calvin, Carrington and Callie thought that hands-on activities should engage students in the learning process and promote critical thinking skills. They all emphasized the importance of connecting the science content that they were teaching to their students' lives. In addition, Carrington and Callie had taken several content courses including the reform course. They each used activities that they thought would best facilitate student understanding of the specific science content that they were teaching. Calvin, Carrington, and Callie, participated in ongoing professional development and collaborated with other colleagues and science specialists throughout the district.

Snapshot Three

Denise

Denise had been teaching for 11 years. She was not a part of the original NASA/NOVA team but had taken several professional development workshops geared toward science education reform. Denise stated in her interview that it was important to model the teaching behaviors that she wanted her students to exhibit as future teachers. She believed that inquiry-oriented instruction was the best approach to science teaching and learning. The observed lesson on plate tectonics revolved around six lab stations in which student groups visited to learn about some aspect of plate tectonics to include mantle, crust, subduction, Pangaea, and continental drift. She said that she chose those specific strategies because students have minimum content knowledge regarding plate tectonics and their short attention span requires the need for a variety of instructional strategies. Denise stated that these concepts were a part of the standards that would be covered in the elementary schools. Denise considered students' prior knowledge and learning difficulties regarding plate tectonics when planning the lesson.

Denise received a PCK rating of Advanced. Her RTOP score was 90, indicating that 90% of the observed classroom instruction was reformed. Her sources of PCK are professional development, science content courses, and her constant reflection on teaching practice.

Deborah

This was Deborah's first year teaching the sixth grade. She was a Liberal Studies major and was only required to take four science content courses during her undergraduate program. She also took the reform course, Internship for Science Teaching. Deborah is a new teacher and has not attended workshops to improve her science teaching. She attended one workshop prior to the beginning of school that focused on science note-taking using foldables. Deborah's orientation toward teaching science was hands- on. She says that the reformed undergraduate course had the greatest impact on how she viewed science teaching and learning:

> Our hands-on science lab [the reform course] really was when I got to really say, "OK. I know these concepts, but why do they work and how do they work?" That's when my whole thought processes about science changed. Because you can memorize these types of animals and these biomes and this happens, but until you really question it and figure it out on your own, it's not as meaningful.

Deborah said that the reformed course was a mixture of content and pedagogy. She said that the faculty instructor provided the background and provided the hands-on experience that would help students in their understanding of the science concepts. Deborah further stated that she learned a great deal from her student teaching experiences.

The lesson observed in Deborah's class was food chains. The big ideas of the lesson were the major components of food chains and their respective roles, the sun is the major source of energy, and that energy flows down the food chain. Deborah emphasized that students must know this information because it is a part of their everyday lives.

> Food chains are part of our everyday lives. It's important for them to think about where their food comes from and how different organisms interact in the food chains that we're a part of. It makes them think about what they see on the news.

The lesson observed was the introduction to the Ecology unit. Deborah provided the background information for the lesson on food chains while her students took notes using the foldables. She said that her students would use the information at a weeklong field trip to an Outdoor School that focused on environmental education. When planning the lesson, Deborah acknowledged the various learning abilities and backgrounds of her students but did not use her knowledge of these differences to plan the lesson. Deborah's observed lesson was very teacher-centered with little student interaction. Although this was the initial lesson, Deborah did not solicit students' prior knowledge or misconceptions about food chains. Deborah spent 25 minutes writing notes on the overhead while students copied these notes in their foldables. There was very little interaction between the students and between the students and the teacher.

Deborah received a PCK rating of *Novice*. Her RTOP score was 36, indicating that the classroom instruction was 36% reformed. Although she said that you cannot just read from a textbook or lecture to students, this is just what was observed during her classroom visit. Deborah said that this is typically the way she introduces a lesson that is needed to provide her students with the background information needed for future activities regarding the lesson. This is similar to her undergraduate experiences in the reform course in which she stated that the faculty instructor typically provided the background information and then engaged the students in hands-on activities for further exploration of the topic. Deborah's sources of PCK are her reform course, science content courses, and substitute teaching experience. The professional development workshop that Deborah attended focused on interactive science note-taking and not science teaching.

Dawn

Dawn had been teaching a combined fourth and fifth grade class for the past 2 years. She was a Liberal Studies major who also took the four required science content courses during her undergraduate program: physical science; life science; field science; and geosciences. She has been attending ongoing professional development workshops for the improvement of science teaching as well as teaching the science curriculum. Her student teaching experiences allowed her to reflect on her teaching practice. She stated in her interview that when she had to teach a science concept it caused her to think about what strategies she would use to teach the topic. Regarding Dawn's orientation toward science teaching, she believed that a variety of instructional strategies should be used to teach a science concept.

The lesson observed in Dawn's class was a review of rock identification and weathering, erosion, and deposition. In reflecting on her learning experiences with rock identification, Dawn stated that she had a difficult time identifying rocks from pictures. She said,

> I know that rocks and minerals were very difficult for me to learn about and identify simply by looking at pictures. I needed to see and touch them, and explore with them.

Based upon her previous learning experiences with rocks, Dawn provided an activity that allowed her students to explore three different rocks and identify them based on their observations and provide a written description of each rock. Regarding the concept of erosion, weathering, and deposition the students modeled erosion and deposition by pouring water over a dirt slope, and then answered questions where they had to explain their observations. Upon completion of these activities, Dawn led her class in a whole group discussion about the results of their activities. She asked her students how they derived at their answers and asked their peers if they agreed with their findings. When planning the lesson, Dawn considers the context of her class and the cognitive abilities of her students and chooses the activities accordingly:

> Kids at this age are very egocentric and have low maturity levels. It's hard for them to see beyond their own worlds. I'm always thinking about how I can connect the material to the lives of this particular group of students and make it relevant for them . . . the students are very hands-on . . . they like to touch and feel . . . they are very social . . . they like to talk, so I give them lots of opportunities to share with one another . . . they want to be big

> kids so they like to have opportunities to be responsible and help one another . . . it also helps them to explain the concepts to one another. . . . I partner students together with different abilities for these reasons.

Dawn received a PCK rating of *Proficient*. Her RTOP score was 78, indicating that 78% of the classroom instruction observed was reformed. Dawn chose specific strategies based on her previous learning experiences regarding rock identification. However, this was her second year teaching this topic but she did not discuss what she has learned from teaching this topic from the previous year nor does she discuss students' prior knowledge or possible misconceptions that students might have regarding rock identification and weathering, erosion, and deposition. Dawn's sources of PCK are the science content courses taken during her undergraduate program, the reform course, ongoing professional development that focused on science content and pedagogy, and her substitute teaching experiences.

The faculty instructor and the inservice elementary teachers believed that engaging students through hands-on activities was the best approach to science teaching and learning. The faculty instructor, Denise, and the inservice elementary teacher, Dawn, specifically used strategies to teach plate tectonics and rock identification that would facilitate student understanding of these abstract concepts. Denise and Dawn used different strategies to teach this one concept giving students with different learning modalities opportunities to learn the material. In addition, Denise and Dawn participated in ongoing professional development workshops geared toward science content and pedagogy. Although Deborah stated in her interview that hands-on activities are the best approach to science teaching and learning and that you cannot spend a great deal of time lecturing to students, she spent the majority of the class period lecturing while students took notes and copied them into foldables. There was a disconnect between her teaching beliefs and the enacted lesson. This is probably due to to Deborah's lack of teaching experience and a lack of professional development geared toward science content and pedagogy.

Snapshot Four

Gerald

Gerald was a faculty instructor with 15 years teaching experience. He was a part of the original NASA/NOVA team. Gerald believed that a hands-on approach is the best approach to science teaching and learning. He stated in his interview that science content should be relevant and facilitate scientific literacy.

The observed lesson on classification revolved around students working in small groups to classify snack chips. Gerald said that the main ideas of the lesson was to acclimate his students to classifying items based on their physical properties by designing a means by which to classify the snack chips. He said that he has taught this topic for many years so he knew that it would help students in their understanding of classification and put them at ease for the upcoming assessment. When planning the lesson, Gerald said that he considered his students' various learning modalities; however, this was more of a global statement rather than specific to the topic of classification.

Gerald received a PCK rating of *Proficient*. His RTOP score was 70, indicating that 70% of the observed lesson was reformed. Gerald's sources of PCK are his years of teaching experience and the NASA/NOVA training.

Gabby

Gabby had been teaching first grade for 3 years. She took one science content course, the reformed course, and one combined science and social studies methods course during her undergraduate program. She attended professional development workshops in her district to learn how to use the science kits with her first grade class. There were a total of three science kits: power and water, weighing and balancing, and animals. Her orientation toward science teaching was a hands-on approach because students remember the activities that they do:

> I came to [the University] where everything was hands-on and it was so much more valuable to me and I remembered it . . . being able to experience something rather than just hear about it is so much more powerful . . . my students are the same way. . . . We don't always do hands-on activities, but when we do those are the ones they remember.

Gabby's observed lesson was on the concept of water. Gabby used the KWL chart, "what we know," "what we want to know," and "what we learned" throughout this lesson. She began the lesson by asking the students what they knew about water and what they wanted to know. She filled out the K and W portion of the chart on a white board throughout the lesson. As the big concepts come up during the lesson she wrote them on their vocabulary list. She passed out a "life box" to the students and had them observe the contents of the box. The life box contained the four things that we need for life: water, air, light, and earth. As the students passed the life box around the teacher asked them to consider what they need for life. Students yelled out the contents of the box. Gabby showed a video segment, The Magic School Bus, on water. She stopped the video to connect what her students were watching to the concept they were discussing in class. Once all of the students had examined the contents of the box and watched the video, they returned to their desk and completed their life box worksheet.

Gabby said that she used the KWL chart to solicit her students' prior knowledge on the concept of water and to get them acclimated to using this chart with future science topics. She wanted her students to be able to copy vocabulary words onto tablet paper because it helps them to become familiar with and memorize those terms. In addition, she uses a lot of visuals to assist students with language barriers. Gabby knew that students would have a difficult time drawing air and water because they are abstract concepts. When planning for the lesson, Gabby considered her students' prior knowledge; however, she did not use this knowledge to drive instruction. The activities used to teach the lesson were straight forward since they were provided by the district.

Gabby received a PCK rating of *Emerging*. Her RTOP score was 69, indicating that 69% of her classroom instruction was reformed. Gabby did not have strong science content knowledge regarding the concept of water. Her rationale for the instructional strategies used to teach the concept of water was to acclimate her students to using KWL and writing vocabulary. She teaches the content found within the science kits only. The only strategy that she used that did not seem to emanate from the kit is her use of visuals to accommodate her ESL students. She relied heavily on the science kits provided by her district to teach all of the science content and did not appear to venture from these kits. Although she believes that hands-on learning is the best approach to science teaching and learning it seems to have stemmed from the hands-on learning philosophy that she encountered during her undergraduate program.

> I went to [The University] where everything was more hands-on and it was so much more valuable to me and I remembered it. Being able to experience something instead of just hearing about it is that much more powerful.

The science content covered and the hands-on activities were embedded in the science kit. Gabby's sources of PCK appear to be the undergraduate reformed science course, years of teaching experience, and the professional development workshops.

Gavin

Gavin had 6 years teaching experience with the fifth and sixth grades. He has been teaching the sixth grade for the past 3 years. Gavin had taken some science content courses, including the reformed course, during his undergraduate program: biology, geology 1 and 2, geography, US science and measures, integrated science, and physical science. Gavin also participated in ongoing professional development workshops for science teaching as well as training for using the district science kits. His orientation toward science teaching was hands-on activities that allow the students to do science because it is more meaningful to them when they get to experience the phenomenon of study.

During the lesson observed, Gavin modeled an experiment so that students could become familiar with the steps to the scientific method. The experiment involved different student groups using different hot and cold liquids to see whether the hot or cold form of the liquid would freeze first. Gavin said that his students needed to know that there are precise steps to the scientific method. This was the beginning of a series of experiments that would culminate with a science fair project. Although, Gavin stressed the importance of students engaging in hands-on activities this was more of a teacher-centered activity. Gavin spent a great amount of time modeling and explaining to students how they should conduct their experiment. He emphasized the importance of being precise in conducting and writing up their experiment so that others could replicate it if they wanted to. He also emphasized connecting the scientific process to the lives of the students:

> We learn from things around us. It’s kind of like the normal way to do it. . . . You observe, you pay attention to what you observe, you write down the things you observe, and you check or change one thing or something different. . . . It’s just kind of the way that *everything’s* been figured out. . . . It just started with an observation.

Throughout the lesson he tells students about how scientists go about their business of conducting scientific investigations. Gavin stated that they will be tested on the scientific process in the seventh grade so it is important that they learn this information now.

Gavin received a PCK rating of *Emerging*. His RTOP score was 59, indicating that 59% of the classroom instruction observed was reformed. Gavin took several science content courses during his undergraduate program and continues to deepen his understanding of science content through participation in ongoing professional development workshops, seminars, and professional meetings. Although Gavin stated that hands-on was the best approach to science teaching and learning it was not evident in his observed lesson. Gavin did most of the talking while his students listened and wrote down the notes in their notebooks. Gavin's rationale for modeling the scientific process was to allow students to see how the steps to the scientific method should be executed. He said that it was important that students understand the scientific method because they will be tested on it and it is a part of their lives and they will use it in future occupations. Gavin knew his students' various learning abilities and knew that some students were visual or tactile learners and grouped them accordingly; however, this grouping procedure was generic and not based on the lesson regarding the scientific method. Gavin's sources of PCK were his science content courses, ongoing professional development, and years of teaching experience.

The faculty instructor and the inservice elementary teachers believed that a hands-on approach was the best approach to science teaching and learning. Gerald, Gabby, and Gavin thought that hands-on activities should be relevant to student lives and facilitate meaningful learning. However, Gavin was constrained by state testing. According to his interview, the overarching goal of the material covered during his class is to prepare students for state testing.

Gabby also embraced the notion of hands-on activities but seemed to only use the science kit provided by her school district. Her limited science content knowledge seemed to constrain her ability to effectively use hands-on activities with her students

Snapshot Five

Hilda

Hilda had 24 years teaching experience. She had been teaching the reformed undergraduate science course for a year. She had also taught chemistry at a local high school for 24 years. Hilda believed that a hands-on approach was the best approach to science teaching and learning. She stated that hands-on strategies, "provide a conceptual background for students, engage them in activities, and provide novel situations to reinforce and test their levels of learning." Hilda stated that students are typically frightened of math and science so she tries to approach the concepts from different perspectives and questions her students often to check for their understanding of the concepts. She made no mention of students' prior knowledge or misconceptions they might have regarding energy conversions.

Hilda's observed lesson revolved around a tightly structured laboratory investigation regarding energy conversions. The following segment was taken from Hilda's observed lesson.

> Instructor has students make a lever with a ruler using the board as a fulcrum in the middle of the ruler. At one end of the ruler they place a penny. (She draws a picture of this on the board.)
> Instructor asks, "Can I change the amount of potential energy?"
> She writes on the board: W = F x distance
> PE = weight x height
>
> Instructor tells students to measure how high the penny "flies up" when a 100g-weight is dropped onto the other end of the lever from a height of 3cm. (She draws a picture on the board to illustrate this.)
> She tells the students to do it multiple times until they get consistent results.

