Nature or Nurture?

A Characterization of the Knowledge and Practices of In- and Out-of-field Beginning Secondary Physics Teachers

by

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ABSTRACT

Previous studies have shown that adequate content knowledge is a necessary, but not sufficient, requirement for affective teaching. While legislation requests teachers to be “highly qualified” in a subject area, such as physics, many teachers are frequently asked to teach in an area when they are not certified through a teaching license to do so. This study uses mixed methods to examine the knowledge of beginning physics teachers. Through semi-structured interviews, classroom observations, and concept maps, the pedagogical content knowledge, subject matter knowledge, and practices of three groups of beginning secondary physics teachers were explored. Data were analyzed qualitatively using cases and quantitatively using descriptive statistics and t-tests, the results of which were combined during the interpretation phase of the research process. The study indicated that, over the first two years of teaching, the in-field group of teachers showed stronger physics content knowledge, a consideration for student difficulties with physics topics, and a positive shift in pedagogical content knowledge impacted by working with students, as compared to the rest of the teachers in the study. This research has implications in the development of secondary physics teachers and in the field of physics education research. Specifically, this research has implications in the physics content support for beginning secondary science teachers, the novice/expert research in physics education research, and the pedagogical preparation of undergraduate students, graduate students, and faculty in physics.

DEDICATION

I dedicate this dissertation to all the family and friends who have stuck with me through this long process. To my wonderful husband, Lynn, there is no way that I would have accomplished this without your love and support. I hope that I have given you as much as you have given me. To my son, Stephen, you are the joy of my life. There were times when I did not think I could make it through – all I needed to do was look at you and your father and know that I could do it. To my mother and father, you gave me the foundation needed for this accomplishment. Without you and your support I would not have had the skills or means necessary to finish this degree. To my sister, Melanie, I thank you for all the hours spent on the phone where you were there to listen to me and not judge. You are the best friend a sister could ever have. To my in-laws, the Neakrases, I thank you for your support of our family. You have helped in good times and bad, and I am very grateful for everything. I also want to thank the countless friends who have been there for us throughout the graduate school process. Krista, you are the best! I thank you for your friendship and your willingness to be a sounding board for the research and writing process. To Nick and Amy, you have been there through the good and bad, and you stuck around! I appreciate all you have done for my family and me. To Kim, without you taking such great care of Stephen I never would have had the time to work on my dissertation. You are the best!

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Chapter 1: Introduction

> Strong science education is essential for producing informed citizens and a knowledgeable and highly prepared workforce. With physics as the cornerstone subject in science education, we must establish a reliable supply of qualified physics teachers to meet this country's education needs.
>
> - Toufiq Hakim, American Association of Physics Teachers [AAPT] Executive Director, January 2008

As Hakim stated, in order to continue to have a strong future workforce and remain competitive, our country needs to focus on strong science education. Strong science education refers to both the students who are doing the learning, and the teachers who are providing the opportunities for learning.

Among science education the National Science Education Standards (NSES) (National Research Council [NRC], 1996) emphasizes scientific literacy as a necessity for all individuals. Scientific literacy is essential for citizens to be able to use scientific information in everyday choices, engage in public debates and discussions regarding science and technology issues, and develop advanced reasoning skills necessary in the a competitive workforce. The NSES document states that other countries “are investing heavily to create scientifically and technically literate workforces” (NRC, 1996, p. 1) and that to keep up with these other countries the U.S. needs an “equally capable citizenry” (NRC, 1996, p. 2). In order to produce this “equally capable citizenry” the authors of the NSES promote that science teachers "must have theoretical and practical knowledge and abilities about science, learning, and science teaching" (NRC, 1996, p. 28). Ensuring that science teachers have this type of proficiency directly influences science teacher education in our country.

In response to the various types of statements and documents made regarding the state of science education there have been two policies implemented which impact science teacher education in the United States. The first, the No Child Left Behind Act (NCLB) (2002), asserted standards for teachers in content areas. Specifically, policy makers developed standards that required teachers to be "highly qualified" in order to teach their subjects. The term "highly qualified" was defined by the Department of Education as a teacher having a bachelor's degree, full state certification or licensure, and demonstrating a high level of subject area competence in each academic subject taught (U. S. Department of Education, 2004). The determination of what characterizes a high level of subject area competence was defined by the U. S. Department of Education as secondary teachers: (a) holding a major in the subject they teach, (b) having credits equivalent to a major in the subject, (c) passing a state-developed test, (d) demonstrating competency through a "high, objective, uniform state standard of evaluation" (HOUSSE) as determined by an individual state, (e) having an advanced certification from the state, or (f) having a graduate degree. In 2004, the Department of Education provided new areas of flexibility in order to ensure secondary teachers were highly qualified. Additional flexibility for the demonstration of highly qualified in secondary science was introduced due to the fact that science teachers typically teach in more than one field of science, and because some states allow science teachers to be certified under a general science degree, while others require a subject-specific certification (Department of Education, 2004). Within this flexibility, states were able to accept demonstration of being highly qualified in either “broad field” science or individual fields of science. This new flexibility has only exacerbated the fact that states are ultimately responsible for determining what characterizes a high level of subject area competence (National Science Board, 2010), leading to more teachers teaching out of their field of discipline.

The second policy, the America Creating Opportunities To Meaningfully Promote Excellence In Technology, Education, And Science Act (America COMPETES) (2007), reinforces the need for a scientifically literate society by seeking to increase the number of scientists and improve the teaching of science. The result of these recent legislations produces, among other areas, a call for more quality teachers of science and mathematics. Yet producing more high-quality science teachers is not as simple as policy makers posit. This is especially true in the physical sciences, where the National Science Board (2008) found that over 30% of the schools surveyed in 2003-2004 had hard to fill vacancies in this area. This indicates that the shortage of physics teachers frequently referenced may not be getting worse, but it is certainly not getting better.

Moreover, with the number of students taking physics or physical science (which includes physics topics and curriculum) courses in high school on the rise, the issue is compounded. Enrollment in at least one high school physics class has steadily increased since the mid-1980s from 20% to currently 37% of the students who graduated from high schools during the 2008-2009 school year (White & Tesfaye, 2010). With more students taking physics or physical science courses, more teachers are needed to teach the increasing number of classes. The immediate solution is to place unqualified or under-qualified teachers into the physics classroom. Given the need to increase the physics or physics education workforce, but a shortage of teachers in the area of physics, it is critical to understand how to best support under-qualified or under-prepared teachers of physics. However, support cannot be offered without knowing the areas in which teachers need support.

When vacancies in teaching physics are hard to fill schools and districts typically place an "out-of-field" teacher, a teacher with neither a physics major nor certification to teach physics, in the classroom. Out-of-field teaching in physics is prevalent and it is unlikely that the NCLB or America COMPETES Acts will address this shortage quickly. This is reflected in a 2005 survey by the American Institute of Physics [AIP], which found that two-thirds of the secondary physics teachers surveyed had neither majored in the subject (physics or physics education) nor taught it on a regular basis (Neuschatz & McFarling, 2003; Neuschatz, McFarling, & White, 2008). Ingersoll (2003) corroborated this finding when he reported that 60% of physical science teachers were teaching without a major or minor in any physical science. When Ingersoll defines an in-field teacher as having both a major *and* a certification in his or her field, reinforcing “highly qualified” as defined by NCLB, the amount of out-of-field teaching substantially increases. Out-of-field teaching is a continuing problem in the physical sciences and impacts a beginning science teacher as his or her knowledge bases are developing over the first few years of teaching.

Statement of the Problem

Broadly concerned, in- and out-of-field physics teachers require adequate preparation within a number of areas in order to teach. Such preparation includes pedagogical content knowledge (PCK), which consists of the intersection of content knowledge with general pedagogical knowledge (PK) (Grossman, 1990; Feiman-Nemser, 2001; Shulman, 1986). PCK influences (and is influenced by) various other areas necessary for teaching such as teaching beliefs, views of the nature of science, PK, and the decisions a teacher makes about instructional practices. In the physics education literature (Etkina, 2005), PCK is described as “an application of general, subject-independent knowledge of how people learn to the learning of physics”. Therefore, to be able to choose or design successful lessons in physics, a physics teacher must be able to weave his or her understanding of the discipline of physics with an understanding of how students learn. An out-of-field teacher in physics may have adequate knowledge of how students learn but inadequate knowledge of the discipline of physics. Any difference between an in- and out-of-field physics teacher will be reflected in PCK.

"Out-of-field" teachers will posses a range of physics comprehension necessary to teach physics and many will be under-prepared. A secondary science teacher certified to teach physics has gone through a certification program requiring a specialization in the discipline of physics. For example, in Arizona, for certification in secondary physics teaching, a potential physics teacher is required to take a proficiency examination that includes 19% general scientific inquiry, 36% mechanics and heat energy, 15% electricity and magnetism, 15% waves, sound, and light, and 15% quantum theory and the atom. A teacher candidate going through a physics certification program will have taken upper-level courses on each of these topics that are more in-depth than an introductory physics overview course, which is what is usually required of other science majors. However, an out-of-field physics teacher will have differing numbers of physics courses completed compared to an in-field teacher. A secondary chemistry teacher may have been required to take a few classes in physics, while a secondary biology teacher may have taken little to no courses in physics. Thus, there will be a varying degree of physics preparation an out-of-field physics teacher will posses when they enter the classroom for the first time to teach physics.

The impact of an out-of-field teacher in the classroom is not well understood and this is mainly due to the fact that "impact" is not something that is easily quantified, especially when measured by student scores on standardized tests, the most common measurement method (Ingersoll, 1999). It has been suggested that an out-of-field teacher will rely heavily on the textbook and this might be what a standardized test best captures. Therefore, if positive results on a standardized test are the measure of the success of teaching, any negative learning outcomes, which might be present, will be masked by the positive result. Other consequences of out-of-field teaching suggested by Ingersoll are: an inability to teach critical thinking skills, a lack of engaging student interest in the subject, a decrease in the amount of course preparation time a teacher has for other course taught, and having to cope with an addition to an already burdensome teaching load. These negative issues are more prevalent in fields that have higher than average out-of-field teachers like physics. Since physics is typically cited as a field with a high number of out-of-field teachers we would expect these issues to be present. However, the impact of out-of-field teaching in physics has not been an area of concern in the physics education research community.

New teachers are a potential source for understanding the knowledge base of a physics teacher, both in- and out-of-field. New beginning teachers have been shown to have “knowledge for teaching” that can be readily modified. Knowledge for teaching, consisting of both an understanding of science content and PCK, is initially developed in a pre-service program and is modified rapidly in the first few years of teaching (Luft, Roehrig, & Patterson, 2003). As the teachers spend more time in the classroom they continue to build their knowledge base for teaching (Berliner, 1987; Borko & Livingston, 1989; Feiman-Nemser, 1983; Lee, Brown, Luft, & Roehrig, 2007). The more expertise teachers gain, the better they are able to draw upon their knowledge base and experience (Berliner, 1987).