> She tells them that they can measure the 3cm from the table or the ruler as long as they do it the same way every time.
> Instructor guides the students to calculate potential energy. (PE = mgh)
> Instructor has students increase the height of the weight and repeat the experiment (Students choose the height this time.)
> Instructor has students predict what happened to the potential energy the second time before they do the calculations.

She guided the student groups every step of the investigation with minimum input from the students. Hilda used reform practices but in a tightly structured manner. Hilda received a PCK rating of *Emerging*. Her RTOP score was 70, indicating that 70% of the observed lesson was reformed. Hilda's sources of PCK were her years teaching experience and her extensive professional development training.

Hailey

Hailey had been teaching kindergarten for 7 years. She had taken three science content courses, including the reform course, during her undergraduate program. Hailey said that science was not one of her strengths but if she had to choose the science content that she was more comfortable with teaching it would be earth science because the concepts are more concrete and more relevant to the lives of her students. Hailey had not participated in any professional development workshops for the improvement of science teaching. She had only attended professional development workshops for reading and math, which were the focus of her school. There was no curriculum for science content so Hailey chose the topics that she wanted her students to learn. Hailey's orientation toward science teaching was hands-on because students have to have direct exposure to the topic that was being covered. However, Hailey equates students being able to do science or have direct exposure to it with touching or manipulating objects such as the Smart Boards:

> That they are directly involved in whatever we're studying in science class. So at least they are able to . . . I mean it's wonderful when they can touch it, but to at least see it or manipulate it, whatever you're talking about. Cause like, if we've talked about a certain animal, we try to take them to the zoo so that they can see it.

The lesson observed was on the two types of trees. Hailey said that the big ideas of the lesson were types of leaves and leaf structure. She had her students bring five leaves to class. She opened the lesson with a review of leaves using the Smart Board. She brought up different types of trees on the screen and asked her students to tell what type of tree it was. Hailey also showed a picture of a leaf on the screen. She named the parts of the leaf and told their respective functions. She then had her students to take out one of their leaves and asked them to compare their leaves with the leaves of their peers. Hailey asked her students if their leaves were the same as their peers. Students examined their leaves and shared their observations with the class. Students made leaf rubbings using the leaves they brought to school. Hailey used the Smart Board and leaf examples to teach about leaf structure and the types of leaves so that students can be exposed to it but not to assist in student understanding of the types of trees and their leaves. Although Hailey is explicit in her views that science content should be practical and relevant to student lives, students did not understand the rationale behind the two types of trees and their leaves.

Hailey's PCK rating was a Novice. Her RTOP score was a 57, indicating that 57 % of the classroom instruction observed was reformed. Hailey had not taken many science content courses and only chose to teach the lesson on the types of trees because she was more comfortable with this topic and it seemed relevant to the lives of her students. She admitted during her interview that science was not a focus for kindergarteners and she integrates science into math or reading whenever she can. As stated before, Hailey said that there is not a curriculum for science so she chooses to teach topics that she feels are relevant to the lives of her students:

> Science is just kind of integrated. And I mean, that's the program that we're with now, where science is kind of integrated into our language arts program . . . . …so at least twice a week it's in my reading program to get at least some science involvement. . . . The curriculum I don't think starts here until maybe 3rd and 4th grade? Because I think in K-2 it's pretty much done on our own. Like we are the ones that are going out and finding the lessons, and we don't have books.

Although Hailey had taught this lesson in previous years, she did not use students' misconceptions or prior knowledge to plan the lesson nor did she discuss any learning difficulties that students might have regarding the types of trees or leaf structure. Hailey's sources of PCK are her years of teaching experience regarding the concept of trees.

Hannah

Hannah had been teaching third grade for 3 months. She had three science content courses, including the reformed course, during her undergraduate program. She had not had the opportunity to participate in any professional development workshop for science teaching. She stated in her interview that hands-on activities are the best approach to science teaching. She also stated that she learned best from hands-on activities because those are the ones that she remembered the most. Hannah equates hands-on activities with labs and/or projects where students draw or build the concept being taught.

The lesson that was observed dealt with desert ecosystems. Hannah wanted her students to know the characteristics of the desert, the climate of the desert, and the type of animal and plant life found in the desert. She stated that content must be relevant to students' lives. Hannah's observed lesson involved her students reading from the textbook and asking them questions about what they read. The following excerpt is taken from Hannah's classroom observation:

> The teacher instructs one of the students to read a section from the textbook out loud about desert plant . . . the teacher asks the class a few questions about what the student just read. . . . The teacher calls on another student to read aloud another part of the textbook about desert animals. . . . A student ask the question "do cactuses have leaves? Oh! Are the arms the leaves?" (The teacher nods and goes on to read the next question.) More plants and animals live in hot deserts than cold deserts. Why might this be so? The students give different ideas. The teacher tells them that the correct answer in the book is that animals survive better where it's warm.

Hannah told her students that they were going to make a desert and created some of the animals that live in a desert, using a shoebox, sand, and play-dough. Again, the activity was taken directly from the textbook. Hannah did not consider her students' prior knowledge or misconceptions regarding desert ecosystems nor did she discuss learning difficulties associated with the teaching of this topic.

Hannah's PCK rating was *Novice*. Her RTOP score was 40, indicating that 40% of the observed lesson was reformed. Hannah did not have the content knowledge needed to teach desert ecosystem so she relied heavily on the teacher's version of the textbook to teach this topic. Hannah had student teaching experiences that caused her to reflect on teaching practice but did not do a lot of reflecting regarding desert ecosystems, she simply followed the text.

Although the faculty instructor believed that hands-on instruction was the best approach to science teaching and learning, the observed laboratory investigation was typically a "cook book" lab that was tightly structured by the instructor. Hailey lacked the science content knowledge to teach types of trees and leaf structure. In addition, she was constrained by the context of her school. There was not a science curriculum for kindergarteners and the emphasis was on reading and math. Hannah also lacked the science content knowledge to teach desert ecosystems. She relied on the textbook as the main source of science knowledge for desert ecosystems.

Snapshot Six

Eleanor

Eleanor had been teaching science for over 15 years. Eleanor was a part of the original NASA/NOVA team. She adhered to a constructivists approach to science teaching and learning. She varied instruction to meet the diverse needs of the students. She believed that the teacher should serve as a coach in science teaching and learning. Eleanor used a variety of instructional strategies to teach about the circulatory system to address the various learning modalities of her students. She was a reflective practitioner and considered her students' misconceptions and prior knowledge regarding the circulatory system. She emphasized the importance of connecting the science content to the lives of her students. She stated the following in her interview,

> What do you recall about the circulatory system. . . . Taking a look at blood flow . . . Case study on heart attack (what does heart attack have to do with blood flow--you have to know how something works--take fundamental concepts about circulatory and apply it to this disease). . . . Physiology--blood pressure (how does it tie it into circulatory system). Take a look at model of heart. . . . For each topic that I do there is some type of inquiry lesson and case studies along with viewing models. . . . (Faculty instructor Eleanor)

Eleanor received a PCK rating of *Advanced*. Her RTOP score was an 80, indicating that 80% of her observed instruction was reformed. Eleanor's sources of PCK were the NOVA training, ongoing participation in professional development workshops, years teaching experience, constantly reflecting on her teaching, and collaboration.

Illise

Illise had been teaching 3 years and this was her first year teaching the second grade at an all-boys school. She was a science and math elementary major and therefore had taken a range of science content courses, including the reformed course and two methods courses during her undergraduate program. During Illise's undergraduate program, she took the reformed and the comparison course. The unique aspect of these two courses was that they were both taught by faculty instructors who went through the NASA/NOVA professional development workshop and who were major advocates of reform. Illise stated in her interview that both of these courses contributed to her views on science teaching and learning,

> I would say that I've always enjoyed it, but it changed after being at [University]. I took classes from [*the NOVA instructors*] and took as many as I could . . . so I really feel that if you get that hands-on learning and you get to kind of figure it out yourself and problem-solve and guess and check and figure that out, you're going to learn more about it . . . so taking those courses helped me see that. . . .

Illise's advocates a hands-on approach to science teaching and learning with emphasis on the scientific process. She placed a heavy emphasis on predicting, questioning, and experimenting because it helps students answer the question why.

> I think hands-on . . . gives them that freedom of experimenting with it and then drawing it into the lesson. . . . I think that's a great way . . . and that's how I learned, so I'm partial to that, but I feel like that's a great way for them to actually see it and sense it and feel it. They can try it and if it fails, [ask] why . . . and talk about why it wouldn't work.

Illise's lesson was on water pollution. She said that water pollution was a part of their state standards. She also stressed the importance of connecting the content to the lives of the students. Illise began the lesson with a whole group discussion about water pollution. She asked her students what they knew about water pollution, and several of her students responded with a variety of answers including the oil spill in the gulf, the Boston Tea Party, and how plant and animal life are affected by water pollution. This draws heavily on her students' prior knowledge regarding water pollution and connects the topic to their lives. After the discussion, Illise told her students that they were going to work in groups to simulate water pollution using water, oil, and dish detergent. Students mixed these substances in the water and made predictions and discussed their thoughts with their group members. Throughout the lesson, Illise questioned the students about their predictions and their rationale for the predictions that they made.

Illise received a PCK rating of *Proficient*. Her RTOP score was an 81, indicating that 81% of the observed lesson was reformed. When planning for the lesson on water pollution, Illise considered the prior knowledge and the context of her class (all boys). She knew that the boys would be familiar with water pollution because their town had just experienced a local oil spill. She also stated that her boys were very active, so the hands-on activity would keep them interested and engaged in the lesson. Illise did not discuss learning difficulties associated with the teaching of water pollution. Illise's sources of PCK were her science content, the reformed courses, her methods course, and her years of teaching experience.

Isabelle

This was Isabelle's first year teaching the sixth grade. Prior to this, she served as a long-term substitute teacher for a period of 1 year, teaching the sixth grade. Isabelle was an elementary science and math major and took a range of science courses, including the reformed course, and one science methods course. Isabelle stated in her interview that hands-on and inquiry were the best approach to science teaching and learning,

> I think that hands-on experiments . . . it means doing activities . . . you know, the kids are touching all the objects and the things . . . they can touch them, they can feel them, they can see them. It's not just me standing there and blabbing away and the kids falling asleep . . . and, I think inquiry-based learning, where kids are sort of figuring it out on their own and making judgments.

The lesson observed was on levels of classification and taxonomic keys. Isabelle stated that classification was a part of the state standards and the students would be tested on them. Isabelle began the lesson with a whole class discussion on classification whereby she asked students a series of questions and they gave their response. After the discussion, she had them individually complete a worksheet on classification using an apple, banana, and orange. Once students completed this activity they individually made bookmarks. Isabelle's rationale for choosing these strategies was so that students could become familiar with taxonomy. Although, she says that classification is an important life skill and that students will be tested on this concept, she does not provide explicit goals for the lesson. Isabelle did not consider prior knowledge, misconceptions, or learning difficulties associated with the teaching of this lesson. In addition, Isabelle did not reflect on her teaching practice. She taught this lesson the previous year and did not discuss what she learned from teaching this lesson the previous year. There was a disconnect between her stated views on science teaching and what we observed during her classroom instruction. The lesson was very teacher-centered and highly structured with very little student interaction.

Isabelle received a PCK rating of *Novice*. Her RTOP score was 43, indicating that 43% of the observed instruction was reformed. Isabelle's sources of PCK may be attributed to her science content courses, the reformed course, and the science methods course.

The faculty instructor and the inservice elementary teachers believed that hands-on activities that actively engaged their students in the learning process were the best approach to science teaching and learning. Both inservice elementary teachers had taken the reform and comparison course and several science content courses. Illise was a biology major and Isabella was a mathematics and science major. Illise was an experienced teacher who had been attending ongoing professional development workshops for science content and pedagogy. However, Isabella had only been teaching for 3 months and she had not had the opportunity to participate in any sort professional development.

Snapshot Seven

James

James was an adjunct professor and had over 10 years teaching experience. He was also a part of the original NASA/NOVA faculty professional development project. He believed that science should be taught in a manner that is practical and relevant to students' lives and used activities that demonstrated this belief. James's observed lesson revolved around drainage and discharge. When reflecting on the teaching of this science concept, he considered his students' prior knowledge and misconceptions when deciding on the strategies to be used teach the drainage and discharge. He recognized his students' misconceptions and his own misconceptions regarding drainage and discharge and he talked about the learning difficulties associated with the teaching of this topic.

James achieved a PCK rating of Advanced. His RTOP score was 85, indicating that 85% of his lesson was reformed. James' sources of PCK were his NOVA training, his participation in ongoing professional development workshops, ongoing collaboration with colleagues and other science educators, and his years of teaching experience.

Jada

Jada had been teaching seven years and was currently teaching prekindergarten-fifth grade at the time of this study. Jada was also one of the district's science specialists. She was an

Ecology major and had taken several science courses, including the reformed course, during her undergraduate program. She also received her Master's degree in science education. Jada stated that the best approach to science teaching was hands-on with an emphasis on the scientific process.

> I think hands-on engagement with science and with the process of science is the best way for elementary students. I think that because it's exciting for them, and if they can get excited by science . . . then I feel like they can push through more difficult parts because they are interested in it. . . . So it can really be a hook for interest . . . through asking questions and then trying to find out answers based upon various ways of gathering evidence. . . . So whether it's observational evidence or collecting data over time, or doing research of information that's already out there.

The lesson observed was on the concept of adaptation and the title of the activity was "Fiddler Crab up Close." Jada introduced the concept by having her students think and talk about the characteristics of the fiddler crabs' habitat and the male and female crab. She stated that the purpose of the observed lesson was to "start layering the foundation so that they could talk at a higher level." Prior to this lesson the student groups built a habitat for their two fiddler crabs. During the observed lesson, student groups examined their crabs and wrote down their observations in their science notebooks. Students were also thinking about the characteristics that fiddler crabs have made to survive their habitat. Jada walked around and monitored the students and encouraged them to provide more regarding their crabs. When the groups had completed their observations, Jada led her students in a whole class discussion on adaptations that fiddler crabs have made to survive in their habitat.

Jada's PCK rating was *Advanced*. Her RTOP score was 77, indicating that 77% of the observed instruction was reformed. Jada was a reflective practitioner and considered her students' prior knowledge when planning for this lesson. She also stated that her students have various science backgrounds regarding adaptation so she tries to provide them with a common experience. She stated in her interview that adaptation is a part of their state standards and students will be tested on it; however, she also understood that adaptations is a part of being scientifically literate,

> In general, I think it's important because we have kind of the whole understanding of what's going on in the world around them . . . so having a deeper understanding of the natural world and why certain things are the way they are . . . so it's deepening and broadening their scientific knowledge as well.

Jada's sources of PCK were her science content courses, the science methods course, ongoing Professional Development workshops, collaboration with teachers and science specialists in her district and at the university, and years of experience teaching.