Studies have shown that beginning teachers have incomplete and superficial levels of PCK (Feiman-Nemser & Parker, 1990; Gudmundsdottir & Shulman, 1987; Shulman, 1987). These beginning teachers tend to rely on subject matter that has not been modified and usually is taken directly from textbooks or curriculum materials. Decisions teachers make tend to be broad pedagogically, and beginning teachers indicate a concern with presenting concepts and ideas that are understandable to their students (Feiman-Nemser & Parker, 1990; Reynolds, 1992). This does not seem to change when the teacher holds a higher degree (e.g. a master's degree in the subject matter) as these teachers also express concerns with their abilities to present the subject matter. Teachers who have a master's degree in their subject area but no formal teacher education, were found to be much less prepared to handle student needs than first-year teachers with a similar content preparation and a completed teacher education program. The teachers incorrectly attributed their students' lack of understanding to levels of motivation and ability due to their inadequate level of PCK (Grossman, 1989).

Beginning physics teachers are at the most risk of teaching out-of-field and, as new teachers, they are often enthusiastic to teach and have the potential to persist in the profession. Knowing more about the impact the degree to which being out-of-field has on a beginning teacher's knowledge base will allow for a better understanding of teaching in or out of one's subject area. Most research into the amount of physics mastery physics teachers hold tends to focus on a teacher's understanding of a physics topic, rather than on how an understanding of physics impacts other areas of knowledge for teaching. Often, studies examining a teacher's mastery of physics are narrowed to examining physics misconceptions held by the teachers (Abell, 2007). These studies have found that teachers' physics content is reflected in what is known about student misconceptions – the same misconceptions were held by the teachers. Current studies have not focused on the different types of knowledge a teacher holds, how these different knowledge bases influence each other, nor how this knowledge is formed over time.

While it is clear from previous research that out-of-field teaching occurs, it is referred to in a very general sense, rather than at the knowledge for teaching level. In order to understand the impact of out-of-field teaching a description of what constitutes being "out-of-field in a content area" needs to be developed. Once the degree to which a beginning physics teacher is out-of-field is characterized, the relationship between the knowledge bases and the teaching practices of these teachers in the classroom can be examined. This will examine the claim that out-of-field teachers do not understand how to represent important concepts in physics to students, an important aspect of PCK as defined by Shulman (1986).

Research Questions

This study specifically looks at the content knowledge, PCK, and practices of a group of beginning secondary physics teachers. It also explores the impact of being in- or out-of-field on these areas. These areas were specifically chosen to examine the extent of teachers' knowledge bases in relation to what and how teachers teach to students (as represented by PCK), in order to have a base for providing a higher level of teacher professional development and support for physics teachers. Practices are the enactment of this knowledge base, and thus give a snapshot into how PCK is being utilized by the teachers in the classroom. Thus, the research questions that guided this study were:

- How do the content knowledge, pedagogical content knowledge, and practices of beginning secondary physics teachers change over two years?
- How does being in- or out-of-field impact these areas for this group of beginning physics teachers?

Significance of the Study

This study will be of value to the field of secondary science teacher education and the physics education communities. First, how a beginning physics teacher represents physics to students is important for maximization of student learning. Because of recently passed legislation calling for highly qualified teachers in the classroom and the need to cultivate a scientifically literate society, it is important to examine the extent to which secondary science teachers are prepared to teach out of their content area. This has implications for physics teacher education due to the high number of secondary science teachers being asked to teach physics when they do not have a certification or background to do so. Ultimately, the findings from this study can impact the methods used to retain physics teachers in the classroom, providing physics specific mentoring to teachers teaching out of their content area, and the effectiveness of these teachers in teaching physics content to their students. Particular attention in this support needs to be given to assisting out-of-field teachers who are involved in teaching physics.

Overview of the Following Chapters

The second chapter provides a literature review from the areas that are most important to this study. These areas include the different models of PCK over the last 18 years from both education and physics education research. Each model is described in terms of how knowledge of the teacher is conceptualized and how specifically PCK fits into that conceptualization. The review also includes literature regarding how subject matter knowledge (SMK) and PCK are related, secondary physics teachers, out-of-field teaching, and teaching knowledge and practices.

The third chapter describes the epistemology, theoretical perspective, and methodology that guided this study. Methods of data collection and analysis are also specifically discussed. The fourth chapter presents the results from the data analysis and the fifth chapter presents the interpretation of the results, conclusions, future work, and implications to physics education research.

Chapter 2: Literature Review

Overview

Essential to this study is an understanding of the content knowledge, PCK, and instructional practices of secondary physics teachers. This chapter reviews previous literature as it pertains to secondary physics teachers. Through this review each concept will be defined and previous work will be presented. With the prevalence of out-of-field teaching in the discipline of physics it is also necessary to define the degree to which a teacher is seen as “out-of-field” and the impact that has on the knowledge and practices of secondary physics teachers. Since the participants in this study are all beginning science teachers it is also necessary to review pertinent research regarding this topic.

While there has been extensive research into the concept of PCK, teachers’ content knowledge, teacher practices, and out-of-field teaching in the fields of teacher education and science education, very little research has been done in the field of physics education. Studies conducted in physics education have mainly focused on the content knowledge, beliefs, and learning practices of students of physics, rather than their instructors. One of the only connections between the practices of physics teachers and the classroom has been through the comparison of student scores on diagnostic tests for traditional and reformed instructors (Hake, 1998).

This chapter will provide a background regarding teachers as it pertains to: (a) PCK, (b) SMK and PCK, (c) secondary physics teachers, (d) out-of-field teaching, and (e) teaching knowledge and practices.

Pedagogical Content Knowledge (PCK)

PCK refers to how a teacher represents and formulates the subject being taught in order for students to be able to understand, and can include areas such as an understanding of a topic that might make them easy or difficult for students to learn, and knowledge of strategies students might use to help them organize their understanding of a concept (Shulman, 1986, 1987). In order for teachers to transform their SMK into classroom lessons a combination of different processes are required. These processes include: preparation of lessons, representation of topic-specific ideas that are cognitively appropriate, selection of instructional materials, and relating the chosen representations in a broader context. If a teacher does not have some degree of content knowledge, then these processes will be enacted with, general PK and this will distort or alter the concept(s) to be taught. Content knowledge is critical in PCK, and in its absence the instruction of a teacher will represent the content superficially.

After the introduction of PCK by Shulman (1986), a number of researchers began to develop different conceptualizations of teacher knowledge. Each of these included different categories of knowledge, and each set of categories had differing definitions for the components. There were four general areas of teacher knowledge that Grossman (1990) identified as “cornerstones of the emerging work on professional knowledge for teaching" (p. 5). These four areas were: (a) general PK, (b) SMK, (c) PCK, and (d) knowledge of context. Grossman displayed the components of each of these areas in a model for teacher knowledge, which can be seen in Figure 2.1.

In regards to the effect of SMK on PCK, Grossman (1990) suggested that the level of a teacher's subject matter preparation may influence a teacher's: (a) decisions about the relative importance of particular content and sequencing, (b) conceptions of what it means to teach a particular subject, and (c) selection of particular curricula and critiques of specific curriculum materials. Therefore a teachers' disciplinary knowledge may influence their conceptions of how to teach particular subject matter and to their curricular knowledge. One aspect of teaching that Grossman (1990) brought up is the importance of learning from experience in the development of PCK. Through actual teaching in the classroom and working with students, teachers learn about students' misconceptions and prior knowledge, as well as strategies and representations that work well for teaching particular topics.

Many researchers have suggested different conceptualizations of how PCK fits into the general knowledge necessary for teaching (Abell, 2007; Cochran, DeRuiter, & King, 1993; Etkina, 2005; Gess-Newsome, 1999; Grossman, 1990; Magnusson, Krajcik, & Borko, 1999; Veal & MaKinster, 1999). These representations all indicate a relationship among a teacher's PCK, PK, science SMK, and knowledge of context.

Each suggested PCK representation presented in the literature names different components comprising the necessary PCK for science teaching. No matter what the names are, the components that are common among the models are a knowledge of: (a) science curricula, (b) assessment of scientific literacy, (c) instructional strategies, and (d) students' understanding of science (Lee & Luft, 2008).

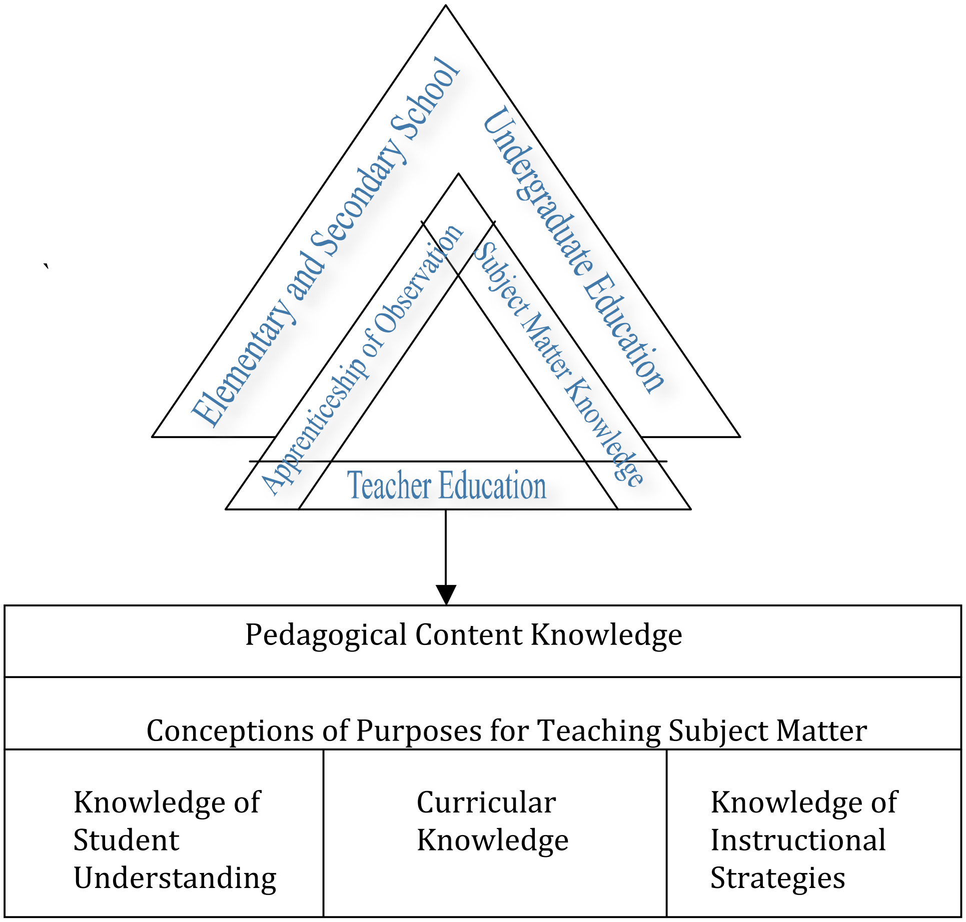
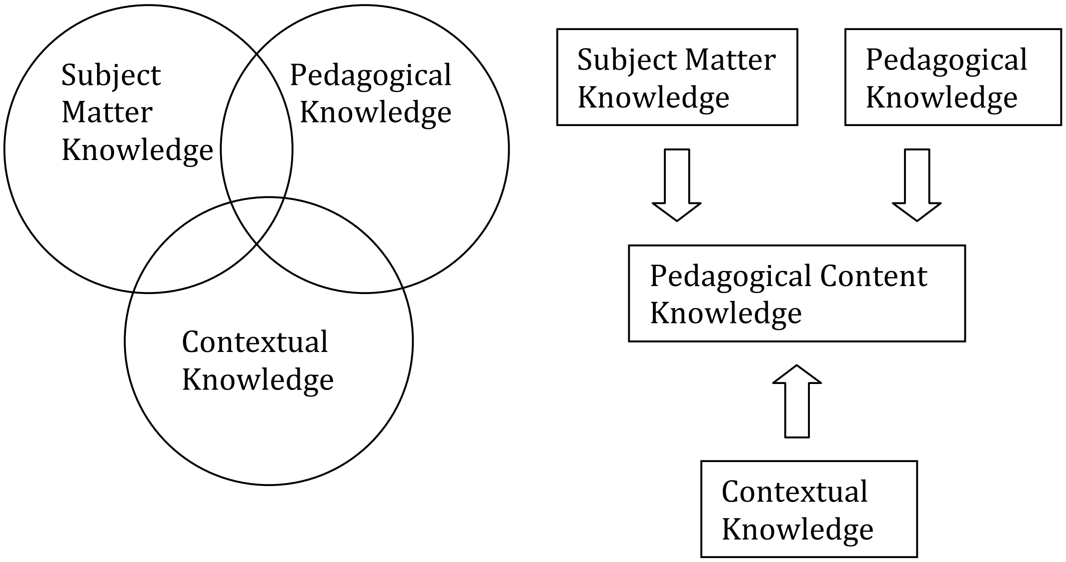


Figure 2.1. Model of PCK as conceptualized by Grossman (1990).

Models of PCK

Gess-Newsome (1999). As described by Gess-Newsome (1999), there are two possible ways to look at PCK – as an integrative or a transformative model. These models are on the extremes of a "continuum of models of teacher knowledge" (Gess-Newsome, 1999, p. 10). The integrative model portrays teaching as the integration of subject matter, pedagogy, and context. In this model PCK does not exist as a knowledge domain (Gess-Newsome, 1999). Each knowledge base is separate from the others, and a teacher will fluidly draw upon each, integrating them, in order to provide effective instruction.

The other model, the transformative model, describes a synthesized knowledge base, where individual knowledge bases (subject matter, pedagogy, and context) are "latent resources in and of themselves and are only useful when transformed into PCK" (Gess-Newsome, 1999, p. 12). This extreme seems to put little emphasis on the impact of context in terms of teaching knowledge and makes the classroom the primary location of teacher knowledge. Table 2.1, from Gess-Newsome (1999), gives an overview of the two models, and Figure 2.2 shows the two models graphically.



Transformative Model

Integrative Model

Figure 2.2. Graphical representation of the two models of teacher knowledge (Gess-Newsome, 1999).

Table 2.1

An overview of two models of teacher cognition and PCK (modified from Gess-Newsome, 1999).

	Integrative Model	Transformative Model
Knowledge Domains	Knowledge of subject matter, pedagogy, and context are developed separately and integrated in the act of teaching. Each knowledge base must be well structured and easily accessible.	Knowledge of subject matter, pedagogy, and context, whether developed separately or integratively, are transformed into PCK, the knowledge based used for teaching. PCK must be well structured and easily accessible.
Teaching Expertise	Teachers are fluid in the active integration of knowledge bases for each topic taught.	Teachers possess PCK for all topics taught.
Implications for Research	Identify teacher preparation programs that are effective. How can transfer and integration of knowledge best be fostered?	Identify exemplars of PCK and their conditions for use. How can these examples and selection criteria best be taught?

Most researchers who examine PCK as a construct fall in between the two extremes. The knowledge bases of subject matter, pedagogy, and context are recognized as foundational, along with the reciprocal relationship between these areas and PCK. New knowledge gained by the teacher influences both PCK and the foundational knowledge bases. However, it is recognized that a change in one knowledge base does not necessarily imply a change in another knowledge base (Gess-Newsome, 1999).

Cochran, DeRuiter, and King (1993). Coming from a constructivist perspective, Cochran, DeRuiter, and King (1993) presented a model of PCK called “pedagogical content knowing (PCKg)”. They defined PCKg as “a teacher’s integrated understanding of four components of pedagogy, subject matter content, students characteristics, and the environmental context of learning”. This definition places equal emphasis on the teacher’s understanding of students and context with PK and SMK. In this model new knowledge in the four areas are not simply acquired and put together, but are simultaneously experienced. Thus, this model is an example of one that is in the middle of the continuum described by Gess-Newsome (1999) – the integration of the four knowledge components comprises PCKg and the transformation of knowledge occurs simultaneously in all four components during the integration. A graphical representation of this model can be seen in Figure 2.3.

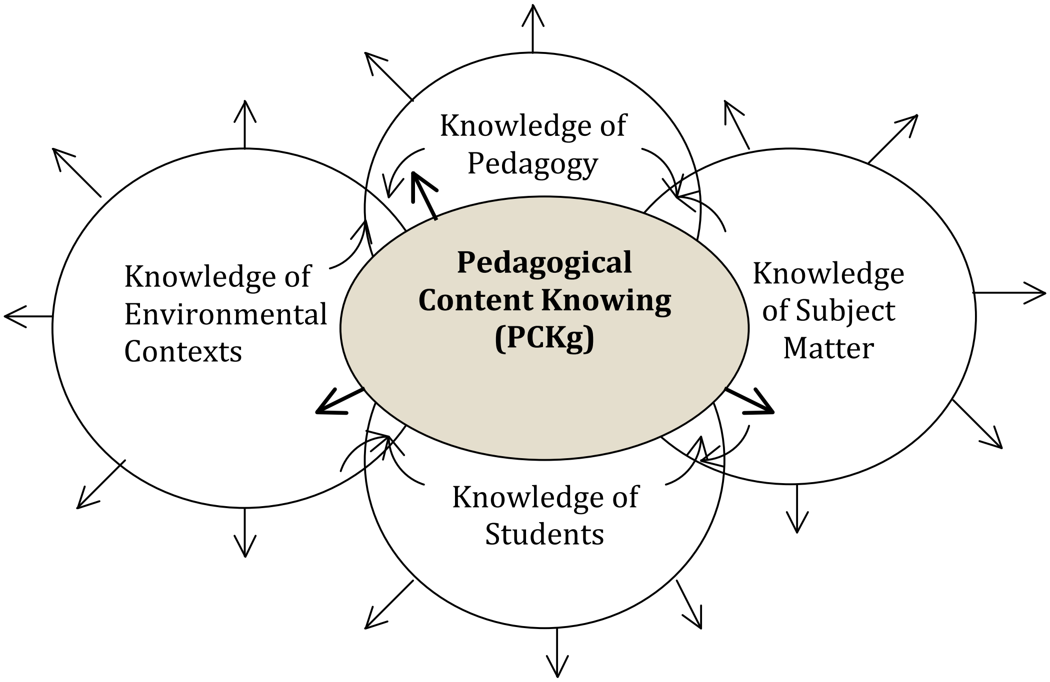


Figure 2.3. Graphical representation of Cochran, DeRuiter, and King's (1993) model of pedagogical content knowing (PCKg).

Marks (1990). In his study on PCK with fifth-grade mathematics teachers, Marks (1990) reconceptualized the components of PCK using the results of interviews with eight teachers, six experienced and two beginning. Each interview, which lasted between 45 and 90 minutes, included a task focusing on fifth-grade mathematics teaching. The tasks included lesson planning and critique, as well as identification to student correctness and suggestions on what to do next. Ultimately four teachers' interviews were used as data for the study. The data was pooled across all four teachers and coded using a set of 12 sub-categories of three main categories (knowledge of subject matter, general pedagogy, and PCK), which had been previously derived in related research. After analyzing a section of the data using the sub-categories, Marks modified the categories and continued the analysis. He continued this until the sub-categories had stabilized and he had a detailed taxonomy for the three main categories.

The results of Marks' (1990) research indicated that PCK is composed of four components. These areas are: "subject matter for instructional purposes, students' understanding of the subject matter, media for instruction in the subject matter, and instructional processes for the subject matter" (p. 4). Unlike many of the conceptualizations of PCK, each of Marks' components revolves around subject matter. Similar to other conceptualizations of PCK, Marks indicated that the different components are all integrated with each other. The focus of Marks' discussion was on the area of "students' understanding of the subject matter". This area was further decomposed into students' learning processes, students' typical understanding of topics, students' common errors (misunderstandings), ideas, topics, or tasks that are hard or easy for students', and particular students' understanding in the specific interview tasks.

Marks' (1990) study was a picture of the PCK for fifth-grade mathematics teachers. Through his study he was also able to provide a similar picture of the SMK and general PK for these teachers. Something new that Marks believed his study provided were examples of the teachers applying their general PK to particular subject matter contexts. Marks named this "content-specific pedagogical knowledge". The different components that make up the four areas found by Marks can be seen in Figure 2.4.