Jan

Jan had been teaching for 13 years, during which time she taught the fifth grade for nine years, the third grade for two years and at the time of this study had been teaching the fourth grade for the past two years. Jan was unique in that she was a communications major during her undergraduate years. She went through a professional development program that allowed her to take several science content courses that focused on content and pedagogy. She believed that hands-on is the best approach to science teaching and learning. Jan stated in her interview that hands-on learning helped students to understand science content and the scientific process.

The lesson observed was on seeds. Jan indicated that this topic was a part of the state standards as well as a part of the fourth grade curriculum. Jan wanted her students to come up with a working definition of seeds based on their observation of the characteristics of seeds. She gave her student groups seeds and non-seeds. Student groups had to examine the items that they were given and determine which items were seeds and which were not. In addition, the student groups had to decide on the features that characterized a seed. Jan facilitated student discussion as she walked from group to group asking students about their items. After student groups had completed their list, Jan led them in a whole class discussion on their choices. Jan said that she initially wanted to give the students seeds only but thought that there would not be enough exploration or thinking about characteristics that make a seed.

Jan took into account the prior knowledge of her students and their ability levels when planning this lesson. She reflected on what she thought would be the best approach to teaching seeds.

> We chose to show students a variety of items, some were seeds and some were not. Students were asked to classify the materials into two groups: seeds or not seeds. We choose this strategy because we wanted students to explore the concept by looking and feeling the seeds, as well as coming to a conclusion as to what makes a seed. . . . The first thought of the lesson was to give students all seeds and have them come up with characteristics . . . we thought that there would not be enough exploring and thinking so we ended up giving them seeds and not seeds.

Jan's PCK rating was *Advanced*. Her RTOP score was 75, indicating that 75% of the observed lesson observed was reformed. Jan's sources of PCK were the science content courses taken through the professional development workshop geared toward content and pedagogy, additional professional development workshops for improving science teaching, the learning-teaching collaborative through the university to become a post-undergraduate teacher, constant reflecting on teaching practice, and years of teaching experience.

The faculty instructor and the two inservice teachers stated in their interviews that a hands-on approach is the best approach to science teaching and learning. However, neither of the inservice elementary teachers had taken the reform or the comparison course. Jan was a communications major during her undergraduate program. She discovered a love for science teaching after she graduated. She went through intensive professional development training geared toward science education reform. The professional development workshops emphasized science content and pedagogy. Both Jada and Jan collaborated with science educators and constantly reflected on their teaching practice.

Summary

The purpose of this study was to examine the long-term impact of varying models of reformed undergraduate science courses on the science pedagogical content knowledge of inservice teachers. Four questions formed the basis of inquiry for this study. Chapter IV presented the data for the research questions. Thirty-five faculty instructors participated in the study. Of the 35 faculty instructors, 21 taught the undergraduate reform course. Of the 21 faculty instructors, 12 participated in the NASA/NOVA professional development workshop while the remainder of the faculty instructors inherited the course.

Ninety-one inservice elementary teachers participated in this study. Of the 91 inservice elementary teachers, 56 experienced the reformed course during their undergraduate program. Of the 91 inservice elementary teachers, 35 took the comparison course during their undergraduate program.

For Research Question 1, are there observed pedagogical differences between faculty teaching reformed and comparison undergraduate science courses, a multivariate analysis of variance (MANOVA) was used to analyze the data. The results of the MANOVA indicated that there were statistically significant differences between the reform and comparison course. Univariate analysis revealed significant group effects on the following subscales: Lesson Design and Implementation, Procedural Knowledge, Communicative Interactions, and Student Teacher Relationships. However, no significant group effects were found for Propositional Knowledge.

Undergraduate student focus groups of faculty of reformed courses corroborated the quantitative data suggesting that faculty of reformed courses taught in a significantly more reformed manner.

Research Question 2 asked, are there instructional differences between elementary teachers who experienced reformed instruction and those who did not based on observed pedagogical differences? A multivariate analysis of variance (MANOVA) was used to analyze the data. The results of the MANOVA indicated that there were no significant differences between teachers who experienced the reform course during their undergraduate program and those who did not. Qualitative analysis revealed that inservice elementary teachers who experienced the undergraduate reform course and those who did not taught in a similar manner. A predominant theme that emerged from the qualitative analysis of the data was the idea that professional development geared toward science content and pedagogy enabled inservice teachers who experienced the reform course to implement reformed pedagogical practices.

Research Question 3 sought to determine whether the level of pedagogical reform experienced in undergraduate science courses is a predictor of the type of science instruction at the elementary level. A multiple linear regression was used to analyze the data. The results revealed that the level of reform experienced in undergraduate science courses was not a predictor of the type of science instruction at the elementary level.

Research Question 4 sought to determine how the level of pedagogical reform experienced in undergraduate science courses related to the pedagogical content knowledge of inservice teachers. PCK snapshots were developed for 21 teachers. Of the 21 teachers, 2 received a PCK rating of *Advanced*, 7 teachers received a PCK rating of *Proficient*, 8 teachers received a PCK rating of *Novice*, and 4 of the teachers received a PCK rating of *Emerging*.

Faculty instructors with PCK ratings of *Advanced* shared the following characteristics: (1) strong science content knowledge, (2) NOVA training or some equivalent, (3) ongoing professional development geared toward science content and pedagogy, (4) collaboration with scientists and science educators, (5) reflective practitioners, and (6) years teaching experience. Faculty instructors with PCK ratings of *Proficient* shared the following characteristics: (1) strong science content knowledge, (2) NOVA training or some equivalent, (3) ongoing professional development geared toward science content and pedagogy, (4) some collaboration with scientists and science educators, and (5) years teaching experience.

Inservice elementary teachers with a PCK rating of *Advanced* shared the following characteristics: (1) science content knowledge regarding the specific science content taught, (2) professional development geared toward science content and pedagogy, (3) reform course or some equivalent, (4) reflective practitioners, (5) provided specific rationales for strategies used to teach content, and (6) collaboration with colleagues and science educators. Inservice elementary teachers with a PCK rating of *Proficient* shared the following characteristics: (1) science content knowledge regarding the specific science content taught, (2) ongoing professional development, (3) provided specific rationales for strategies used to teach content, and (4) some collaboration. Inservice elementary teachers with PCK ratings of *Emerging* or *Novice* shared some of the following characteristics: (1) lacked science content knowledge regarding the science content taught, (2) constrained by school cultures that emphasized reading and math, (3) disconnect between teaching beliefs and enacted lesson, (4) lack of PD in science content and pedagogy, and (5) constraints of state testing.

CHAPTER V

SUMMARY, CONCLUSIONS, IMPLICATIONS, AND RECOMMENDATIONS

Chapter V summarizes the findings of the research questions proposed in Chapter I. The purpose, methods, and results from both quantitative and qualitative data analysis are presented here. Conclusions and implications from the data analysis are also provided. Lastly, recommendations for further research are discussed.

Summary of Study Results

This study evaluated the long-term impact of faculty-created undergraduate science reform courses on the pedagogical content knowledge of inservice elementary teachers. My study involved the use of archived data from a larger study, the National Study of Education in Undergraduate Science, funded by the National Science Foundation. Thirty-five faculty instructors and 91 inservice elementary teachers participated in the study. The faculty instructors of the reformed courses originally participated in the NASA Opportunities for Visionary Academics professional development program between 1996 and 2005. Twenty-one faculty instructors taught the undergraduate reformed science course. Of the 21 faculty instructors, 12 participated in the NOVA professional development project, while the remainder of the faculty instructors replaced the original NOVA instructors. Fourteen faculty instructors taught the comparison course. Fifty-six inservice elementary teachers completed the undergraduate reformed science course during their undergraduate programs and 35 inservice elementary teachers completed the comparison science course required in their academic programs.

Quantitative data were collected through classroom observations conducted with faculty instructors and elementary inservice teachers. The quantitative data were supported with qualitative data derived from interviews, which resulted in CoRes and PaP-eRs for each faculty instructor and each elementary inservice teacher, as well as, interviews with undergraduate student focus groups. All data were analyzed to determine the impact of reformed undergraduate science courses on the pedagogical content knowledge of inservice elementary teachers.

Statistical analysis of classroom observations of faculty instructors of reformed and comparison courses revealed significant differences between the pedagogical practices of these two groups. Overall, results of reformed teaching in entry-level undergraduate science courses were significantly different from the comparison courses for the total RTOP and for the RTOP subscales. Significant differences were found for Lesson Design and Implementation, Procedural Knowledge, Communicative Interactions, and Student/Teacher Relationships. There was not a significant difference between faculty instructors of reformed and comparison courses for the Propositional Knowledge subscale. Qualitative analyses of faculty instructors' interviews and field notes from their RTOPs, as well as their CoRe and PaP-eR, supported findings from quantitative analysis of data. The following themes arose from qualitative analysis of data for faculty teaching reformed courses: (1) reflective practitioner, (2) hands-on approach to science teaching through inquiry, (3) science content that is relevant and facilitates scientific literacy, (4) use of strategies that considered students' prior knowledge and misconceptions, (5) collaboration with colleagues, and (6) ongoing professional development.

Overall, faculty instructors teaching reformed courses (1) embraced the notion of less is more, (2) considered their students' prior knowledge and misconceptions, (3) employed a constructivist approach to science teaching and learning, and (4) were reflective practitioners. In addition, faculty instructors teaching reformed undergraduate science courses participated in ongoing professional development, collaborated with other colleagues, possessed strong evidence of content knowledge and pedagogical knowledge, and had orientations consistent with reformed instruction. These findings are consistent with the research on undergraduate science reform and pedagogical content knowledge. Implementation of reform pedagogical practices is more likely to occur when faculty participate in ongoing professional development (Sunal, Hodges, Sunal, Whitaker, Freeman, Edwards, Johnston, & Odell, 2001; *National Science Teachers Association for the Preparation of Science Teachers*, 2003; Wainwright, Morrell, Flick, & Schepige, 2004); collaborate with other faculty and colleagues (Christopher & Atwood, 2004; Fullan, 2007; Goldston, Clement, & Spears 2004; Sunal et al., 2004); have strong content (Kaya, 2009; Loughran, Berry, & Mulhall, 2006); and pedagogical knowledge (De Jong, Van Driel, &Verloop, 2005; Kaya, 2009; Loughran et al., 2006).

Qualitative analyses of the undergraduate student focus group interviews substantiated the findings of data obtained from faculty instructors. The undergraduate student focus groups from the reform course reported that their instructors engaged them in science by having them do investigations that required them to ask questions, make predictions, experiment, and discuss their findings. Also, students from the undergraduate student focus groups said that experiences in the reformed course enabled them to (1) understand science as a process, (2) conceptualize difficult science concepts through models and investigations, (3) apply science concepts learned in class to novel situations, and (4) reflect on their learning and think about how they can use the information in their teaching practice.

Faculty instructors who taught the comparison course focused more on content rather than pedagogy. The following themes emerged from the qualitative analysis of faculty instructors of the comparison course: (1) teacher-centered (lecture was dominant mode of instruction), (2) little student discourse, and (3) lecture and laboratory were separate. In addition, faculty instructors teaching the comparison course did not attend professional development to improve science instruction and did not collaborate with other colleagues regarding science education reform.

Qualitative analysis of the interviews from the undergraduate student focus groups from the comparison course corroborated the instructional practices observed for the faculty instructors of the comparison course. Students stated that faculty instructors of the comparison courses spent the majority of the class time lecturing and giving notes. They also were able to make the connection between the science content discussed during the lecture to the laboratory investigations. Overall, quantitative and qualitative analysis of data revealed that faculty instructors of the comparison course employed a traditional approach to science teaching and learning. Common characteristics of the comparison courses include (1) teacher-centered instruction where lecture was the predominant mode of instruction, (2) little student discourse, and (3) traditional lecture and lab.

Quantitative and qualitative analysis of classroom observations did not reveal significant differences between the pedagogical practices of inservice elementary teachers who experienced the reform course during their undergraduate program and those who did not. Overall, these results demonstrate that the level of reformed teaching in elementary classrooms is statistically similar for both groups. The recurring theme that emerged from qualitative analysis of the interviews is the idea that professional development geared toward science content and pedagogy helped to impact their instructional practice.

Statistical analysis of data was done to determine whether the level of pedagogical reform experienced in undergraduate science courses was a predictor of the type of science instruction observed in elementary classrooms. Statistical analysis revealed that the model was not a predictor of reformed instruction in elementary classrooms.

Qualitative analysis of interviews, and CoRes and PaP-eRs of faculty instructors to examine their pedagogical content knowledge, revealed that five faculty instructors received a PCK rating of *Advanced*; one faculty instructor received a PCK rating of Proficient; and the one faculty instructor received a PCK rating of *Emerging*. Qualitative analysis of the 21 inservice elementary teachers revealed that 8 inservice elementary teachers received a PCK rating of *Proficient* or *Advanced*. All of the inservice elementary teachers were inclined to a hands-on approach to science teaching and learning. Only 8 of the 21 inservice elementary teachers, however, were able to provide a rationale for why they used a hands-on approach to teach the science concept during the observed lesson. These 8 inservice teachers stated that students' prior knowledge, curriculum, and various learning modalities informed their decision to use specific instructional strategies to represent the science concept taught during the observed lesson. The two teachers that received the *Advanced* PCK rating were reflective practitioners.

The 13 teachers who received a PCK rating of *Novice* or *Emerging* also stated that a hands-on approach was the best approach to science teaching and learning. These teachers' understanding of "hands-on," however, was fragmented. These teachers equated hands-on learning with activities that allowed students to “do, see, or feel” something, such as manipulating a microscope or using the Smart Board.

The eight inservice elementary teachers who received the PCK rating of *Proficient* or *Advanced* took four or more science content courses in addition to the reform course or comparable course. They each exhibited content knowledge regarding the science concept that they taught during the observed lesson. They each used their knowledge of context, students’ prior knowledge and/or misconceptions, and learning difficulties associated with the teaching of that specific topic to choose strategies that helped to transform the science content to facilitate student learning. These eight inservice elementary teachers were involved in ongoing professional development workshops geared toward science teaching. Their teaching experience ranged from 2 to 13 years. Two of the eight teachers received an *Advanced* PCK rating. The two teachers who received an *Advanced* PCK rating, not only used their knowledge of content and their knowledge of their students to inform their teaching of the science topics observed but they constantly reflected on their teaching practice.

Overall, the eight inservice elementary teachers taught in a reformed manner and purposefully chose instructional strategies that would best facilitate student learning based on what they knew about how their students learn.

Inservice elementary teachers with a *Novice* or *Emerging* rating took one to three science content courses including the reformed undergraduate science course. Many of them attended professional development workshops that focused on reading, literacy, and science or a combination of all three. These findings are consistent with the research on the status of elementary school science teaching regarding science content courses taken during teacher education programs and the amount of emphasis given to math and reading instruction (Weiss, Banilower, MacMahon, & Smith, 2001). Some of these teachers attended professional development workshops that taught the teachers how to use district provided science kits. Inservice elementary teachers with a *Novice* or *Emerging* PCK rating did not use their knowledge about how their students learn to inform their teaching of the specific topics observed during their classroom lesson. Overall, teachers with a *Novice* or *Emerging* PCK rating had taken fewer science content courses, did not use their knowledge of their students to inform teaching practice, and were not reflective practitioners.

These findings are consistent with the literature on pedagogical content knowledge: (1) content knowledge is interrelated with pedagogical knowledge and other components of PCK (Halim & Meerah, 2002; Kaya, 2009); (2) content knowledge positively influences PCK (Kapyla, Heikkinnen, & Asunta, 2009; Ozden, 2008); (3) lack of content knowledge affects teacher trainees awareness of likely misconceptions (Halim, Subahan, & Meerah, 2002); (4) observed differences in preservice teachers' PCK was probably due to variations in their subject matter knowledge (De Jong, Van Driel, & Verloop, 2005); (6) lack of science content knowledge limits pedagogical content knowledge (Appleton, 2008); and (7) lack of science content knowledge may result in elementary teachers using hands-on activities as a substitute for science PCK (Appleton & Kindt, 1999, 2000).

Several of the inservice elementary teachers in my study stated that time, lack of resources, an emphasis on math and reading, and state testing served as impediments to science teaching.

> I mean the trainings that we've gone to have kind of been all inclusive, but most of my focus is usually on reading and math. (Hailey)

> Lack of materials . . . if you want to have good materials, you have to buy a lot of them yourself. (Jack)

> Teaching to the test; schedule of testing; lack of supplies. (Jane)

> Time . . . we have so many standards and so little time . . . time, just time. We have so many standards and so little time. And as you can see, it's not just teaching science. (Jennifer)

> This is the first year that the district is making us follow the textbook to the letter. I'm really frustrated right now because the test is driving instruction. That's not how it should be. (Kelvin)

These barriers were beyond the control of the teachers. The inservice elementary teachers were constrained by the context of their school environment. In addition, several of the inservice elementary teachers cited testing as a goal of science teaching and felt pressured to cover a lot of science content in a short amount of time. These barriers could serve as impediments in the development of pedagogical content knowledge.

Conclusions

This research supports the need to strengthen inservice elementary teacher's pedagogical content knowledge. Overall, quantitative and qualitative analyses demonstrate that undergraduate reform science courses *alone* do not impact the pedagogical practices and the pedagogical content knowledge of inservice elementary teachers.

First, quantitative and qualitative analyses of faculty instructor's data revealed that pedagogical differences do exist between faculty instructors of reformed undergraduate science courses and those who taught the comparison course. Faculty who had participated in the NASA/NOVA professional development program or comparable workshops taught in a significantly reformed manner as evidenced in their classroom observations.

Faculty instructors teaching reformed science courses designed lessons that allowed for student exploration of the science concepts and that solicited students' prior knowledge and understandings about that concept. Faculty instructors of the reformed course achieved a mean score of 70.81 for total RTOP score, and faculty instructors of comparison courses achieved a mean score of 49.28. Faculty instructors of reformed courses achieved a mean rating of 12.65 out of a possible 16.00 for lesson design and implementation, while faculty of comparison courses achieved a mean score of 8.38. Faculty teaching reformed science courses exhibited a deeper understanding of how to use procedural knowledge to facilitate scientific reasoning through using activities that allowed students to manipulate information, arrive at conclusions, and evaluate knowledge claims. Faculty of reformed courses achieved a mean rating of 12.62 for the procedural knowledge subscale, while comparison faculty achieved a mean score of 8.16. Faculty teaching reform courses were more likely to understand the importance of knowledge construction in an environment in which students are allowed to communicate their ideas and understandings with their peers, achieving a mean rating of 14.57, while comparison faculty achieved a mean rating of 8.70. Finally, faculty instructors teaching reform science courses differed from faculty in comparison courses in the quality of student/teacher relationships achieving a mean rating of 15.27, while comparison faculty had a mean rating of 10.11.

Faculty who had RTOP scores of 67 or better participated in ongoing professional development, collaborated with other colleagues, possessed strong evidence of subject matter knowledge and pedagogical knowledge, and had orientations consistent with reform instruction. Consistent with the literature, when faculty participate in ongoing professional development (*National Science Teachers Association for the Preparation of Science Teachers,* 2003; Sunal, Hodges, Sunal, Whittaker, Freeman, Edwards, Johnston, & Odell, 2001; Wainwright, Morrell, Flick, & Schepige, 2004); collaborate with other faculty and colleagues (Christopher & Atwood, 2004; Fullan, 2007; Goldston, Clement, & Spears 2004; Sunal et al., 2004); possess strong content knowledge (Kaya, 2009; Loughran, Berry, & Mulhall, 2006) and pedagogical knowledge (De Jong, Van Driel, & Verloop, 2005; Loughran et al., 2006; Kaya, 2009) then reform practices are implemented and retained. Qualitative analyses of undergraduate student focus groups corroborated the data obtained from the faculty instructors.

Second, quantitative analyses of data obtained from inservice elementary teachers revealed that pedagogical differences do not exist between inservice elementary teachers who experienced the reform courses during the program and those who did not. Of the 91 teachers, 67 observed received an RTOP score of 50% or greater, indicating that 50% of the classroom instruction observed was reformed.

Lastly, qualitative analyses of interviews, CoRes, and PaP-eRs regarding the pedagogical content knowledge of faculty instructors (N = 7) and inservice elementary teachers (N = 21) showed variations regarding pedagogical content knowledge. First, six faculty instructors had *Proficient* (N = 1) and *Advanced* (N = 5) PCK ratings. These faculty instructors taught in a reformed manner and had advanced pedagogical content knowledge for the science topic taught during the observed lesson. Second, inservice elementary teachers with PCK ratings of *Novice* (N = 8) or *Emerging* (N = 4) had RTOP scores ranging from 26 through 76. Teachers who had PCK ratings of Proficient (N = 7) or Advanced (N = 2) shared the following characteristics: (1) strong evidence of science content knowledge regarding the science concept that they taught, (2) considered the prior knowledge of their students, (3) purposefully used hands-on activities to represent the science concept and facilitate student understanding, (4) observed lessons had elements of inquiry, (5) participated in ongoing professional development geared toward science content and pedagogy, (6) student teaching or teaching experience, (7) the reform course in which content and pedagogy was combined, and (8) were reflective about teaching practice.

These findings are consistent with the literature on pedagogical content knowledge. The development of PCK depends to a large extent on content knowledge (Borko, 2004; Kaya, 2009; Loughran, Berry, & Mulhall, 2006; Nilsson, 2008; Ogletree, 2007; Ozden, 2008; Smith & Neale, 1989; Van Driel, De Jong, & Verloop, 2002). Limited content knowledge hinders the teachers' ability to effectively use instructional strategies and knowledge of students' learning difficulties and misconceptions associated with teaching a particular science topic (Berg & Brouwer, 1991; Halim & Meerah, 2002; Kaya, 2009; Ogletree, 2007; Van Driel et al., 2002). In addition, the development of pedagogical content knowledge is influenced by teachers reflecting on teaching practice (Bryan & Abell; 1999; De Jong, Van Driel, & Ver Loop, 2005; Joyce & Showers, 2002; Loughran, 2002; Loughran, Mulhall, & Berry, 2008; Nilsson & Van Driel, 2008; Osborne, 1998; Schon, 1983; Shulman, 1987) and teachers' ongoing participation in professional development workshops geared toward science content and pedagogy (Appleton, 2008; Avraamidou & Zembal-Saul, 2010; Clermont, Krajcik, & Borko, 1994; Grossman, 1990; Hawley & Valii, 1999; Loucks-Horsley, Love, Stiles, Mundry, & Hewson, 2003; Van Driel et al., 2002).

Implications

The *National Science Education Standards* and the *National Science Teachers Association* describe what science content elementary teachers should know and what pedagogical knowledge they should have for science teaching and learning in Kindergarten-6th grade classrooms. Paramount to these recommendations is the notion that young children should be active learners, constructing science understanding through hands-on/minds-on inquiry experiences; engage in science investigations wherein they ask questions, collect and make sense of data, and come to conclusions that are supported by evidence; and investigate authentic questions generated from student experiences (NRC, 2000, 2007). Students should also experience science inquiry such that they develop positive attitudes, skills, and knowledge about science and the relationship between science and society (Schwarz & Gess-Newsome, 2008). This type of instruction places a heavy demand on elementary teachers who must not only have expertise in science content but they must have expertise in all of the subjects they teach. Teachers must go beyond knowledge of science content and traditional, generic pedagogical knowledge to ensure meaningful learning experiences for students in Kindergarten-6th grade classrooms. More emphasis on pedagogical content knowledge is needed.

Pedagogical content knowledge regarding specific science content enables expert teachers to transform science content using instructional strategies and knowledge of students' learning difficulties, prior knowledge, and misconceptions into forms young students can understand. Elementary teachers with *Advanced* or *Proficient* PCK used their knowledge of the science content and pedagogy to inform teaching practice. This study's results provide evidence of this. Quantitative analyses revealed no significant differences in the observed pedagogical practices between inservice elementary teachers who took the reformed course during their undergraduate program and those who did not. Qualitative analyses, however, revealed that differences exist in the pedagogical content knowledge of inservice elementary teachers. Inservice elementary teachers who had PCK ratings of *Proficient* or *Advanced* had the higher RTOP scores. The reverse of this previous statement is not true. Teachers who had high RTOP scores did not necessarily achieve higher PCK ratings regarding the specific science concept that was taught. The following characteristics emerged from inservice elementary teachers who had high PCK ratings and high RTOP scores: (1) evidence of science content knowledge regarding the specific concepts taught during the observed lesson; (2) ongoing professional development geared toward science content and pedagogy; (3) school culture that emphasized science teaching and learning; (4) a supportive school culture; (5) instructional strategies that considered student learning difficulties, prior knowledge, and/or student misconceptions; (6) purposeful use of instructional strategies to represent science concept and facilitate student learning; and/or (7) reflective teaching practice.

This research is among the first to examine the impact of a reformed undergraduate science course on the pedagogical content knowledge of inservice elementary teachers. The reform course was unique in that it was a combination of science content and pedagogy. These courses were taught by content specialists who participated in the NASA/NOVA project to improve the way they taught science to their students. Although the reformed course does well to introduce preservice teachers to innovative ways of science teaching, the reform course alone does not inform the pedagogical content knowledge of inservice elementary teachers.

Pedagogical content knowledge is a complex construct and even more complex are the variables that mediate the development of it. Several variables seem to mediate the pedagogical content knowledge of inservice teachers. The following implications emerged from the findings of this study.

1. Quantitative analysis demonstrated no significant differences between inservice elementary teachers who experienced the reform course and those who did not. More than 50% of the inservice elementary teachers used hands-on activities during the observed lesson. Several variables may blur the lines between the observed pedagogical practices of the two groups of teachers. First, many teachers attended some form of professional development workshops to improve science teaching. The ethos of these workshops varied in nature and focus. Some workshops focused on science notebooks while others focused on standards. Some of these

workshops provided science kits for the inservice teachers to use with their students. These kits typically revolved around a science unit and had some elements of inquiry. Professional development workshops appeared to blur the lines between the pedagogical practices of inservice teachers who experienced the reform course and those who did not take the reform course but participated in professional development workshops to improve their science teaching. Teachers who did not take the reform course but participated in professional development workshops geared toward content and pedagogy were similar to teachers who took the reform course in terms of observed pedagogical practices. Second, teachers who took the reform course but were teaching in settings where more emphasis was given to reading and math instruction were not able to teach science on a consistent basis.

2. Qualitative analysis revealed that teachers who experienced a higher level of pedagogical reform, had opportunities to teach the science content and reflect on their teaching during their undergraduate programs, and participated in professional development workshops that were geared toward science content and pedagogy were more effective at implementing reform practices as evidenced in their PCK ratings and RTOP score. Most of the inservice teachers employed a hands-on approach to science teaching; however, inservice teachers with PCK ratings of *Proficient or Advanced* specifically used hands-on activities to facilitate student learning and the scientific process. Inservice teachers with *Novice* or *Emerging* PCK ratings seemed to use hands-on activities from a more generic or global perspective. This suggests that teachers may believe that these sorts of activities (i.e., hands-on activities) can be used to teach any given science concept. Mason (1999) suggested that when novice teachers are not provided with the opportunity to apply pedagogical knowledge to specific issues, they tend not to

understand what particular teaching strategies should be used to contextually teach specific concepts.

3. Inservice elementary teachers who experienced the reformed course and those who did not were constrained by barriers such as testing and school culture. Inservice teachers who were constrained by testing felt pressured to cover a lot of science content in a short amount of time in order to prepare students for state tests. Also, in school cultures where reading and math were the focal point of the school curriculum, science may have been taught as a reading lesson.

Recommendations for Future Research

This study investigated the impact of faculty-created reformed undergraduate science courses on the pedagogical content knowledge of inservice teachers who took these courses during their undergraduate programs. As a result of the findings of this study, recommendations are made for future research.

1. This study examined the impact of an undergraduate reformed science course on the pedagogical content knowledge of inservice elementary teachers who experienced these courses during their undergraduate programs. Although not addressed in this study, future research should explore the relationship between the pedagogical content knowledge of inservice elementary teachers and student achievement.

2. Several of the inservice elementary teachers in this study expressed that they were not comfortable teaching some science concepts because of a lack of science content knowledge. Future research should explore sustained professional development workshops that are specifically geared toward science content and pedagogy that will help inservice elementary

teachers acquire the science content knowledge and pedagogical knowledge needed for effective classroom practice.

3. Some of the inservice elementary teachers in this study had taken fewer than three science content courses and one science methods course. As stated in chapter I, teacher education programs tend to stress unilaterally either content or pedagogy often providing preservice and inservice teachers with a host on non-contextualized and unconnected activities (Mason, 1999). The only course that was a unique blend of content and pedagogy was the reform course. Future research should explore the possibilities of changing the curriculum for elementary preservice teachers within teacher education programs to incorporate more courses that stress the interconnectedness of science content knowledge and pedagogical knowledge for effective science teaching.

4. This study attempted to examine the content knowledge of Kindergarten-6th grade inservice elementary teachers. Because many of these teachers had fewer than three content courses it was difficult to specifically gauge their level of content knowledge regarding the specific topics taught. These teachers may have had misconceptions about the lesson observed but it was not noted during their observation because the inservice elementary teachers were only observed one time. Future research should explore science content knowledge tests for Kindergarten-6th elementary teachers to determine their level of science content knowledge regarding specific science concepts. Science content tests of this sort would serve to determine the level of science content knowledge of inservice elementary teachers and it could help inservice elementary teachers to determine what their understandings or misconceptions are regarding specific science concepts. Currently, there is not a science content test to assess the level of science content knowledge for Kindergarten -6th grade inservice elementary teachers.

5. Inservice elementary teachers stated that the mandates of state testing and a school culture that emphasized math and reading constrained their ability to teach science. Both the *No Child Left Behind* (*NCLB*) *Act of 2001* and the Race to the Top Initiative have brought evidence-based research front and center in education by requiring federal programs under each act to use their allocations on evidence-based strategies for the purposes of improving teaching and learning in Kindergarten-12th grade institutions across our nation. One recommendation for future research is to explore how the constraints of high-stakes testing impede science teaching and learning in Kindergarten through 6th grade classrooms. Such research could provide evidence to policymakers as to how the impact of testing constrains science teaching and learning in Kindergarten-6th grade classrooms.