Based on his study and data, Marks (1990) suggested three different descriptions of PCK. He suggested that different aspects of PCK are derived from different aspects of a teacher's knowledge base: SMK, general PK, and an equal combination of the other two areas. This lead to what Marks called "ambiguities" regarding PCK. Due to its nature, PCK contains elements of both SMK and general PK. A teacher's actions or descriptions may be interpreted as stemming from either area depending on the focus of the researcher. As an example Marks referred to a teacher in his study who spoke about where the understanding of simple form in the teaching of simplifying fractions should be placed. If the teacher's statements

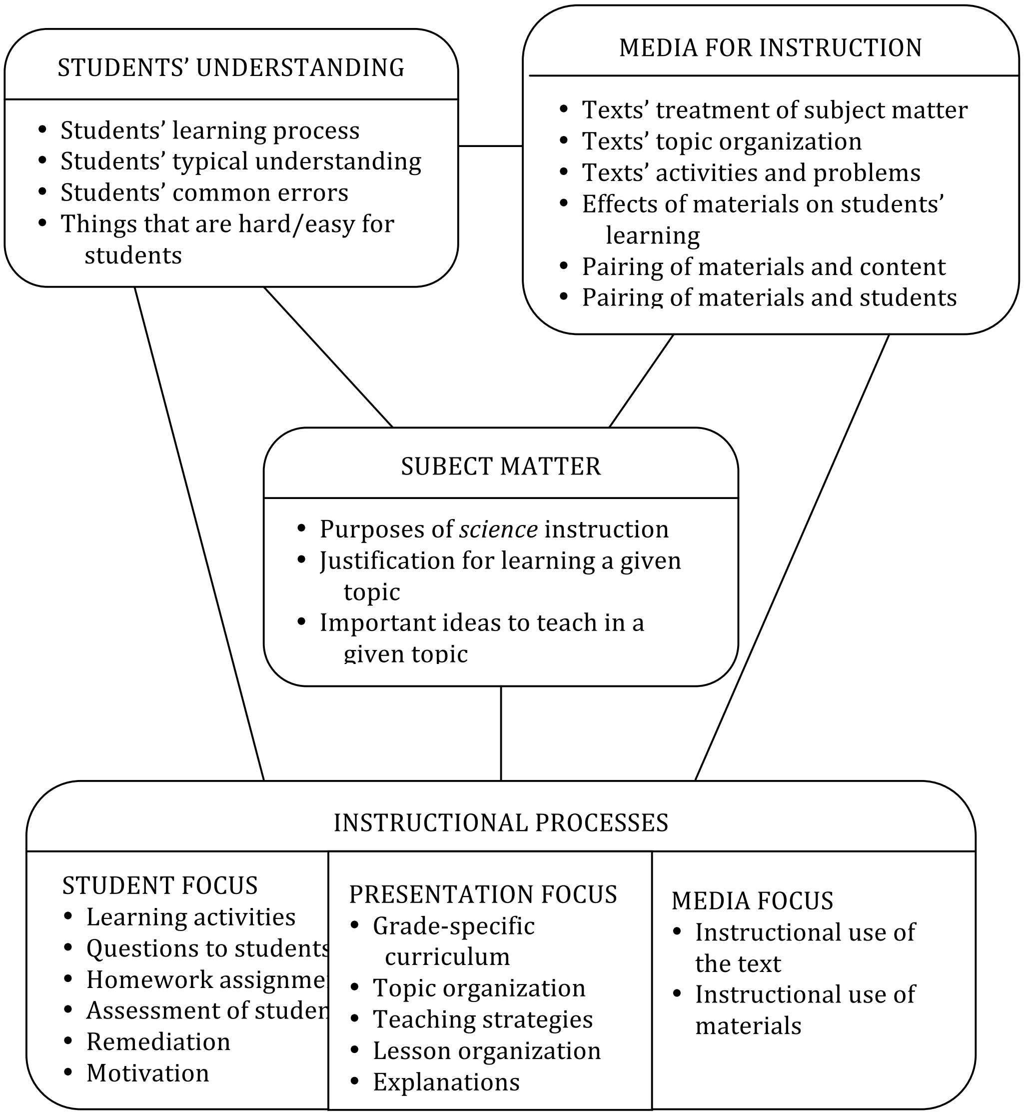


Figure 2.4. Marks' (1990) structure for PCK.

were analyzed as a whole they represented PCK. However, if the statements were analyzed into different components, the components represented different aspects of the teacher's knowledge base. Marks also discussed the fact that a teacher's statements regarding subject matter may in fact translate directly into PCK. This may confuse the analysis of teachers' statements since the statement could be seen as an example of SMK or as PCK.

These "ambiguities" are not a barrier to defining what PCK is or how it develops, but rather they offer a way to determine whether a conceptualization or description of PCK is appropriate. Boundaries between the different components of PCK are blurred and possibly arbitrary. Instances of teacher knowledge may fall within an area or on the boundary of areas. This is something a researcher studying PCK must keep in mind when analyzing statements of a teacher in an interview. Marks echoed the feelings of other education researchers in that PCK is a knowledge base held by those teaching and not by a non-teaching subject matter expert or by teachers who know little of the subject matter.

van Driel, Verloop, and de Vos (1998). As PCK began to be explored in more depth, researchers came up with more ways to conceptualize the construct. One way to present PCK was in terms of the concept of craft knowledge. van Driel, Verloop, and de Vos (1998) defined craft knowledge in teaching to be the integrated knowledge that includes teachers' "articulated wisdom with respect to their teaching practice"(p. 674). This form of knowledge includes a teacher's knowledge and beliefs regarding areas such as pedagogy, students, subject matter, and the curriculum. It includes knowledge previously obtained through prior education and on-going school activities, and is influenced by personal backgrounds and current work environment. Craft knowledge, in relation to PCK, focuses on the types of knowledge that guide behavior during classroom practice. PCK in this context is a transformation of SMK in order to mediate the communication between teachers and students in the process of learning.

Magnusson, Krajcik, & Borko (1999). Magnusson, Krajcik, and Borko (1999) defined PCK as a transformation of knowledge of subject matter, PK, and knowledge about context. The resulting knowledge from this transformation can in turn develop knowledge in the different domains in a reciprocal relationship. This conceptualization of PCK is similar to and based upon that of Grossman (1990). PCK for science teaching, as described by these researchers, included five components: (a) orientations toward science teaching, (b) knowledge and beliefs about science curriculum, (c) knowledge and beliefs about students' understanding of specific science topics, (d) knowledge and beliefs about assessment in science, and (e) knowledge and beliefs about instructional strategies for teaching science.

Orientations toward science teaching include the "knowledge of the purposes and goals for teaching science at a particular grade level" (p. 97). This includes how the teacher generally views science teaching and the "conceptual map" guiding instructional decisions about daily objectives, content of student assignments, the use of textbooks and other curricular materials, and the evaluation of student learning. Knowledge of science curriculum refers to both the mandated goals and objectives for students in the subject they are teaching, and specific curricular programs and materials relevant to teaching a particular domain of science. Knowledge of students' understanding of science includes the knowledge teachers need to have of students in order to help students develop specific scientific knowledge. This component includes the requirements for learning science concepts and areas of science students find difficult (e.g. misconceptions). Knowledge of assessment in science consists of the knowledge of the dimensions of science learning important to assess and the methods by which learning can be assessed. Lastly, knowledge of instructional strategies refers to the knowledge of subject-specific strategies (those broadly applicable) as well as topic-specific strategies (those within a domain of science).

Based on their conceptualization of PCK, Magnusson et al. (1999) posit that there is a critical amount of SMK necessary in order for a teacher to develop the PCK required to perform to current reform recommendations. They suggested that if a teacher has too little SMK in the area in which they are teaching, the teacher might not have had the experiences needed to implement inquiry in the classroom.

Veal and MaKinster (1999). Veal and MaKinster (1999) presented an alternative model of PCK. This model describes a general PCK taxonomy that hierarchically begins with general PCK for different disciplines (e.g. mathematics, history, science, etc.), moves to domain specific PCK for Science (e.g. biology, chemistry, physics, etc.), and then moves to a smaller grain size of topic specific PCK (e.g. kinematics, electricity, magnetism, etc. for the domain of physics). Domain-specific PCK focuses on one of the different domains or subject matters within a particular discipline. It is positioned between specific disciplines and domains of science, in order to represent a level of specificity of subject matter and pedagogy that includes the individual tools and purposes that are specific to the subject matter.

As an illustration, Veal and MaKinster (1999) referred to Kuhn (1962) and the way in which he outlines the inherent distinction between different domains of science. They did not compare the knowledge of teachers to scientists, but rather compared the two different groups of teaching disciplines. Within their respective communities, chemistry and physics education, divergent worldviews were developing in the same way. The taxonomy of PCK types Veal and MaKinster presented reflects a distinction between physics and chemistry teachers and the common topics they teach. Although the knowledge held by two teachers within different domains may be the same, a teacher’s orientation toward his or her content will increase or decrease the relative importance and use of pedagogical practices. This is termed by Gess-Newsome (1999) as “content-specific orientations to teaching” and has also been noted by others (Grossman, 1990; Gudmundsdottir, 1990; Veal & Kubasko, 2003). A teacher’s orientation is a complex combination of content knowledge, beliefs, and values. While it has not been shown in the literature that PCK can be broken down this finely, it is a useful way to conceptualize the development of PCK in a beginning teacher. Veal and MaKinster’s conceptualization of PCK can be seen in Figure 2.5.