6. Inservice elementary teachers who had *Proficient* and *Advanced* PCK ratings were knowledgeable of science content, experienced the reform course or some comparable course, participated in ongoing professional development workshops for science content and pedagogy, and, in some cases, were reflective practitioners. Future research should explore the possibilities of university-based induction programs for newly graduated elementary teachers. Such programs would comprise science educators, science content specialists, and experienced Kindergarten-6th grade teachers and whose role would be to help new teachers deepen their understanding of science content and pedagogy to improve teaching practice.

REFERENCES

American Association for the Advancement of Science. (1990). *Science for all Americans*. New York: Oxford University Press.

Appleton, K. (2003). How do beginning primary school teachers cope with science: Toward an understanding of science teaching practice. *Research in Science Education, 33,* 1-25.

Appleton, K. (2002). Science activities that work: Perceptions of primary school teachers. *Research in Science Education, 32,* 393-410.

Avaarimidou, L., & Zembaul-Saul, C. (2010). In search of well-started beginning science teachers: Insights from two first-year elementary teachers. *Journal of Research in Science Teaching, 47*(6), 661-686.

Avaarimidou, L., & Zembaul-Saul, C. (2005). Giving priority to evidence in science teaching: A first-year elementary teacher's specialized practices and knowledge. *Journal of Research in Science Teaching, 42*(9), 965-986.

Christopher, J. E., & Atwood, R. K. (2004). Interdisciplinary curriculum planning in a college course. In D. W. Sunal, E. L. Wright, & J. B. Day (Eds.), *Reform in undergraduate science teaching for the 21st century*. (pp. 123-135). Greenwich, CT: Information Age.

Bigge, M. L., & Shermis, S. S. (2004). *Learning theories for teachers*. Boston: Allyn and Bacon.

Bozkurt, O., & Kaya, O. N. (2008). Teaching about ozone layer depletion in Turkey: pedagogical content knowledge of science teachers. *Public Understanding of Science*, 17, 261-276. http://pus.sagepub.com/cgi/content/abstract/17/2/261

Bryan, L. A., & Abell, S. K. (1999). Development of professional knowledge in learning to teach elementary science. *Journal of Research in Science Teaching, 36,* 121-139.

Cannon, J. R. (2007). The constructivist learning survey may help halt student exodus from college science courses: Comparing students' preferences and perceptions of constructivist style learning environments. *Journal of College Science Teaching, 27*(1), 67-71.

Clermont, C. P., Krajcik, J. S., & Borko, H. (1993). The influence of an intensive inservice workshop on pedagogical content knowledge growth among novice chemical demonstrators. *Journal of Research in Science Teaching, 30*(1), 21-43.

Creswell, J. W. (2007). *Qualitative inquiry & research design: Choosing among five approaches*. Thousand Oaks: Sage Publications.

DeBoer, G. E. (2006). History of the science standard move in the United States. In D. W. Sunal & E. L. Wright (Eds.), *The impact of state and national standards on K-12 science teaching* (pp. 7-49). Greenwich, CT: Information Age Publishing.

DeBoer, G. E. (1991). *A history of ideas in science education: Implications for practice*. New York: Columbia University Teachers College Press.

DeJong, O., Van Driel, J. H., & Verloop, N. (2005). Preservice teachers' pedagogical content knowledge of using particle models in teaching chemistry. *Journal of Research in Science Teaching, 42*(8), 947-964.

Faikhamta, C., Coll, R., & Roadrangka, V. (2009). The development of Thai preservice chemistry teachers' pedagogical content knowledge: From a methods course to field experience. *Journal of Science and Mathematics Education in Southeast Asia, 32*(1), 18-35.

Friedrichsen, P. M., & Dana, T. M. (2003). Using a card-sorting task to elicit and clarify science teaching orientations. *Journal of Science Teacher Education, 14*(4), 291-309.

Friedrichsen, P. M., & Dana, T. M. (2005). Substantive-level theory of highly regarded secondary biology teachers' science teaching orientations. *Journal of Research in Science Teaching, 42*(2), 218-244.

Friedrichsen, P. M., Van Driel, J. H., & Abell, S. (2011). Taking a closer look at science teaching orientations. *Science Education, 95*, 358-376.

Gall, M. D., Gall, J. P., & Borg, W. R. (2007). *Educational research: An introduction* (8th ed.). Boston: Allyn & Bacon.

Gess-Newsome, J. (1999). Pedagogical content knowledge: An introduction and orientation. In J. Gess-Newsome & N. Lederman (Eds.), *Examining pedagogical content knowledge* (pp. 3-20). Dordrecht: Kluwer.

Goldston, M. J., Clement, M., & Spears, J. (2004). A large university perspective on reform in teaching: A geologist's personal practice Theories and pedagogical change. In D. W. Sunal, E. L. Wright, & J. B. Day (Eds.), *Reform in undergraduate science teaching for the 21st century* (pp. 245-266). Greenwich, CT: Information Age.

Grossman, P. L. (1990). *The making of a teacher: Teacher knowledge and teacher education.* New York: Teachers College Press.

Halim, L., & Mohd-Meerah, S. (2002). Science trainee teachers' pedagogical content knowledge and its influence on physics teaching. *Research in Science & Technological Education, 20*(2), 215-225.

Johnson, R. B., & Onwuegbuzie, A. (2004). Mixed methods research: A research paradigm whose time has come. *Educational Researcher, 33*(7), pp. 14-26.

Jorgensen, M. A., & Hoffman, J. (2003). History of the No Child Left Behind Act of 2001 (NCLB). Retrieved September 2, 2011, from www.pearsonassessments.com

Joyce, B., & Showers, B. (2002). *Student achievement through staff development* (3rd ed.). Alexandria, VA: Association for Supervision and Curriculum Development.

Judson, E., & Sawada, D. (2001, April). *Tracking transfer of reform: Tracking transfer of reform methodology from science and math college course to the teaching style of beginning teachers*. Paper presented at the annual meeting of the American Education Research Association, Seattle, Washington.

Käpylä, M., Jussi-Pekka Heikkinen, J. P., & Asunta, T. (2009). The effects of content knowledge on pedagogical content knowledge: The case of teaching photosynthesis and plant growth. *International Journal of Science Education, 31*(10), 1395-1415.

Kaya, O. N. (2009). The nature of relationships among the components of pedagogical content knowledge of preservice science teachers: "Ozone layer depletion" as an example." *International Journal of Science Education, 31*(7), 661-688.

Lawrenz, F., Huffman, D., & Gravely, A. (2007). Impact of the collaboratives for excellence in teacher preparation program. *Journal of Research in Science Teaching, 44*(9), 1348-1369.

Loucks-Horsley, A., Love, N., Styles, K., Mundry, S., & Hewson, P. (2003). *Designing professional development for teachers of science and mathematics*. Thousand Oaks, CA: Corwin.

Loughran, J., Berry, A., & Mulhall P. (2006). *Understanding and developing science teachers' pedagogical content knowledge.* Rotterdam: Sense Publishers.

Loughran, J., Milroy, P., Berry, A., Gunstone, R., & Mulhall, P. (2001). Documenting science teachers' pedagogical content knowledge through PaP-eRs. *Research in Science Education, 33*, 289-307.

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.

Loughran, J., Mulhall, P., & Berry, A. (2008). Exploring pedagogical content knowledge in science teacher education. *International Journal of Science Education*, *30*(10), 1301-1320.

Lowery, N. V. (2002). Construction of teacher knowledge in context: Preparing elementary teachers to teach mathematics and science [Electronic version]. *School Science & Mathematics, 102*(2), 68-84.

MacIsaac, D., & Falconer, K. (2002). Reforming physics instruction via RTOP. *The Physics Teacher, 40*, 16-22.

Magnussen, 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* (pp. 95-132). Dordrecht: Kluwer.

Mason, C. L. (1999). The triad approach: A consensus for science teaching and learning. In J. Gess-Newsome & N. Lederman (Eds.), *Examining pedagogical content knowledge* (pp. 277-292). Dordrecht: Kluwer.

Mulhall, P., Berry, A., & Loughran, J. (2003). Frameworks for representing science teachers' pedagogical content knowledge. ***A****sia-Pacific Forum on Science Learning and Teaching*, *4*(2), 1-25.

Mulholland, J., & Wallace, J. (2005). Growing the tree of knowledge: Ten years of learning to teach elementary science. *Journal of Research in Science Teaching, 42*(7), 767-790.

National Assessment of Education Progress: The nation's report card. Retrieved March 7, 2011, from http://nationsreportcard.gov/science 2009.

National Center for Educational Statistics. The nations report card science 2009. Trends in International Mathematics and Science Study. Retrieved March 7, 2011, from http://nces.ed.gov/timss.

National Research Council. (1996). *National science education standards*. Washington, DC: National Academy Press.

National Science Teachers Association. (2003). *Standards for science teacher preparation*. Washington, DC: National Academy Press.

Nilsson, P. (2008). Teaching for understanding: The complex nature of PCK in pre-service teacher education. *International Journal of Science Education*, *30*(10), 1281-1299.

Nilsson, P., & Van Driel, J. (2008, March). *Experienced primary teachers' and primary science student teachers' collaborative learning through reflection on their science teaching*. Paper presented at NARST, Baltimore, MD.

Sandler, J. O. (2003). Lest science be left behind. *Education Week*, *22*(29).

Sawada, D., & Piburn, M. (2000). *Reformed teaching observation protocol (RTOP): Reference manual*. Phoenix, AZ: Arizona Collaborative for Excellence in the Preparation of Teachers.

Schon, D. A. (1983). *Educating the reflective practitioner: Toward a new design for teaching and learning in the profession*. San Francisco: Jossey-Bass.

Schwartz, R.S. & Gess-Newsome, J. (2008). Elementary science specialist: A pilot study of current models and a call for participation in the research. *Science Educator*, *17*(2), 19-30.

Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher, 15*, 4-14.

Shulman, L.S. (1987). Knowledge and teaching: Foundations of the new reform. *Harvard Educational Review, 57*, 1-22.

Sunal, D. W., Hodges, J. Sunal, C. S., Whittaker, K. W., Freeman, L. M., Edwards, L. E., Johnston, R. A., & Odell, M. (2001). Teaching science in higher education: Faculty professional development and barriers to change. *School Science and Mathematics, 101*(5), 246-257.

Sunal, D. W., Sunal, C. S., Mason, C., & Zollman, D. (2008, June). *Assessment of undergraduate courses in the sciences: A national study*. Paper presented at Enriching the Academic Experience of College Science Students National Conference, Ann Arbor, MI.

Symonds, J. E., & Gorard, S. (2010). Death of mixed methods? Or the rebirth of research as a craft. *Evaluation and Research in Education, 23*(2), 121-136.

U.S. Department of Education: No child left behind. Retrieved February 10, 2011, from http://www.ed.gov/nclb.

Wainwright, C., Morrell, P. D., Flick, L., & Schepige, A. (2004). Observation of reform teaching in undergraduate level mathematics and science courses. *School Science and Mathematics, 104*(7), 322-335.

Weiss, I. R., Banilower, E. R., McMahon, K. C., & Smith, P. S. (2001). *Report of the 2000 National Survey of Science and Mathematics Education*. Chapel Hill, NC: Horizon Research.

Wright, E. L., & Sunal, D. W. (2004). Reform in undergraduate science classrooms. In D. W. Sunal, E. L. Wright, & J. B. Day (Eds.), *Reform in undergraduate science teaching for the 21st century* (pp. 33-51). Greenwich, CT: Information Age.

APPENDIX A

CONTENT REPRESENTATION (CoRe)

	Important Science Ideas/Concepts						
What will be the main ideas of this lesson?							
What do you intend the <u>students</u> to learn about these ideas?							
Why is it important for students to know this?							
What do you anticipate will be some difficulties and/or limitations connected with teaching this idea?							
What knowledge about students' thinking influences your teaching of this idea?							
What are other factors that influence your teaching of this idea?							
a) Describe how you will teach the main ideas in this lesson. b) Why will you be using this procedure to teach these main ideas?							
What are specific ways you will use to determine students' understanding or confusion around this idea?							

APPENDIX B

REFORMED TEACHING OBSERVATION PROTOCOL (RTOP)

RTOP
Reformed Teaching Observation Protocol

I. BACKGROUND INFORMATION

Instructor/teacher Code # ________________ Announced Observation?________________
(yes or no, or explain)

Location of class ____
(university, building, room/school district, school, room)

Lesson Observed ____ Year/Grade Level ___________

Observer _________________________________ Date of Observation ________________

Start time ________________________________ End time __________________________

II. CONTEXTUAL BACKGROUND ACTIVITIES

In the space provided below please give a **brief description of the lesson observed**, the **classroom setting** (space, seating arrangements, etc), **and learning climate** in which the lesson took place (cooperative groups, teacher & student attitudes toward learning, classroom management strategies used etc), and **any relevant details about the students** (number, gender, ethnicity), **teacher, building climate, administrative constraints, and other factors not covered in RTOP** that you think are important for RTOP and other qualitative analysis that will lead to completion of the final report for the site visit. Use diagrams and more pages if they seem appropriate and are needed.

Record salient events observed here that you will use in completing RTOP.

Time	Description of Events
	Lesson Begins

Record salient events observed here that you will use in completing RTOP.

Time	**Description of Events**
	Lesson Ends

III. LESSON DESIGN AND IMPLEMENTATION

		Never Occurred				Very Descriptive
1)	The instructional strategies and activities respected students' prior knowledge and the preconceptions inherent therein.	0	1	2	3	4
2)	The lesson was designed to engage students as members of a learning community.	0	1	2	3	4
3)	In this lesson, student exploration preceded formal presentation.	0	1	2	3	4
4)	This lesson encouraged students to seek and value alternative modes of investigation or of problem solving.	0	1	2	3	4
5)	The focus and direction of the lesson was often determined by ideas originating with students.	0	1	2	3	4

IV. CONTENT

Propositional Knowledge

6)	The lesson involved fundamental concepts of the subject.	0	1	2	3	4
7)	The lesson promoted strongly coherent conceptual understanding.	0	1	2	3	4
8)	The teacher had a solid grasp of the subject matter content inherent in the lesson.	0	1	2	3	4
9)	Elements of abstraction (i.e., symbolic representation, theory building) were encouraged when it was important to do so.	0	1	2	3	4
10)	Connections with other content disciplines and/or real world phenomena were explored and valued.	0	1	2	3	4

Procedural Knowledge

11)	Students used a variety of means (models, drawings, graphs, concrete materials, manipulatives, etc.) to represent phenomena.	0	1	2	3	4
12)	Students made predictions, estimations and/or hypotheses and devised means for testing them.	0	1	2	3	4
13)	Students were actively engaged in thought-provoking activity that often involved the critical assessment of procedures.	0	1	2	3	4
14)	Students were reflective about their learning.	0	1	2	3	4
15)	Intellectual rigor, constructive criticism, and the challenging of ideas were valued.	0	1	2	3	4

V. CLASSROOM CULTURE

Communicative Interactions

		Never Occurred				Very Descriptive
16)	Students were involved in the communication of their ideas to others using a variety of means and media.	0	1	2	3	4
17)	The teacher's questions triggered divergent modes of thinking.	0	1	2	3	4
18)	There was a high proportion of student talk and a significant amount of it occurred between and among students.	0	1	2	3	4
19)	Student questions and comments often determined the focus and direction of classroom discourse.	0	1	2	3	4
20)	`There was a climate of respect for what others had to say	0	1	2	3	4

Student/Teacher Relationships

21)	Active participation of students was encouraged and valued.	0	1	2	3	4
22)	Students were encouraged to generate conjectures, alternative solutions strategies, and ways of interpreting evidence.	0	1	2	3	4
23)	In general the teacher was patient with students.	0	1	2	3	4
24)	The teacher acted as a resource person, working to support and enhance student negotiations.	0	1	2	3	4
25)	The metaphor "teacher as listener" was very characteristic of this classroom.	0	1	2	3	4

*Adapted from Turley, J., Piburn, M., & Sawada, D. (2001).

Additional comments you may wish to make about this lesson.

APPENDIX C

FACULTY INTERVIEW

Faculty Interview Questions

Background: (CoRe)

1) **How long have you been teaching science at the undergraduate level?**

2) **How long have you been teaching this "identified NOVA" or comparison course?**

3) **What other courses do you teach over a normal one-year period of time?**

4) **Have you taught at any other levels such as high school, community college, or graduate school? If so, for how long?**

5) **Have you participated in any university professional development for improving teaching? Please describe the extent of this experience.**

6) **Have you taken university level education courses such as teaching methods? If so, please elaborate (certification, education degree, etc.).**

Course:

7) **Describe your students' interest in this course and science in general.**

8) **What are the main goals that you wish your students to learn from this course? What should your students take away about science in general after taking this course?**

9) **What were the important knowledge and skills you needed to develop and teach this course?**

10) **Describe your teaching methods (strategies) and why you use them in this course?**
11) **What were the significant barriers you overcame in planning and teaching this course?**

12) **Compare this course to other courses you have taught at this academic level.**

13) **What advice would you give future faculty members when they start teaching about effective science instruction and/or strive to teach science effectively themselves?**

Class Session: (CoRe) (Note to the interviewer: These questions should be based on the lesson observed, but if the lesson has been observed prior to the interview, adjust the questions accordingly.)

14) **What will be the main ideas or concepts addressed during this class session or lesson? What specifically do you intend your students to learn about these main ideas or concepts?**

15) **Describe how you will teach these main ideas or concepts, and explain why you chose to use these strategies.**

16) **How typical is this lesson for this class? If this is not typical, please describe a typical class session in this course.**

17) **Why is it important for students to know the aforementioned main ideas or concepts you taught during this class session?**

18) **What do you anticipate will be some difficulties and/or limitations connected with teaching these ideas or concepts?**

19) **What knowledge about students' thinking and/or learning influences your teaching of these ideas or concepts?**

20) **How will you assess students' understanding of, or confusion about, these ideas? How confident are you that the students will understand these concepts at the end of the lesson? Why?**

APPENDIX D

ELEMENTARY INSERVICE TEACHER INTERVIEW

Elementary Inservice Teacher Interview Questions

Background: (CoRe)

1) **How long have you been teaching? What grade levels and number of years at each level have you taught? Have you been involved in any specialized teaching (i.e. as a departmentalized science teacher, etc.)?**

2) **Have you participated in professional development for improving your science teaching? Describe the extent of your professional development.**

3) **What university level science courses have you taken?**

4) **Have you taken any university level science education courses (i.e. teaching methods or content courses for education majors)? How many? What courses?**

Science Courses taken at the University:

5) **How would you define science or the nature of science? Has your definition of science and the scientific process changed over time due to a single university course or set of courses? If so, in what ways?**

6) **Has your <u>understanding of science content</u> (i.e. the main ideas or concepts) changed as a result of a single university course or set of courses? If so, in what ways?**

7) **Has your <u>understanding of science teaching</u> (i.e. pedagogy, methods, implementing curriculum) and the ways in which you teach science changed as a result of a single university course or set of courses? If so, in what ways?**

8) **Which instructional strategies (activities, assignments, etc.) did you experience as most beneficial to your learning science at the university?**

9) **What science content areas do you feel most (least) prepared to teach? Why?**

Teaching Science at the Elementary School Level:

10) **What science content areas are most/least important to teach at the elementary level in general? Why? What science content areas are most/least important in <u>your teaching</u> at the elementary level? Why?**

11) **What do you feel is the best way to teach science in elementary classrooms? Why? Do you feel as though this is the way that you teach science in your classroom? Why or why not?**

12) **What barriers have you had to overcome in planning and teaching science?**

13) **How interested do your students seem to be in science?**

14) **What should your students take away from science in your class this year? (What are your goals in teaching science to your students this year?)**

15) **What is some of the important information that you would advise future teachers to take from their university science courses? What is the least important information to take away?**

Science Lesson: (CoRe) (Note to the interviewer: These questions should be based on the lesson observed, but if the lesson has been observed prior to the interview, adjust the following questions accordingly.)

16) **What will be the main ideas or concepts of this class session or lesson? What <u>specifically</u> do you intend your students to learn about these main ideas or concepts?**

17) **Describe how you will teach these main ideas or concepts, and explain why you chose to use these strategies.**

18) **How typical is this lesson for this class? If this is not typical, please describe a typical class session in this course.**

19) **Why is it important for students to know the aforementioned main ideas or concepts taught during this class session?**

20) How confident do you feel teaching about these concepts? Why? What do you anticipate will be some difficulties and/or limitations connected with teaching these ideas or concepts?

21) What knowledge about students' thinking and/or learning influences how you teach the main ideas or concepts?

22) How will you assess students' understanding of, or confusion about, these ideas? How confident are you that the students will understand these concepts at the end of the lesson? Why?

23) Overall, how successful do you think the lesson will be today? Why?

APPENDIX E

PEDAGOGICAL CONTENT KNOWLEDGE FRAMEWORK

The following PCK Framework and Rubrics were designed to address research question number four:

How does the level of reform aid in the development of inservice teachers pedagogical content knowledge?

Categories were chosen and vetted the research literature regarding pedagogical content knowledge (Schulman, 1986; Loughran, Mulhall, and Berry, 2004; and Magnussen, Borko, and Krajcik, 1999). More specifically, in my study only orientations toward science teaching, content knowledge and pedagogical knowledge are used to capture snapshots of faculty instructors and inservice elementary teacher's PCK. The interview data and the CoRes and PaP-eRs were analyzed using these categories. The following table provides a PCK framework in order to gauged snapshots of teacher's PCK by analyzing questions derived from the interview and the CoRes and PaP-eRs The framework allowed the researcher to develop a PCK checklist on each faculty instructor and inservice elementary teacher. The table outlines the questions used to inform the PCK categories. The PCK checklist is used to record components of PCK derived from the interviews (CoRe) the classroom observations and field notes (RTOP & PaP-eRs) and are use to corroborate information about PCK found in the interviews. Based on the checklist, an overall PCK score was given for each faculty instructor and inservice elementary teacher. Pseudonyms are given to the faculty instructors and inservice elementary teachers to protect their identity.

**Please note that PCK is topic specific therefore faculty instructors and teachers are analyzed based on their knowledge of content and strategies chosen for the topic that they were teaching during the observed lesson.

Orientations to Teaching Science

Orientations toward Teaching Science (OTS)	Teacher-Centered	Goals & Characteristics	Questions to ascertain Orientations, CK, and PK
	a) **Didactic** b) **Academic Rigor**	a) Goal is to transmit the fact of knowledge through lecture or discussion b) Goal is to represent a particular body of knowledge by challenging students with difficult problems and activities. Laboratory work and demonstrations are often times used to verify science concepts	1. Has your <u>understanding of science teaching</u> (i.e. pedagogy, methods, implementing curriculum) and the ways in which you teach science changed as a result of a single university course or set of courses? If so, in what ways? 2. What do you feel is the best way to teach science in elementary classrooms? Why? Do you feel as though this is the way that you teach science in your classroom? Why or why not? 3. Which instructional strategies (activities, assignments, etc.) did you experience as most beneficial to your learning science at the university? 4. What do you feel is the best way to teach science in elementary classrooms? Why? Do you feel as though this is the way that you teach science in your classroom? Why or why not?
	Reform Efforts **a) Process, Activity Driven, Discovery Orientations** **b) Conceptual Change, Project Based, Inquiry, Guided Inquiry**	a) Process orientations emphasize the development of science process skills through student participation in activities that allow student to develop thinking process and integrated thinking skills. b) Activity Driven orientations allow students to be active with the materials, "hands-on experiences. These hands-on activities are used for purposes of verification or discovery. c) Discovery orientations provide opportunities for students to use their own for discovery through exploration of the natural world following their own interests discovering patterns of how the world works through during explorations. d) Conceptual change facilitates the development of scientific knowledge by confronting students' alternative conceptions through discussion and debate for the justification of knowledge claims. Project based (Project-Centered) allows students to investigate solutions to authentic problems through use of projects. e) Inquiry orientations are investigation centered allowing for students to define and investigate problems, draw conclusion, and assess the validity of knowledge from their conclusions. f) Project Based Orientations is project centered and activities center on a driving question that organize concepts and principles and drives	

		activities within a topic of study. g) Guided Inquiry orientations constitute a community of learners whose members share responsibility for understanding the physical world in which the teacher and students participate in defining and investigating problems, determining patterns, inventing and testing explanations, and evaluating the utility and validity of their data and the adequacy of their conclusions.	
Content Knowledge			
Content Knowledge	**a) Syntactic Knowledge** **b) Substantive**	a) Facts, concepts, principles b) Knowledge about procedures, knowledge integration c) Content that is relevant and practical **d**) Goal of content is science literacy	1. What university level science courses have you taken? 2. How would you define the Nature of Science? 3. What will be the main ideas of this lesson? 4. What do you intend the students to learn about these ideas? 5. Why is it important for students to know this? 6. Have you taken university level science courses? (Biology, etc.). List the title of those you remember? 7. Content Areas that you feel most comfortable teaching?
Pedagogical Knowledge			
Pedagogical Knowledge	**a) Knowledge of Students Understanding of Science** **b) Knowledge of Instructional Strategies** **c) Knowledge of Assessments** **d)Knowledge of Curriculum**	a) Requirements for Learning (prerequisite knowledge and skills) b) Areas of Student Difficulty (i.e. prior knowledge, misconceptions) c) Nontraditional assessments d) Discussion e) Journals f) Knowledge of goals associated with state and national science standards.	1. Have you taken any university level science education courses (i.e. teaching methods or content courses for education majors)? How many? What courses? 2. Describe how you will teach the main ideas in this lesson? 3. What do you anticipate will be some difficulties and/or limitations connected with teaching this idea? 4. What knowledge about students' thinking influences your teaching of this idea? 5. What other factors influence your teaching of this idea? 6. What are specific ways you will use to determine student understanding or confusion around this idea?

APPENDIX F

PEDAGOGICAL CONTENT KNOWLEDGE CHECKLIST

CK—Content Knowledge
PK-Pedagogical Knowledge
OST- Orientations to Science Teaching
PD-Professional Development
Sources of PCK

PCK CHECK LIST

Faculty/Teacher	CODE	CK	PK	OST	Sources of PCK

APPENDIX G

PEDAGOGICAL CONTENT KNOWLEDGE RUBRIC

PCK RUBRIC		
4	Advanced	The teacher’s responses and actions show in-depth content knowledge of the key science concept(s) of the lesson being taught. Language used is scientifically accurate, descriptive, purposeful, and appropriate for the lesson and grade level. The content discussed is relevant and current, and facilitates scientific literacy. The teacher understands that science content is fluid and presents it as such. The teacher integrates information from other disciplines in teaching specific content. Emphasis is on the notion that less is more. The teacher’s responses and actions show an in-depth understanding and knowledge of ways to represent content that leads to student understanding. Teacher selects specific instructional strategies that are useful for helping students comprehend specific science concepts. Teacher exhibits knowledge of ways to represent specific concepts or principles in order to facilitate student learning as well as an understanding of the strengths and weaknesses of such activities. Representations may include illustrations, examples, models, or analogies. The teacher knows whether and when a representation will be useful to support and extend the comprehension of a particular teaching situation. When planning a lesson, the teacher considers students learning difficulties and prior knowledge. Teacher knows about the prerequisite knowledge needed for learning specific science content, as well as, the abilities and skills that students might need. Teachers also know and understand variation in approaches to learning based on students varying development needs. In addition, the teacher knows that students have misconceptions and prior knowledge about science content and use these to guide instruction.
3	Proficient	The teacher’s responses and actions show solid content knowledge of the key science concept(s) of the lesson. Language used is scientifically accurate, descriptive, purposeful, and useful. The content discussed is relevant. The teacher’s responses and actions show a solid understanding of the way students’ think. Teachers use prior knowledge in planning or teaching only, but not both. Appropriate learning goals were set for the students. Teachers know that students have misconceptions, but may or may not use these misconceptions to guide instruction. In addition, the teacher knows and understands ways to represent the teaching of the lesson that leads to student understanding. Teachers have a plethora of teaching strategies but do not necessarily use those strategies for teaching topic- specific concepts. These strategies may subject-specific (learning cycle) rather than topic specific. They also do not necessarily select strategies based on how students learn. Use some student data but mostly experience to guide instruction.
2	Emergent	The teacher’s responses and actions show partial content knowledge of the key science concept(s) of the lesson. Language used has some scientific inaccuracies, is not always descriptive, and lacks a clear purpose. The teacher makes an attempt to make content relevant to student lives. The teacher’s responses and actions show a partial understanding and knowledge of ways to represent specific science concepts. They have a number of activities that they may use to teach specific science concepts but not necessarily to facilitate student understanding. These may be activities that work and are used because they arouse student curiosity, maintain discipline, are mandated by district, or are fun. The teacher’s responses and actions show a partial understanding of the way students’ think. Aware that students have prior knowledge, but did not use it in planning or teaching. Some appropriate learning goals were set for the students and they may or may not be aware of student

		misconceptions.
1	Novice	The teacher's responses and actions show very limited content knowledge of the key science concept(s) of the lesson. Language used has many scientific inaccuracies, is not descriptive, and lacks a clear purpose. Teacher relies on textbook for science content. The teacher's responses and actions show a very limited understanding of the way students' think. Prior knowledge was not considered in the planning of the lesson. The teacher demonstrates misconceptions regarding student thinking and their own instruction. The teacher's responses and actions show a very limited understanding and knowledge of ways to represent specific science concepts, and tend to rely on textbook for teaching science concepts.