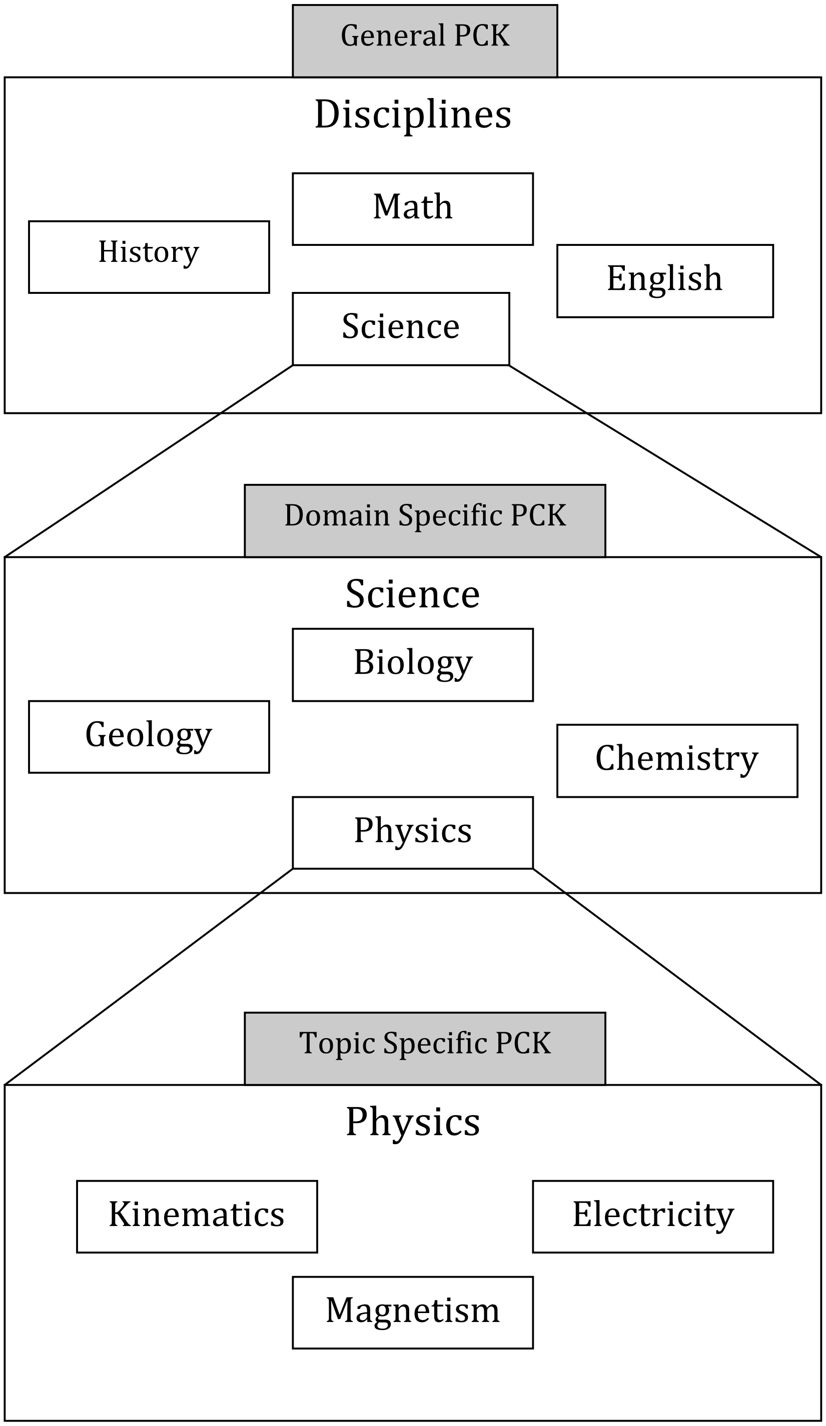


Figure 2.5. Veal and MaKinster's (1999) general taxonomy of PCK.

Angell, Ryder, and Scott (2005). Angell, Ryder, and Scott (2005) reported on a longitudinal study of the development of the conceptual and pedagogical knowledge of beginning physics teachers in their first three years of teaching. The focus of the study was on the teaching and learning of physics. They framed their study under a framework that characterized the development of expertise of science teachers. The framework is made up of three aspects of practice: knowledge base, pedagogical action, and fundamental influences. Within each component of knowledge development there is a progression from a novice teacher to an expert teacher. A difference between this framework for teacher knowledge and others is the inclusion of Mortimer and Scott's (2003) "communicative approach" as an important element in moving from novice to expert science teacher. This is seen in the framework as "authoritative" or "dialogic" in the pedagogical action column.

In this way, pedagogical action is related to the different components of a teacher's knowledge base (e.g. knowledge about content, teaching strategies, student reasoning). A beginning teacher's framework might have an understanding of science content, but less knowledge regarding the teaching strategies used to teach that knowledge. This is another way to frame PCK within a teachers' knowledge base and the framework can be found in Figure 2.6.

Guided by this framework, Angell et al. (2005) used an eight item written questionnaire in order to probe teachers' thinking about content and pedagogical issues. They were interested in how content knowledge was expressed in a pedagogical context, specifically in teachers' identification of student misconceptions, prior knowledge, and the sequencing of the answers. This part of the study used aggregated data from four of the questions along with two individual questions as the analysis. The study included 41 trainee physics teachers, 24 of which had a strong physics background. The other 17 had little physics background but had participated in a six-month course to enhance physics content knowledge before beginning a teacher training course. Angell et al. also had 16 experienced teachers (at least three years of teaching and known to be exemplary physics teachers as defined by the authors) complete the questionnaire. The questions were coded, checked for reliability, and interpretations were modified and refined by discussions. The inter-rater reliability between coders was 80%. A final categorizing and coding was then completed based on the final interpretations. Angell et al. acknowledged the difficulty in probing teachers' PCK and state that the written questions were a "starting point for a more detailed analysis of teacher expertise that draws upon classroom observations and post-lesson teacher interviews" (p. 5). As a statistical analysis of the data, the Mann-Whitney U significance test (a non-parametric test) was used for individual questions and the aggregated data from the four chosen questions. The questions were typical physics concepts and presented in a teaching context. For example, one question focused on the net force of a ball thrown up in the air and another focused on the teaching of light and the concept that an eye must receive light in

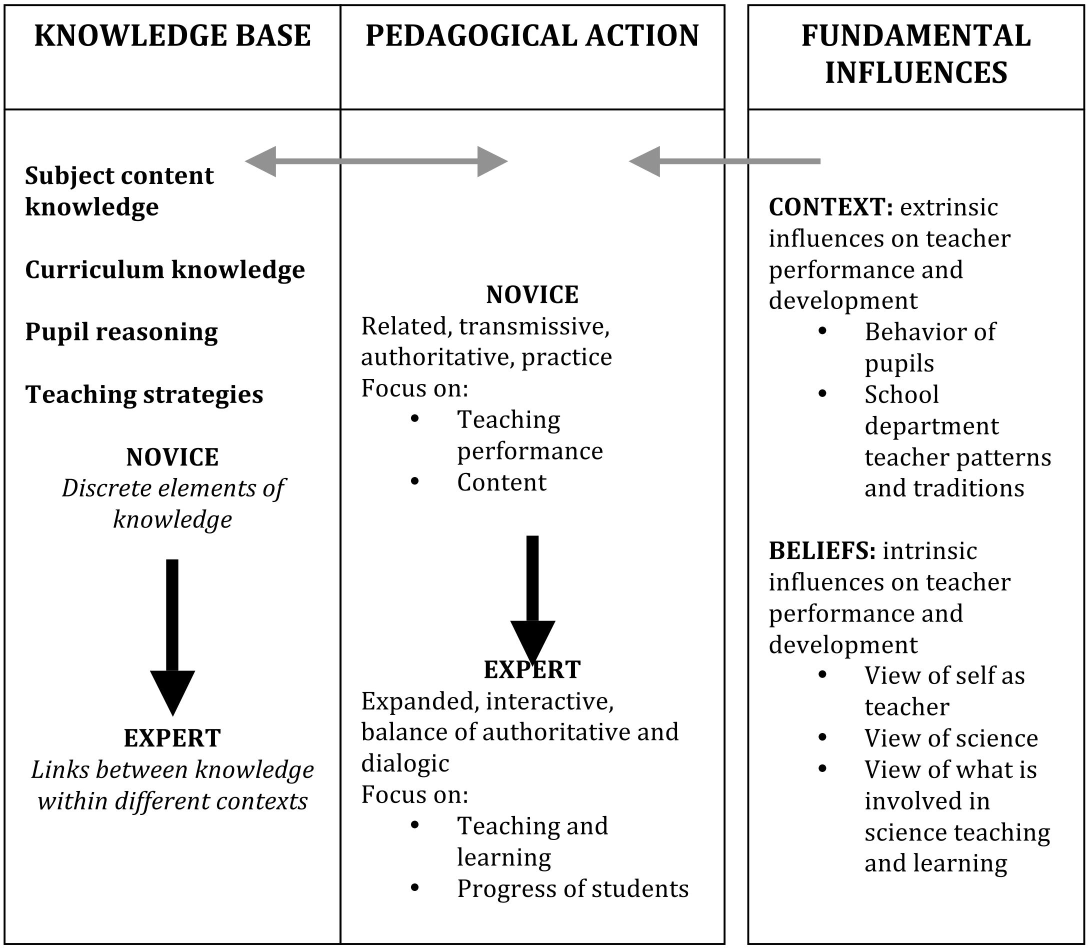


Figure 2.6. Framework for the development of science teacher expertise (Angell, Ryder, & Scott (2005)).

order to see. For the net force question the participants were first asked whether the student's answer in the scenario was correct, and then what should be said in reply. Based on the results to the example questions in the paper, there were no differences seen between the answers of the beginning and expert teachers in terms of content, however there were significant differences in terms of pedagogy (Mann-Whitney U; $p < 0.05$). Across the eight questions, the expert teachers gave, on average, more pedagogical arguments compared to the beginning teachers. On average the expert teachers gave 16.3 pedagogical arguments as compared to 7.4 for the beginning teachers. While they also compared the responses of the teachers with and without a specialization in physics, no significant differences were found in either content or pedagogy. This could be due to the fact that the teachers who did not specialize in physics had gone through an intensive physics content course before teaching.

This study echoed what other studies on novice and expert teachers' PCK have found. Beginning teachers have significantly less PCK than expert teachers, but similar content knowledge. However, while this study did attempt to compare those teachers who specialized in physics with those teachers who did not, the comparison was not informative since the non-specialists had gone through an intensive course specifically targeting the necessary physics content knowledge. Due to this course, it was likely the level of the non-specialists physics content knowledge was comparable to those who had degrees in physics. A study comparing non-specialists without any extra physics content support with the beginning physics specialist teachers could have gleaned more information. This study, however, was mainly focused on examining the elements necessary to develop from a novice to an expert science teacher. The results comparing those two groups of teachers was more salient for this study and illustrated the difference between understanding the content and understanding how to teach that content. With content knowledge being “equal”, it is clear from this study that beginning teachers start with lower PCK than expert teachers, something that has been found by other researchers as well.

Hashweh (2005). Due to the various different conceptualizations of PCK in the research literature and the possibility that PCK has “lost one of its most important characteristics, its topic specificity” (p. 274), Hashweh (2005) has proposed a model for PCK which highlights the interrelation between PCK and other categories of teacher knowledge and beliefs. He also suggests a new term for PCK called “teacher pedagogical constructions (TPCs)” in order to better convey the meaning and development of PCK. To support this new model Hashweh refers to his initial study on PCK (Hashweh, 1985), which conceptualized PCK as “the topic-specific knowledge that the teacher develops and accumulates in relation to teaching that topic” (p. 276).

Hashweh (1985) proposes a definition of PCK based on a reconceptualization of the definition presented previously (Hashweh, 1985; Shulman, 1986, 1987). This “new” definition takes into account studies on PCK conducted over the last 20 years, as well as ideas on the structure of memory from Schank (2000). Thus, Hashweh defines PCK as:

> the set or repertoire of private and personal content-specific general event-based as well as story-based pedagogical constructions that the experienced teacher has developed as a result of repeated planning and teaching of, and reflection on the teaching of, the most regularly taught topics. (Hashweh, 2005, p. 277)

This definition of PCK contains four main ideas. The first is that PCK is personal and private knowledge of the teacher, and is captured by observing teachers during their teaching and talking with them. This personal and private knowledge is then transformed into public knowledge by the researcher or by teacher self-reports and research. Secondly, PCK is a conglomeration of pieces or units called TPCs. This particular conceptualization of PCK has not been previously discussed in the PCK literature. TPCs develop mainly in planning, but also in the interactive and post-active phases of teaching. They are also made up of generalized event-based and story-based memory, are topic specific, and are connected to other categories and subcategories of teach knowledge and beliefs. Hashweh (2005) provides an analogy from chemistry where TPCs are molecules and PCK is a mixture of different molecules, but not a new compound. This is different from the deep, well-organized, and hierarchically ordered knowledge of subject matter that has been previously discussed regarding PCK (Gess-Newsome, 1999; Marks, 1999; Veal & MaKinster, 1999).