APPENDIX H

FACULTY CHECKLIST

FACULTY	PCK Rating	RTOP	CK	PK	OST	Sources
BONNIE Bailey, Beverly, Bettye	Advanced	**(83)**	Faculty is a content specialist and stresses the importance of having to know science; Says you have to know the science content to be at ease in changing or modifying the curriculum to suit the needs of students; understands content should connect to other disciplines; emphasis on content being relevant and scientific literacy	Used examples to represent phenomenon that are relevant to student lives/ takes into account prior knowledge; Use models to represent abstract concepts(e.g. circuits)/ Also aware of the various learning styles of his students; Used this strategy because it would enable students to conceptualize how circuits work. *"They need to know how to explain circuits, and to trouble shoot why things "go wrong*."	Inquiry oriented instruction for the purposes of facilitating science as a process; she stated that a hands-on approach was best approach to science teaching and learning	Content Specialist; Did not take the NOVA professional development but has taken PD that is geared toward reformed pedagogical practices; Collaboration; Does a lot of reading to stay abreast of current reform practices in science education *"I learn a lot from talking with colleagues and attending meetings that discuss science education."*
Calvin Carrington Chris Callie	Advanced	**89**	30 years teaching experience; Emphasizes less is more; emphasis on relevancy and science literacy; science concepts taught during observed lecture—isomers,	Used models to represent isomers so students could see structure of isomers; "*we'll take the hydrogen off of the models… I want them to see how the*	Hands-group work; inquiry-oriented instruction	Part of the original NOVA team; continues to attend workshops geared toward science teaching; collaboration;

			nomenclature	*structure is the same, even without hydrogen…"* He doesn't depend on lesson plans to facilitate lesson..he allows his students understanding of the content to drive the lesson…he has been teaching the course for several years and is comfortable in doing this		Constantly reflects on teaching practice and encourages her future teachers to do so *"Always question why you teach what you teach and how you teach it"*
DENISE Deborah, Dawn, Dana	Advanced	**90**	Teacher has seven years teaching experience; Has a Masters in Science Education; Chunks of info/ Standards	Considers prior knowledge; Understands students have varied learning modalities; takes into account background and interest; uses activities that her students can use with their students; uses; web activities; emphasizes activities that can be used in elementary classrooms; The lesson observed was an introduction to plate tectonics; Six stations were set up in the lab for students to rotate to regarding: mantle, crust, and subduction; computer with the history of plate tectonics; earthquakes and	Activity-Driven/ LEC(she models what instruction should look like); encourages future teachers to model behaviors that they want their students to exhibit	Faculty was not an original member of the NOVA project however attended some equivalent to the NOVA professional development workshop; she has attended PD geared toward science education reform; attends PD geared toward content and pedagogy; Reflects on teaching practice

				the San Andreas fault & convection currents; computers dealing with the theory of plate tectonics (hot spots and back in time); Pangaea and continental drift; plate boundaries dealing with convergent and divergent movement; Although stations were set up for students, teacher spent a great deal of time providing background information to her students; Understands that her students lack science content knowledge regarding plate tectonics; encourages students to reflect on their learning		
GERALD Gloria, Gavin, and Gabby	Proficient	**70**	Fifteen years teaching experience; Content specialist; emphasizes relevance and scientific literacy; says elementary teachers should know a wide array of content but not necessarily the depth of the content; lesson observed was classification/taxonomy; aligns curriculum with	This faculty This faculty instructor started the lesson by discussing the history of classification and its importance. They classified different types of snack chips as their small group activity. Upon completion of activity students did group presentations to entire class; His rationale for	Hands-on activities; collaboration; small and whole group discussion	Faculty a part of the original NOVA Team; science content specialist; attends PD only to do presentations; has not attended PD to improve or enhance science teaching

			benchmarks from Project 2061.	using this activity is that it puts students at ease for upcoming assessment and it enables them to come with their own classification scheme but not necessarily to deepen their understanding of this concept; he considers their students background and tries to be accommodating however this was more from a global perspective		
HILDA Hailey, Hannah, Harvey	Emerging	**71**	24 years teaching experience; adjunct at the University; High School chemistry teacher; content specialist; has credentials in biology, chemistry, and mathematics; Lesson observed was energy and energy conversions	Faculty used a structured laboratory investigation to teach energy/energy conversions—rationale for using this lab was that her students could use the lab with their future students but they must be able to do higher level mathematical calculations; Labs were very traditional and did not allow for much student engagement and did not promote critical thinking skills; teacher led most of the lesson	Believes in a constructivist practices and activities that allow students to conceptualize science concept; "These strategies provide a conceptual background for students, engage them in activities and provide novel situations to reinforce and test their levels of learning."	Faculty instructor was not an original member of the NOVA team; Extensive amount of PD; 24 years teaching experience
Eleanor	Advanced	**(80)**	Content specialist/Connects content to other disciplines;	Takes into account student misconceptions and prior	Inquiry-oriented instruction to	Faculty was a part of the original

Isabelle, Ida, Illise			content should be relevant; More is not better;	knowledge; knows students are afraid of the math; use of case studies; use of models to represent abstract phenomenon; questioning; uses a variety of representations to aid student understanding	facilitate scientific process; academic rigor; problem-solving	NOVA team and continues to participate in PD geared toward science teaching; also does science research; collaborates with other science and science education colleagues
James Jan, Jennifer, Jada	Advanced	**(85)**	Content specialist; Emphasizes the practicality of science and that it should be connected with other disciplines	Takes into account misconceptions; reflects a lot on science teaching in considering lesson; Used models to represent abstract concepts (drainage, discharge) ; uses models to show process of science (observation, collection of data);	Project based (heavy emphasis process)/ EXP/ DISC (long-term project emphasizing the processes of science)	Part of the original NOVA team and continues to participate in PD; Reflects on practice and has made changes accordingly

APPENDIX I

INSERVICE ELEMENTARY TEACHERS' PCK CHECKLIST

Teacher	PCK Rating	RTOP Score	CK	PK	OST	Sources of PCK
Beverly	Proficient	85	Taught four years; Has taken three science content courses (including the reform course and comparison course) but has attended several workshops geared toward science teaching; has taught first grade for four years; attributes much of her understanding to science content and pedagogy to PD and years teaching; also says that content should be relevant (connected to students lives); Topic taught was concept of air; big ideas were the characteristics of air	She uses a variety of strategies to teach this one concept for the purpose of reinforcing the topic; for the concept of air she brought in several objects to allow students to explore the attributes of air using materials that students are familiar with; she considered their various learning styles and prior knowledge when planning the lesson	Constructivist: evident in her observation and interview; says that hands on is the best because it allows for student exploration	PD: NOVA course; Teaching experience
Bettye	Novice	26	7 years teaching experience. Last two years teaching fifth grade; Little content knowledge; has taken three	In general teacher says that the best way to teach science is hands-on and science notebook because it facilitates the scientific process	Teacher says that she believes that students should engage in science in order to understand the process of	PD geared toward science and literacy; teaching experience; Reform course

			science content courses to include the reform course; her methods course was geared toward various subjects and not just science; attributes content and pedagogy to PD geared toward content and teaching with focus on science and literacy…says that students must know standards for testing purposes; lesson observed was the concept of matter; big ideas of lesson was matter is made up of atoms; matter takes up space and has mass (teacher did not focus on the science content during the observed lesson); emphasis on standards and testing	(not evident in classroom observation); she taught the concept of matter using overhead; teacher does say that she attempts to tap students prior knowledge but did not discuss this in conjunction with this specific concept During the observed lesson, the teacher gave students new scenario. Students cut out and glue into science notebooks. Students and teacher then read the scenario out loud together and pick out the "important information." Teacher writes key words on board.	science however there was a disconnect in what she says and what actually took place during the observed; the lesson is traditional with teacher "guiding students as to the correct answer"	
Bailey	Proficient	80	Teacher has taken two content courses; says that her	Teacher provides students with topographic maps and has them to	Constructivist: teacher says that the best way to teach to	PD; Teaching Experience; does not attribute

			PD has really helped her in understanding the content and how to teach the content; she connects the concept of topographic maps to the lives of her students; also says that standards dictate the curriculum b/c that is what they will be tested on; Lesson taught was topographic maps	list all of their observations in their science notebooks; she allows them to compare their observations with the “real thing” to see what the similarities and difference are; teacher understands that students varying abilities and tries to accommodate them through	science is hands-on because it allows students to manipulate their own learning; she says that hands-on facilitates understanding of concepts; this was evident in teacher’s observation—she allowed students to acquire understandings of topographical maps by comparing their observations to the actual maps	understandings of content or pedagogy to reform course
Carrington	Proficient	70	Teacher has taught science for nine years; the last six years she has taught science in a self-contained classroom; Teacher has taken several science content courses during her undergraduate program including the reform course (Geology	Teacher uses students 3 D model of earth’s tectonic plates to discuss movement of earth’s crust; serves as backdrop for the day’s lesson; uses a hands-on activity to generate and observe a convection current because it helps them to conceptualize the notion of convection	Believed that hands-on was best approach to science teaching and learning; teacher used hands-on activities to assist in students understanding or conceptualizing phenomenon; encourages students to find the answer based on	PD; Reform Course; science content courses; Teaching experience

			minor); familiar with standards b/c students will be tested on these standards; teacher also connects the concept of convection currents (lesson being taught) to her students' lives	currents because students need visuals to aid in their learning b/c concept is too difficult to understand; She also encourages the students to make predictions	observations; encourages students to reflect on their learning; make predictions	
Chris	Novice	49	Teacher has taught for three years and currently serves as a permanent substitute teacher; The teacher has had four science content courses during his undergraduate science program; he places emphasis on connecting the science content to student lives; In his definition of NOS, he does not seem to understand what the NOS is and what it is not;	Teacher relies on textbook to teach magnetism; he uses a lot of examples that relate to the students lives to aid in their understanding of the topic; the teacher feels as though this is the best approach to science teaching and learning (i.e. reading the textbook and doing a lot of demonstrations) which was evident during his classroom observation; these representations are global and not necessarily topic specific; teacher does not consider prior knowledge or misconceptions; to gauge if	Traditional: traditional in his approach to teaching; believes students have to been given the information and given an explanation as to the meaning of that information; does not believe students have the capacity to explore on their own depending on their level of ability	Undergraduate science courses; No PD

				students understand the content he ask questions and ask them to perform some task; again this is not necessarily topic specific		
Callie	Proficient	71	Nine years teaching experience (5years teaching 6th grade and 4 years teaching 5th grade); currently teaching the 5th grade; Although this teacher was a liberal studies major in undergraduate program, her concentration was science (seven or more science content courses); she has taken several science content courses; her emphasis is on connecting content to student lives; connects science to other disciplines	Generally feels as though the best approach to science teaching and learning is hands-on because it deepens student understanding of content; teachers uses hands on activities and models to represent the water cycle; says that students don't understand that water is recycled and present everywhere; *She began with a short review of the three states of water, students conduct an activity to simulate the water cycle ("Water Cycle Model")*— teacher says that "students don't understand where condensation comes from...they don't understand that water is in the air …this is a simple experiment	Believed students understand best when they can do science; does not believe that science learning is passive; if students do the science they will remember it better; it allows them to conceptualize abstract science concepts	Some PD; several science content courses; years of experience; Reform Course

				that they can help them understand…these strategies will help them to conceptualize the water cycle"		
Deborah	Novice	37	This is her 1st year teaching; she was a liberal studies major and only required to take four science content courses during her undergraduate program including the reform course; teacher emphasizes that content (food chains) must be connected to the lives of the students; emphasizes that students will need to know information because it is a part of their lives	This lesson serves as the introduction to food chains; this initial lesson is teacher centered but teacher believes that students must be provided with the background and then allowed to do the hands-on activities that will help them to learn the concept; teacher recognizes that students have different abilities and backgrounds but does not use this information in the planning of the lesson or engaging her students in hands-on activities; Teacher spent 25 minutes lecturing to her students while they took notes and copied them into foldables; she spent the last five minutes of class reviewing the notes	Teacher knows that learning is not a passive process but this is not evident in the observed lesson; teacher says that when students engage in hands-on activities then they understand the concept better; teacher also says that students must be provided with background info initially	PD on note taking (foldables); Some science content courses; This is teacher's first year teaching this topic so has not develop expertise in this the area of food chains
Dawn	Proficient	78	Teacher has taught a 4th/5th	Teacher used specific strategies	Teacher favors hands-on	Science content

			grade science class for two years; Teacher was a Liberal Arts major who took four science content courses during her undergraduate program; emphasis on connecting content to students lives	to teach rock identification and erosion that were taken from reform course that she took in her program; used these activities because she says that students have a difficult time understanding concepts that they cannot see; these activities help students to understand concept of erosion, weathering; also considered students background and prior experiences; understands students have deficient scientific vocabulary on rocks, erosion, weathering and tries to accommodate some of this through working is collaborative groups and explaining concepts to each other using the appropriate scientific language; uses different assessments to gauge students understanding of	activities but definitely believe that you must use a variety of strategies to teach science content	courses; Reform course; ongoing PD that focused on curriculum, science content, and pedagogy; stated that all of her science content courses emphasized pedagogy

				topics		
Dana	Emerging	74	Teacher has 2 years teaching experience but this is first year teaching 1st grade; Was a Liberal Studies major and took the required four science content courses during her undergraduate program; places emphasis on connecting content to the lives of her students; says concepts should build from grade level to grade level	Teacher uses the KWL chart to tease out student prior knowledge; she stresses vocabulary and reading for the ESL students; uses collaborative groups so that students can share with one another; uses journaling to reinforce what students have learned; She also believes that you must use a variety of strategies to teach content; she uses visuals so that students could connect the vocabulary to the pictures; recognizes students learning difficulties and considers that when planning the lesson	Teacher says that hands-on activities are the best approach to science teaching because it facilitates meaningful learning; During her classroom observations, students look at pictures and predict which animals will live in which habitat based on characteristics of habitat; Teacher admits that this not a typical approach due to time and her persona l schedule	Has not participated in PD; Content Courses; Reform Course
Gabby	Emerging	69	Teacher has taught 1st grade for 3 years using 3 science kit units provided by the district; she has taken only one science content course (REFORM) during her undergraduate program; much emphasis is	Although teacher believes that hands-on is the best approach to science teaching there was very little of hands-on during the classroom observation; Teacher seems to have embraced the idea of hands-on because of her experiences	The teacher says that she believes a hands-on approach is the best approach to science teaching and learning however this is not noted during her classroom observation (teacher says	3 years teaching experience; Reform Course; PD on science kits

			placed on connecting content to student lives	during her undergraduate program but only uses the activities found within the kit; teacher considers student prior knowledge (KWL) and considers difficulties that students may have in understanding water because it is an abstract concept; Strategies used to teach this topic are vocabulary, video, and life box that contained things that living things need to live (had students to draw objects); her overall goal of this lesson was to get students excited about science	that this is the introduction of the lesson)	
Gloria(67)	Proficient	67	Teacher has taught kindergarten for 4 years; has taken several science content courses; heavy emphasis on connecting science content to lives of students; students used language in scientifically appropriate	Teacher says that she will use a variety of instructional strategies to accommodate various learning needs of her students (ability, language); Teacher says that hands-on activities are the best approach to science teaching because it	Teacher says that hands-on activities are the best approach to science teaching because activities of this sort best facilitate student learning; students remember concepts better	A lot of PD geared toward science teaching; continues to educate herself through reading and the web; Reform course

			manner during course of lesson; teacher introduced scientifically appropriate language pertaining to the concept of water; because of her four years of teaching experience she is comfortable with adding science content that she feels is important to student learning that is not a part of the district curriculum;	facilitates understanding of content; Teacher admits that the lesson observed was more focused on art and literacy and not science investigation; She had an activity planned but bad weather did not permit them to do it; teacher also considers difficulties that her students might have in grasping the concept such as level of ability and language; teacher also takes into account students prior knowledge; teacher says that students must have certain background knowledge before going to the next grade; also knowledgeable of standards	when they are allowed to construct knowledge for themselves; although teacher believes in a hands-on approach the lesson observed was mainly focused on literacy and art around snowflakes (where does water come from); however this was the introduction to the lesson and that the next activity will involve students more in scientific investigation	
Gavin	Emerging	59	Teacher took several content courses during his undergraduate program and continues to attend professional development workshops to enhance his	Teacher says that he uses a variety of instructional strategies to accommodate the varying learning styles of his students; Students are grouped based on Bloom's Taxonomy; The observed lesson	Teacher says that the best approach to science teaching and learning is Hands-On because it helps students remember the content; He also believes	Ongoing PD; science content courses taken during undergraduate program; years teaching this topic

			content knowledge; teacher says that the overarching goal of content is to prepare students for test in the fourth grade; knows that students must have certain prerequisite knowledge for each grade and if they don't they will not be ready for the test; teacher emphasizes that content must be connected to student lives; also teachers in this school system are concerned about state testing and there seems to be more emphasis on reading and math	scientific method was a teacher centered activity with the teacher telling the students what to do concerning the writing portion of assignments and gathering the materials and conducting the experiment (teacher ended up doing the experiments for the students); there was not much hands-on activity that was observed during this lesson; takes into account that students have various backgrounds and experiences which impact students prior knowledge;	that activities should connect to the lives of the students	
Hailey	Novice	57	Teacher had 7 years teaching experience with kindergarteners; Had taken 2 science content courses; teacher emphasizes content that is relevant and connected to	Teacher uses these strategies to teach the types of trees and characteristics of leaves to students: Smart Board (" I like to do a lot of stuff on the Smart Board… I mean they'll sit and	Teacher suggests that the best approach to science teaching is Hands-on Activities or Direct Exposure however this	PD focus has been reading and mathematics;

			student lives; science is not a focus at her school but reading and math; there is not a specified curriculum for science so teacher just fits it in when she can	they'll behave like excellent whenever it comes to doing anything on the Smart Board"); teacher had students to bring in different types of leaves of their choosing to discuss characteristics of leaves with each other and also because it gives the students a sense of ownership; Teacher says she has done this activity with a previous class and has made adjustment to the activities based on her experience using these strategies to suggests teacher reflecting her teacher practice; Activity and discussion were very structured with little engagement on the part of the student; teacher recognizes that knowledge of these concepts are needed for upper grades	includes reading and working with the Smart Board; the goal of these sorts of activities is to have students exposed to concept because it will help them to remember it better and not necessarily impact their learning; Looks for easiest way to make the content make sense to students. *She had a tightly controlled discussion and activities rather than letting them engage in some critical thinking* No mention of skills that students should develop from science; There is no goal for this orientation other than connecting the science to student lives	

Hannah	Novice	40	Teacher took 3 science content courses during her undergraduate program; this is her first year teaching 3rd grade; she says that it is important that students have the background knowledge needed for the 4th grade; Also teacher had some misconceptions in her own understanding of deserts: *In cold deserts it doesn't go to freezing so it doesn't snow;* Teacher does not have the content knowledge for this topic: During her classroom observation, she refers students back to the textbook to find the right answers to the questions that she ask them as she monitors their projects	Teacher says that a hands-on approach to science teaching is best but has a very traditional approach to science teaching and learning; teacher had students read about the topic, desert ecosystems, and then take notes that were written on the board—" *I followed the book and what we always do. We always read the textbook and then I ask them questions about what they just read*"; teacher also has students to make a desert ecosystem but with no clear cut goal for the purpose of the activity (more of an art project than a science lesson); teacher knows that students have different learning needs but does not know how to accommodate them; does not appear to reflect on her teaching and student learning	Very traditional approach to science teaching and learning; although teacher says that hands on activities are the best approach to science teaching, she seems to equate this to "projects" that are textbook derived without any clear purpose or goal for these sorts of activities; The main strategies used seem to be reading and taking notes as suggested by her interview and observed during her classroom observation: *There are notes displayed on the smart board and the students are copying them: Coniferous forest – (definition): Desert – An ecosystem where there is very little rain 2 kinds of desert: hot and cold*	No PD; very little science content knowledge; only source of any PCK is the integrated methods course taken during her undergraduate program that emphasized hands on investigations but she does not make the connection between content and pedagogy.

Harvey	Novice	57	Teacher has only been teaching 4th grade for a couple of months; has taken only 2 science content courses (one of which was the reform course) during his undergraduate program; does not understand the Nature of Science; does understand the goals of the lesson as outlined in his curriculum; uses the science kit provided by the school/district; teacher admits that he does not have a lot of science content knowledge; he stated in his interview that math, reading and writing (these will be tested) was the focus at his school and that he is given 30 minutes a day for science; emphasized that the knowledge of the water cycle should be	Teacher says that the best approach to science teaching is through hands-on activities but equates these activities with kids doing or manipulating something like using a microscope; the main ideas of the lesson observed were cloud formation, water vapor, high and low pressure; He taught this concept through an activity "Cloud in a Bottle"; teacher said that he used this specific activity because students could actually see the clouds forming and what happens in the midst of low and high pressure; He said that students can see step by step how clouds form; Although this was supposed to be a student-centered activity the teacher practically did the entire activity for the students (as observed during the lesson) by	Teacher is inclined to using a hands-on approach to science teaching because students need to have something to do or manipulate something like a microscope	Elementary methods course; Reform course was more lecture based; Has not attended any PD in as much as this is his first year teaching

			practical and relevant to students' lives	demonstrating for what should be done at each step in the activity not allowing students to engage in critical thinking; The teacher questions the students throughout the activity about what they see; teacher knows that students must be engaged in hands-on activities so that students can see or conceptualize difficult concepts; does not consider learning difficulties associated with the teaching of this topic; does not take in to account prior knowledge or misconceptions		
Isabelle	Novice	43	Teacher has taken several content courses; she took the reform and comparison courses taught by the NOVA faculty; she stated the big ideas of the lesson and said that they were a part of the state standards	Teacher had the students making taxonomic keys however it was more of an art project to reinforce their memorization of the various levels of classification not because it was the best strategy in helping students to understand the	Although this teacher said that a hands-on and inquiry-based approach was the best approach to science teaching it was a very teacher-centered lesson. Her interview revealed that she was	Science Content Courses; Science methods course; No PD as of yet in as much as she is a first year teacher

			(Learning Standard 1: for grades 6-8); She considered classification and organization as life skills and that students will be doing it all of their so that's why they need to understand it	concept of organization; teacher does not consider prior knowledge	inclined to inquiry but also stated that art projects are typical in her class as observed during her classroom instruction; she stated that by having students create their own taxonomic keys and bookmarks would help her students to become familiar with the levels of classification; there was little student interaction that occurred during the lesson	
Ida	Novice	69	Teacher has taken several content courses at the college; she has been teaching 1st grade for 3 months; she does not refer to the standards but the big ideas of the lesson are a part of the state standards (possibly due to the fact that this is private	She uses a song to introduce the topic because of the students love for music and they learn the words quickly (it helps them learn the vocabulary); she uses hands-on activities because she believes that students learn best when they are allowed to do the science (still a bit global);	Believes that science should be taught through hands-on activities that allow students to "do" science. She said that activities should allow students to see or track changes in experiments	New teacher so has no PD; Content courses and the Reform and Comparison courses

			Christian school			
Illise	Proficient	81	Teacher has been teaching for 3 years at an all boys school; Currently was teaching 2nd grade; Teacher has taken several content courses in biology; promotes relevancy; connects content (water pollution) to student lives; although teacher provides specific goals of the lesson, she does not make mention of standards. Although teacher has a strong content background, she does not use scientifically appropriate language during the discussion (colloids, suspensions)	Teacher uses hands-on activities to teach concept of water pollution to promote science processes (predicting, questioning, and experimenting); she considers their prior knowledge and knows that they have varying learning needs. This is still a bit general because she believes that all topics should be taught through hands-on activities	Teacher uses hands-on activities to promote scientific process; She places heavy emphasis on Science as a Process and uses activities to encourage hypothesizing, predicting, and questioning. She believes that this is the best approach to science teaching;	Teacher took both courses from faculty who went through the NOVA training; science content courses; some PD on science/math; she also says that her classroom experience has contributed to her classroom practice encouraging her to reflect on her teaching practice; This is her first full year as a 2nd grade teacher; she previously served as a fulltime substitute
Jan	Advanced	75	Characteristics of seeds; teacher mentioned that these were a part of the state standards;	Teacher used seeds and non seeds to represent phenomenon (i.e. characteristics of seeds as living things)—students	Teacher believes science should be hands-on; believes that students should have	Professional Development geared toward content and pedagogy; Internet; ongoing PD;

			(standard 2.1 under life science); did not take science courses as an undergrad but rather as a graduate student through a rigorous professional development project (TUFTS) that provides science content for teachers; says concept should be relevant, practical. Taught current grade for two years (13 yrs teaching experience)	came up with definition of seeds based on observed characteristics; teacher felt that by them "seeing" and "touching" it that it would facilitate their understanding of this concept; also teacher took into account their prior knowledge about seeds; This teacher does not use traditional assessment but listens to her students explanations as they work in groups; reads their journals; and has them reflect on their learning by having them write down their thoughts about what they learned during the activity.	opportunity to explore to aid in their understanding of concept; students should be able to ask questions and draw conclusions; This is also seen in her RTOP	Constantly reflects on her teaching and student learning.
Jada	Advanced	77	Has taught K-5 for last two years (7 years teaching experience); Has an undergraduate degree in Biology; stresses the importance of science content being relevant and practical—	Although she does not see her kids often she understands that they have different learning needs; she uses student models to represent the concept of habitat and adaptation; students observe their fiddler crabs (male and female)	teacher tends to use hands on activities to get students excited about science and because she wants them to be active learners; says that hands-on activities aid in student understanding	Participates in ongoing District PD; attends NSTA every other year; facilitates science workshops so collaborates with other colleagues; coaches other science

			“real-world”--Teacher says that these are a part of the state curriculum	and make note of observations which eventually lead to discussions on adaptation; teacher says that it is important that students have a common experience; she also states that she takes into account prior knowledge and attempts to build from their prior knowledge and common experience; teacher uses a variety of assessments to assess student learning to include: discussions; performance-based assessments. Teacher says that the discussion allow her to address any misconceptions that the students have about the topic	of science concepts and the scientific process	teaches; Constantly REFLECTS on her teaching and student learning
Jennifer	Emerging	76	Jennifer has taught 6th grade for the past four years; She has not taken any science content courses; she does mention that science	Teacher says that the most important for knowing content is because of state assessment; she does mention this as a barrier because there are	Jennifer believes that hands-on activities are the best approach to science teaching because these	Participates in ongoing district PD; classroom experience

			should be hands-on and connected to student lives. There is a heavy emphasis on the standards because students will tested on those standards; During the classroom observation, the teacher makes statements that could lead to student misconceptions (comparing microwaves to autotrophs because each makes its own food); teacher does use language that is appropriate for grade level and content with few inaccuracies	so many standards to learn and little time to cover it; the strategies chosen for the review are to engage students in their learning so that they can take ownership of their learning and so that they can become aware of their mistakes; Although she has taught this lesson many times and suggests that she has ironed out the wrinkles of the lesson she does not consider students prior knowledge for the lesson (however the researcher acknowledges that this is difficult to gauge because this lesson is a review of the standards already covered); She assessed their understandings of the lesson covered by listening to their feedback; the students were to be assessed by a traditional paper pen test the following class period (benchmark test)	sorts of activities engage students in the learning process; also states that activities should connect to the lives of the students	

APPENDIX J

IRB APPROVAL

Office for Research

Institutional Review Board for the
Protection of Human Subjects

THE UNIVERSITY OF
ALABAMA
RESEARCH

September 14, 2011

Donna Turner
Department of Curriculum and Intruction
College of Education
Box 870232

Re: IRB # EX-11-CM-074 "Long Term Impact of Reformed Undergraduate Science Courses on the Pedagogical Content Knowledge of Kindergarten Through Sixth Grade Inservice Teachers"

Dear Ms. Turner:

The University of Alabama Institutional Review Board has granted approval for your proposed research.

Your protocol has been given exempt approval according to 45 CFR part 46.101(b)(4) as outlined below:

(4) Research involving the collection or study of existing data, documents, records, pathological specimens, or diagnostic specimens, if these sources are publicly available or if the information is recorded by the investigator in such a manner that subjects cannot be identified, directly or through identifiers linked to the subjects.

Your application will expire on September 13, 2012. If your research will continue beyond this date, complete the relevant portions of Continuing Review and Closure From. If you wish to modify the application, complete the Modification of an Approved Protocol Form. <u>When the study closes, complete the appropriate portions of FORM: Continuing Review and Closure.</u>

Should you need to submit any further correspondence regarding this proposal, please include the above application number.

Good luck with your research.

Sincerely,

[redacted]

Carpantato T. Myles, MSM, CIM
Director & Research Compliance Officer
Office for Research Compliance
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IRB Project #:

UNIVERSITY OF ALABAMA
INSTITUTIONAL REVIEW BOARD FOR THE PROTECTION OF HUMAN SUBJECTS
REQUEST FOR APPROVAL OF RESEARCH INVOLVING HUMAN SUBJECTS

I. Identifying information

	Principal Investigator	Second Investigator	Third Investigator
Names:	Donna P. Turner	Dr. Dennis W. Sunal	
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College:	The University of Alabama	The University of Alabama	
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Title of Research Project: Long Term Impact of Reformed Undergraduate Science Courses on the Pedagogical Content Knowledge of Kindergarten Through Sixth Grade Inservice Teachers

Date Submitted: August 9, 2011
Funding Source:

Type of Proposal ☐ New | ☐ Revision | ☐ Renewal Please attach a renewal application | ☐ Completed | ☒ Exempt
Please attach a continuing review of studies form
Please enter the original IRB # at the top of the page

UA faculty or staff member signature: ____________________

II. NOTIFICATION OF IRB ACTION (to be completed by IRB):
Type of Review: _____ Full board _____ Expedited (Exempt)

IRB Action:
___ Rejected Date: ________
___ Tabled Pending Revisions Date: ________
___ Approved Pending Revisions Date: ________
X Approved-this proposal complies with University and federal regulations for the protection of human subjects.
Approval is effective until the following date: 9/13/12
Items [redacted])

[redacted]