The third main idea is that TPCs are developed through experience, are comprised of knowledge built and accumulated during the teaching of specific regularly taught topics, and initially developed through teacher planning. Hashweh (2005) lists seven questions a teacher would ask when planning to teach a topic, for example photosynthesis to eighth-graders:

- What level of details and understanding do I expect/aim to accomplish when I teach it to eighth-graders?
- How can I utilize the topic to emphasize important ideas in biology?
- What other ideas can I relate it to?
- What other ideas in higher grades will build on what I am teaching now?
- What are the student difficulties and alternative conceptions that might be present, and how do I engage these prior knowledge and understandings?
- What representations of knowledge (analogies such as the factory and the leaf, examples, demonstrations, activities) can I use?
- How do I assess student understanding of this topic?

All of these questions, while rooted in PCK, also require the teacher to draw upon many sources of knowledge. The other important knowledge bases and beliefs that Hashweh lists are: knowledge of subject matter, of students, pedagogy, and assessment. These questions also demonstrate that PCK develops with experience rather than in a pre-service program.

The fourth, and last, main idea of Hashweh's (2005) definition of PCK is that the pedagogical constructions are influenced by an interaction of the different knowledge and beliefs of the teacher. Similar to other researchers who focus on PCK, Hashweh believes that a rich understanding of PCK is not the result of deep knowledge in a single area or category. However, Hashweh cautions that PCK is not a part of other knowledge and beliefs categories, and is also not a subset of the subject matter category.

Based on his re-conceptualized definition of PCK and using one of the six teachers' data from his original study (Hashweh, 1985), Hashweh (2005) proposes a model for a teacher's pedagogical construction. He compares it to Strike and Posner's (1992) 'conceptual ecology' for a certain point in time. The teacher is a 'hypothetical' since it was based on a reanalysis of data from the original study, the aim of which was not to describe the full range of teacher knowledge and beliefs. The proposed model can be found in Figure 2.7, and shows how the different knowledge categories might interact, but is not a developmental view.

Abell (2007). Recently Abell (2007) presented a review of teacher knowledge beginning with the historical definitions of "teacher knowledge" that led up to Shulman's (1986) characterization. Based upon the PCK definitions of Grossman (1990) and Magnusson, Krajcik, and Borko (1999), Abell suggests a framework for teacher knowledge with PCK at the center. She uses this framework to organize the previous research on science teacher knowledge. The framework includes three main influences for a teacher's PCK: science SMK, PK, and knowledge of context. These different components of teacher knowledge influence, and are influenced by, one another. This particular conceptualization of PCK is a valid summary of all of the prior frameworks and useful to help frame this study. The framework can be found in Figure 2.8.

The review of teachers' SMK is separated into general science and the four main disciplines of science. Abell (2007) comments that physics is the field in which the most amount of research on science teachers' SMK has been done. However the studies that Abell mentions only look at the knowledge teachers have of physics topics, not of how they structure their knowledge of physics or how they use their knowledge in the classroom. In fact, Abell comments that previous studies looking at how science background relates to teaching are not very conclusive.

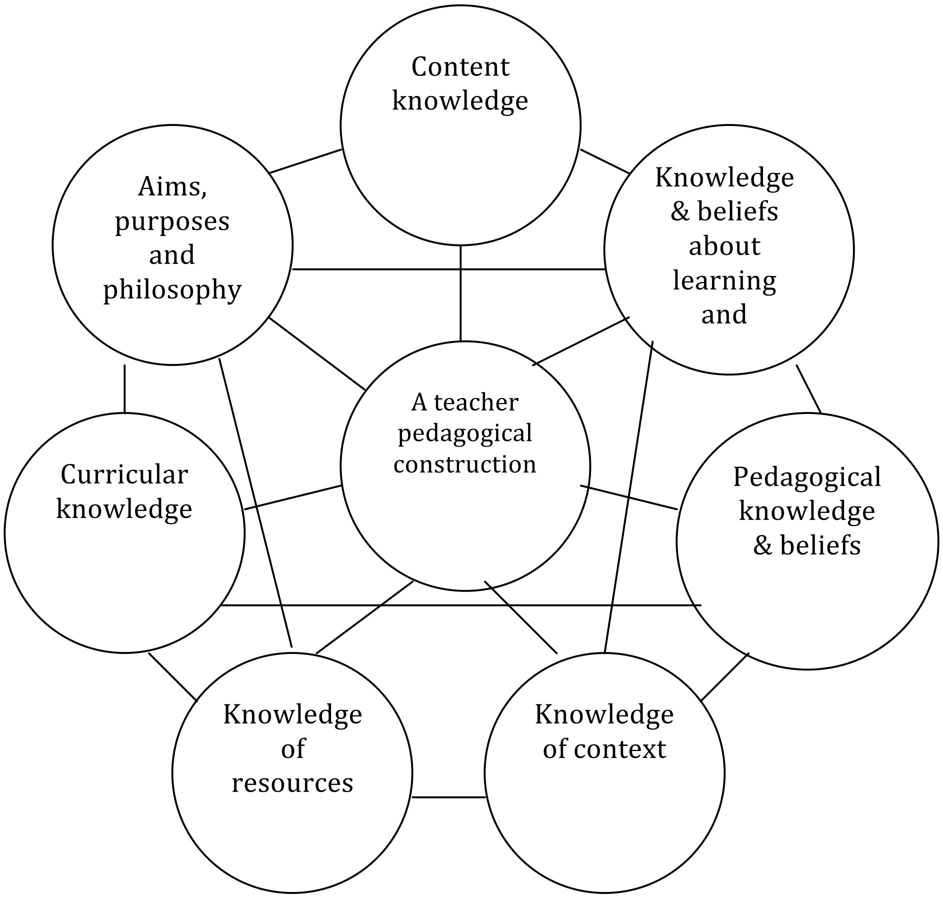
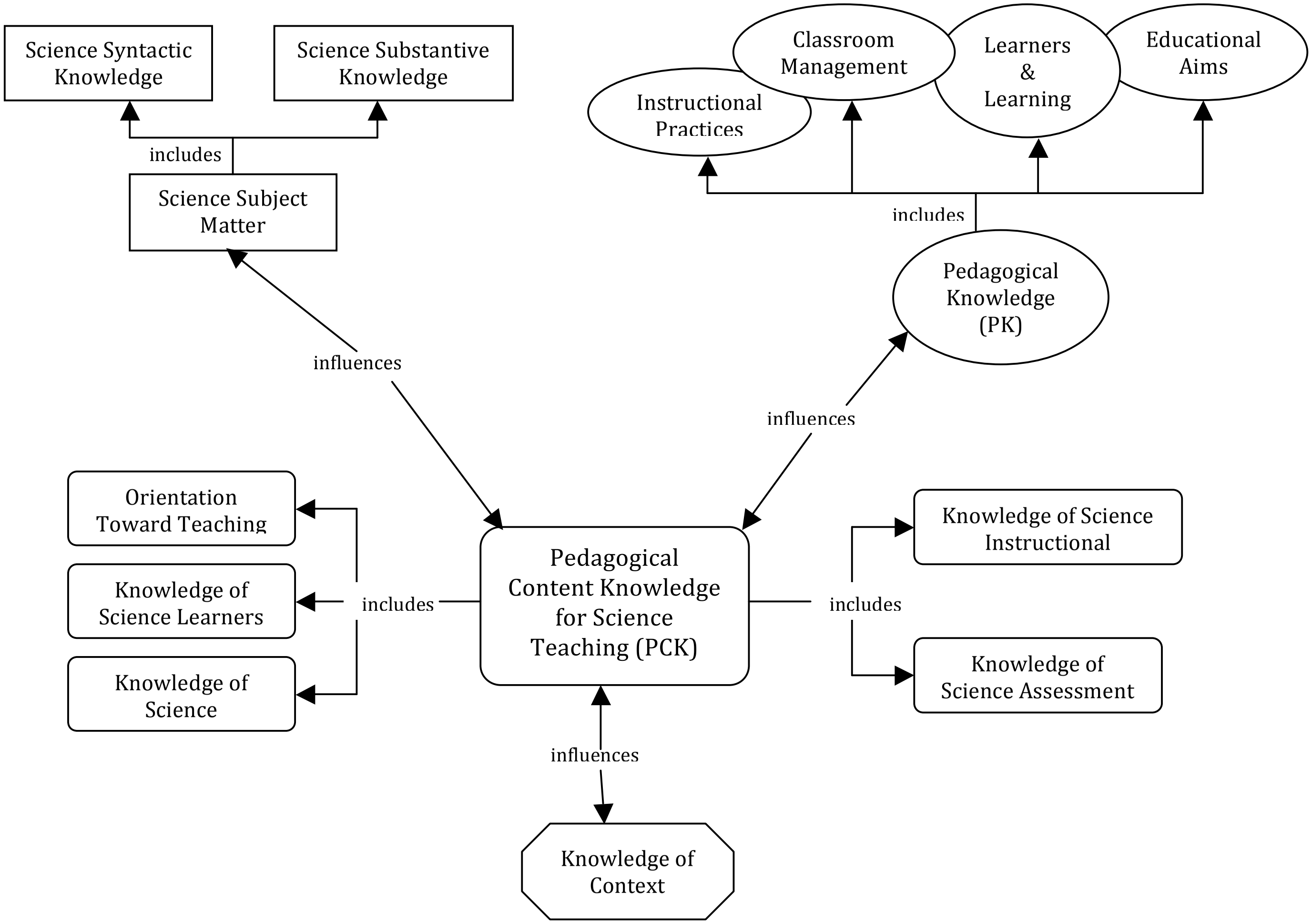


Figure 2.7. Hashweh's (2005) model for teacher pedagogical construction.

Figure 2.8. A model of teacher knowledge (from Abell, 2007; modified from Grossman, 1990 and Magnusson, Krajcik, and Borko, 1999).



Etkina (2005) and Wenning (2007). The PCK of physics teachers is a field that has been largely unexplored using research studies in physics education research. Drawing upon education research, physics educators have begun to describe the elements necessary for physics teachers to be able to effectively teach students of physics. PCK has been discussed theoretically by Etkina (2005) and Wenning (2007) within the discipline of physics and in relation to physics teacher preparation programs. They describe three elements that make up the knowledge base of physics teachers: content knowledge, PK, and PCK.

Content knowledge includes knowledge of the discipline, including procedural knowledge. Wenning (2007) believes that a secondary physics teacher should have a broad and current understanding of the major content areas of physics. These areas include topics such as mechanics, electricity and magnetism, heat and thermodynamics, waves and light, optics, and modern physics. Under this component Wenning also includes the symantic and substantive elements as described by Schwab (1978) and knowledge of the elements of scientific inquiry as described by NSES (NRC, 1998). Etkina (2005) describes this knowledge as knowing physics concepts, relationships among the concepts, and the methods of acquiring physics knowledge.

PK is described by Wenning (2007) as an understanding of what constitutes effective teaching and being able to distinguish authentic teaching practices from traditional teaching practices. He likens it to the “generic how and why” of teaching (p. 1). This knowledge includes understanding of planning and preparation, quality teaching, inquiry practices, cooperative or collaborative learning, problem-based learning, multiple representations, preconceptions and concept change, learning cycles, and instructional resources. Many of these things are included as important elements in PCK by education researchers, rather than as part of general PK. Etkina (2005) however, describes PK as consisting of a knowledge of brain development, cognitive science, collaborative learning, classroom discourse, the classroom, and management and school laws, which matches more closely to those elements of PK described by education researchers.

In terms of PCK, Wenning (2007) defines the construct as a “situation-specific overlap of content knowledge and pedagogical knowledge” or the “specific why and how” (p. 1). Wenning limits his discussion of physics teacher PCK to teachers’ familiarity with the information contained within a set of four books about the teaching of physics. Etkina (2005) however describes PCK in physics as having knowledge of: (a) physics curricula, (b) student difficulties in physics, (c) effective instructional strategies for a particular concept, and (d) knowledge of assessment methods. Etkina posits that these characteristics cannot be developed through separate paths of physics content knowledge and PK, where a teacher “simply adds the knowledge of educational psychology to the knowledge of physics” (p. 4). Along with the model presented by Abell (2007), this model of physics PCK, as suggested by Etkina, was also used to help frame this study of PCK within the discipline of physics and can be found in Figure 2.9.

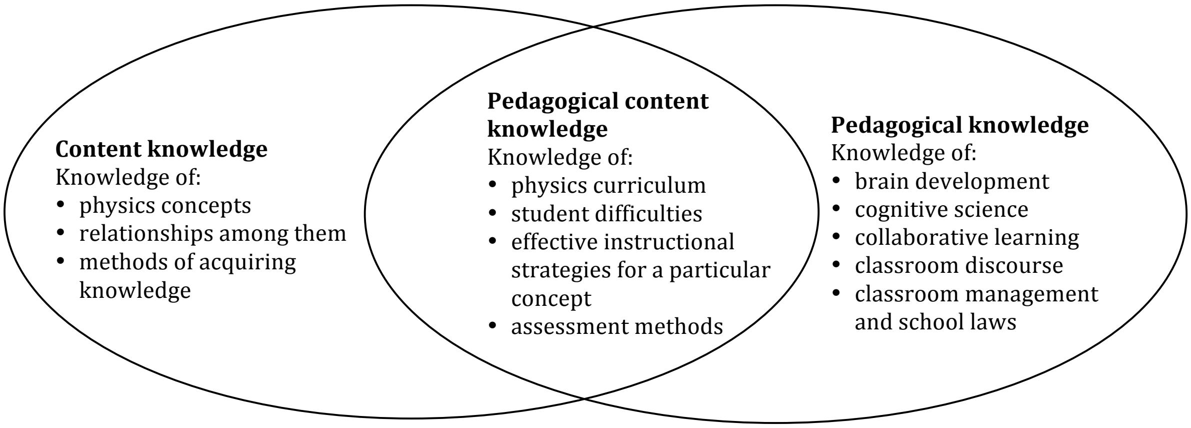


Figure 2.9. The structure of physics teacher knowledge (Etkina, 2005)

SMK and PCK

Conceptualizations of PCK include an expectation of the teacher to understand why a given topic is central to the discipline and when a topic might be peripherally important (Hashweh, 1987; Reynolds, Haymore, Ringstaff, & Grossman, 1988; Shulman, 1986). In order to determine the important ideas and skills in a domain, and how those who produce knowledge in the field add or abandon ideas and skills, a teacher must understand the structures of the subject matter, the principles of conceptual organization, and the principles of inquiry. This all contributes to how much influence the amount of discipline-specific content knowledge a teacher has on the concepts chosen to be taught, how to teach a concept, how to know when students don't understand a concept, and how to represent the content to the level of the students. In general, subject matter content knowledge, as depicted by Shulman (1986, 1987), includes Schwab's (1978) structure of a subject: substantive and syntactic structures. Substantive structures are the various paradigms within a field that affect both how the field is organized and the questions that guide further inquiry (Grossman, 1990). With this type of scientific knowledge the teacher communicates the ways in which knowledge is determined in science, along with the set of attitudes and values that will influence student understanding of the scientific process. Syntactical structures are the methods used in a discipline in order to construct knowledge within that discipline. Often referred to as the nature of knowledge, this type of scientific knowledge includes the set of rules used in the discipline and what breaks those rules down. Together the syntactical and substantive structures are essentially the rules and procedures of good scholarship or inquiry in a discipline. The degree to which teachers possess knowledge of substantive and syntactic structures of their fields may influence how they represent their discipline to students (Ball & McDiarmid, 1990; Feiman-Nemser, 2001; Grossman, 1990; Kerr, 1981; Wilson & Wineburg, 1988).

Studies examining the PCK of secondary science teachers have revealed that adequate knowledge is essential for a teacher to understand what important discipline-specific concepts should be taught and how those concepts should be taught to students. When asked to identify the central concept in a biology textbook, physics teachers were unable complete the task. The same was found with biology teachers when they were asked to correct a misconception in a physics chapter (Hashweh, 1987).

While their study was conducted with primary teachers rather than secondary teachers, Parker and Haywood (2000) examined subject specific aspects of the teaching and learning of forces. They suggested that it is not just enough to know something, a teacher must have a "coherent, causal explanation which makes sense…such that they feel skilled in teaching the concept to children" (p. 89). In other words, a teacher must be able to discriminate between "knowing" and "understanding".

Veal and Kubasko (2003) examined 12 pre-service and experienced biology and geology teachers teaching the same content of evolution. Using the philosophy of science, sociocultural theory, and a taxonomy of PCK to frame their study, Veal and Kubasko used classroom observations, semistructured interviews, unstructured conversations, and documents from a science methods course as sources of data. The data were analyzed qualitatively using content analysis. Categories were determined, discussed between the authors, clustered into broad categories, and subcategories were then determined.

Differences between the geology and biology teachers were found. Geology teachers having knowledge of biology were able to incorporate geologic terms with biology terms and students prior knowledge in biology when teaching evolution. The two groups of teachers also focused instruction from different content areas. While the geology teachers focused on rocks, the earth, and inanimate objects, the biology teachers focused instruction on humans, life, and animate objects. Veal and Kubasko state that the data indicates the "nature of geology" and the "nature of geology" are different from each other, and that this is due to the different "communities of inquiry" or "communities of practice" in which each group is situated.

Other studies have indicated that teachers who are more confident in their knowledge of subject matter are more likely to depart from the organization of content found in textbooks (Reynolds, et al, 1988). If a teacher does not have adequate knowledge, enacting typical teaching tasks such as identifying central concepts and using reformed teaching practices by drawing on only general PK may not be enough to be effective in the classroom. Studies have suggested that what might be needed is developed PCK including adequate SMK (Hashweh, 1987; Monk, 1994; Reynolds et al., 1988).

When considering PCK for physics teaching, questions arise regarding what kind and how much discipline-specific content knowledge a science teacher needs to know in order to effectively teach a subject, especially physics. This distinction is important to examine when comparing teachers who are teaching in their content specialization versus those who are not. In the field of physics education, Deng (2004) looked at two questions regarding the physics knowledge of a science teacher. The first question asked whether there is a fundamental difference between the knowledge required for teaching science and the knowledge required of a discipline in science. The second question asked whether a teacher has to transform the knowledge of a discipline of science in order to be effective. These questions were looked at conceptually by using Dewey's logical-psychological distinction as a way to frame the distinction between the two types of knowledge. As an example, Deng referenced a previous study (Deng, 2001) where experienced high school physics teachers were teaching the topics of color, the speed of light, and light interference. The study investigated the difference among the key ideas that were needed to teach the topics. Deng gathered data through participant observation of the two experienced teachers, examination of two popular high school textbooks and two optics textbooks for physicists, and interviews with the two physics teachers and two physics professors specializing in optics.

Deng (2001) found that the knowledge needed for teaching a school science embodies some of the essential features of PCK, namely that it distinguishes the understanding of the science teacher from that of the scientist. What a physics teacher uses in classroom teaching is not the same knowledge of the academic discipline of physics. Deng (2004) believes that the knowledge required for teaching is formulated within a view of helping students assimilate and incorporate the subject matter into their experience and understanding. If this were the case, then discipline-specific knowledge itself would embody a "method of instruction" (Deng, 2004, p. 4) for the teachers. The physics teachers in the Deng (2001) study did not use the same knowledge of academics in physics and it is not clear how their views about either science in general, or physics in specific, might have impacted their teaching practices and their PCK.

In a study examining pre-service physics teachers in Malaysia, Halim and Meerah (2002) found that teachers' knowledge of student difficulties in physics (e.g. misconceptions) and the strategies chosen to explain physics to students, both knowledge components of PCK, were dependent on teachers' understanding of physics content knowledge. The teachers' ability to transform the subject matter appropriately for the students was effected by the teachers' poor understanding of the content.

In this study, Halim and Meerah (2002) designed a survey where teachers were asked to respond to a series of physics questions as though they were explaining the ideas to lower secondary school students. Since it was suspected that a written survey may underestimate the teachers’ ability to transform their knowledge, interviews with a sub-sample of pre-service teachers were conducted. These interviews explored the teachers’ ability to anticipate student difficulties and/or misconceptions of the topics and their ability to formulate analogies, explanations, examples, and demonstrations to teach the topic.

The interviews were conducted with twelve pre-service teachers who volunteered to participate. Each of the participants had already received an undergraduate degree in a science or related field. The prior teaching experience of the participants was less than three years, if they had any experience at all in the classroom. Out of the twelve participants, three had a degree in physics, two in chemistry, five in the life sciences, one in mechanical engineering, and one in geology. The physics, geology, and engineering students were enrolled in a physics methods course, the chemistry students were enrolled in a chemistry methods course, and the life science students were enrolled in a biology methods course.

The survey questions for the interview were based on physics concepts required at the lower secondary level and were chosen such that the topics would check to see the extent to which the teachers could identify common student misconceptions and the explanations the teachers might provide for the concepts. The participants were interviewed one at a time with the opportunity for follow-up questions by the interviewer. The data was analyzed in regards to the pre-service teachers’ answer to the questions (grouped by correctness) and then by the relationship between the identification of student misconceptions with the suggestions for teaching the concepts to students.

The analysis found that about half of the pre-service teachers were able to show an understanding of the physics concepts. However, there was no indication whether the students who correctly identified any physics concepts had degrees in physics or another discipline. Halim and Meerah (2002) continued to report the number of pre-service teachers who were or were not aware of student misconceptions and who provided teaching strategies to address student understanding. Within each of the results there was no indication which pre-service students are included. There was no indication of whether the pre-service students who could identify student misconceptions with physics topics, or provide teaching strategies have degrees in physics, were enrolled in a physics methods class, or had experience in a secondary classroom.

Halim and Meerah (2002) concluded that the pre-service teachers' knowledge of the two components of PCK (awareness of misconceptions and suggestions of teaching strategies) depended on their understanding of the content knowledge. They claimed their findings showed a majority of the teachers had trouble understanding the physics ideas themselves. They also reported that the pre-service teachers' inability to transform the subject matter into appropriate representations conveying the scientifically correct answers was due to a lack of content knowledge. Finally, this study found that even if the teachers could correctly identify common student misconceptions they failed to consider these misconceptions in their teaching suggestions. The teachers tended to restate their own understandings as a strategy.

Secondary Physics Teachers

The 1996-1997 American Institute of Physics [AIP] High School Physics Teacher Survey found that of the high school physics teachers who did not have a physics degree, the highest degrees earned were: 28% biology or life-science, 18% chemistry, 20% mathematics or engineering, 22% other science, and 12% non-science. The certification of the teachers reflected 61% of teachers at public schools held a full physics certification, while only 27% of teachers at private schools did. At the private schools 38% of physics teachers held no certification at all and 29% held a full or temporary certification in general high school science, mathematics or another science, compared to 1% and 33% respectively for public schools (Neuschatz and McFarling, 2000).

Duit, Neidderer, and Schecker (2007) indicated that more research is needed in two areas of physics education in regards to the teaching and learning of physics. First, they suggested investigations into how teachers can become familiar with research findings and how teachers' views about teaching and learning physics may be improved. Once this investigation has been conducted the next step is to look at whether instructional practice improves or not. In order to carry out this second line of research, teachers' initial views about teaching and learning physics needs to be examined. While this has been done to a certain extent in the past, much of the research has been on student epistemological views about teaching and learning physics rather than on teachers' views.

For example, Hammer (1994) discussed the epistemological beliefs of students in physics. He interviewed six undergraduate physics students over the course of one semester. Four of the participants volunteered for the study and two were chosen due to high midterm scores in order to provide a range of physics performance. The four volunteers participated in five 1-hour interviews and the high score students participated in three interviews. Other data sources included a third of the lectures, several laboratories, and the assigned readings, problem sets, and exams from the course. Because of the nature of probing beliefs, Hammer chose to engage the participants in a variety of conversations related to the course. In this way the students would feel comfortable talking with him and their beliefs could be ascertained through comments made or behavior. Students were asked general questions (e.g. "How is the course going?"), to perform more directed tasks (e.g. going over a graded midterm), and to have discussions about the specific content (e.g. definitions of terms).

The analysis consisted of examining the data for instances of epistemological beliefs regarding physics, learning physics, the teaching of physics, or the physics course itself. Through the analysis Hammer (1994) developed a basic framework of students' epistemological beliefs of physics consisting of three dimensions. These three dimensions included:

1. Beliefs about the structure of physics

2. Beliefs about the content of physics
3. Beliefs about learning physics

Hammer characterized each dimension by two or more categories and he used the interview data to support the framework. Students' beliefs about the structure of physics were characterized as either a collection of isolated pieces or as a single coherent system. However, Hammer realized that students' beliefs fit more within a continuum – where somewhere in between "isolated pieces" and "coherence", a student's beliefs might be considered as "weak coherence". Student beliefs labeled as "weak coherence" would characterize a student who sees a coherent or conceptual content to physics, and that content is the responsibility of experts. Physics knowledge exists but is not accessible or essential for students.

Beliefs about the content of physics are characterized by a continuum that goes from using formulas to the concepts, which underlie the formulas. The middle ground for this dimension includes "apparent concepts" and/or "weak concepts". This includes the belief that physics knowledge is made up of symbols and formulas that are loosely associated with conceptual content. The beliefs about learning physics dimension is characterized by receiving information or involving an active process of reconstructing one's understanding.

Hammer (1994) used his framework to provide a characterization of two of the participants in the study, representing two main groups that appeared in his study. One group fit the "Weak Coherence, Apparent Concepts" classification and the other group fit the "Concepts and Independent" classification. Interestingly the four participants who volunteered for the study fit in the first group and the two students selected by having high midterm scores fit the second group. Generally Hammer found support for previous findings by other studies regarding reasoning in physics. Novice students showed weakly organized knowledge, use only formula manipulation when solving problems, and held various misconceptions. There were however substantial differences seen among the students in the study. Hammer attributed the differences seen in the participants to differences seen in content-level knowledge, general cognitive resources, and goals in the physics course.

The implication of a study on student epistemological beliefs about physics is in how an instructor in physics approaches the students in his or her class. Acknowledging students' beliefs about physics can help a physics teacher in different aspects of teaching, including identifying student misconceptions and knowing if an instructional method might be counter to student beliefs about how physics should be taught. While the framework developed by Hammer referred to *students'* beliefs about knowledge and learning in physics they can also apply to *teachers'* beliefs about how students gain knowledge and learn in physics.

Out-of-field Teaching

"Out-of-field" teaching has been defined in many different ways. How the term is defined impacts the estimates of how widespread out-of-field teaching is in secondary and middle schools. Ingersoll (2003) discussed the various ways "out-of-field" teaching has been defined, and often included a minimum prerequisite for teaching in a subject as having at least a minor or certificate in the subject taught or a related field. This measure includes both “academic and education majors and minors” (p. 12). Therefore, a qualified teacher includes “at a minimum preparation in how to teach, preparation in the particular subjects one is assigned to teach, and also preparation in how to teach particular subjects” (p. 12-13). This assumption mirrors Monk’s (1994) findings that adequate understanding in the subject area is a necessary but not sufficient condition for effective teaching.

Sanders, Borko, and Lockhard (1993) specifically looked at out-of-field teaching with experienced secondary science teachers. They were interested in the similarities and differences in the planning, teaching, and reflecting of these teachers when they were asked to teach within and outside of their area of certification. The three teachers in this study had been teaching in their area of certification for between three and eight years. The areas of certification of the teachers in this study were biology, chemistry, earth science, and mathematics. The unfamiliar areas the teachers were asked to teach in were astronomy, physical science, and photography.

The data sources included interviews and observations during a two-week period for five consecutive days in each subject area. The interviews, focusing on planning and reflection, were conducted before and after each class and each week of observation. All interviews were transcribed and notes were taken during the observations. The teachers’ lesson plans and notes, copies of transparencies, seating charts, maps of the classroom, worksheets and handouts, and the researcher's daily journal were also used as additional data sources. The data were analyzed following Spradley (1979, 1980) using the domain, taxonomic, and componential techniques, and by Miles and Huberman (1984) for charts, checklists, and summaries. The interviews were coded and entered into a modified "Framework for Data Analysis" (Borko & Livingston, 1989; Borko, Bellamy, & Sanders, 1992). Major and subcategories were determined and checked for reliability. After the categories were determined the data was examined for trends and patterns. Comparisons were made between the two teaching areas for each teacher, and then among all three teachers in the study.

The teachers in this study resembled experts when teaching in their certification area, and like novices when teaching out of their area. The whole knowledge base of the teacher (content knowledge, PK, and PCK) influenced all aspects of teaching. In general the teachers had a sense of what worked in their classroom, how lessons in general should flow, what classrooms and students would be like, and they valued reflection after each lesson. These were all qualities demonstrated by the experienced teachers regardless of the topic they were teaching.

When teaching in their area the teachers had plenty of resources and materials available, however when teaching outside their area they sought outside help due to a lack of materials and resources. Presentations of the material were developed the day of the lesson and were accompanied by pages of notes. This led to planning that was time consuming and inefficient. How much content knowledge also influenced the planning and teaching of the teachers. While the teachers knew important content and what and how they wanted students to learn when teaching in their areas, when teaching outside their fields they had difficulty deciding what the important, key concepts were. While teaching within their areas the teachers knew several ways to present the concepts and were able to answer questions as they developed. However, outside their areas the teachers were uncertain of content, were sometimes confused themselves, and occasionally made errors.

From their experience teaching in their areas the teachers knew they needed to know students' prior knowledge when planning and incorporated ways to determine this knowledge. Outside of their fields the teachers also had difficulty planning lessons because they no longer knew how long things would take. These teachers also had difficulty determining how much content to present at any one time and the how to sequence their presentations when teaching outside their area, something they had a very good handle on when teaching in their certification area. Outside of their certification areas the teachers used checkpoints to determine how they should proceed to the next topic or activity and the focus of activities were teacher-centered. Within their areas the teachers were able to utilize unexpected events or questions in order to direct the flow of the class, changing lessons based on student input.

Sanders, Borko, and Lockard (1993) found patterns that were unique to the teacher teaching outside of their certification areas. As experienced teachers they did not rely on the textbook or curriculum guide to present content to their students. This was in contrast to trends seen by Borko, Bellamy, and Sanders (1992) and Hashweh (1987). The teachers were able to use information from a combination of many different resources. They were also more selective in how they used this information in planning their lessons than seen in novices in previous studies. While these teachers had characteristics of novice teachers when they taught outside of their comfort zone, it was clear that they were experienced teachers and utilized the general pedagogical techniques, as they were applicable.

Based on the findings from their study, Sanders, Borko, and Lockhard (1993) suggested that when assigning teachers to teach out of their fields, the teachers should be experienced in order to have the resources of PK to draw upon in the unfamiliar field. They also suggested that when choosing a teacher to teach in a science area, that teacher should be another science teacher so as to be able to draw upon general science PCK. However, as has been indicated by Ingersoll (1999) many of the teachers asked to teach out of their fields are the new or beginning teachers.

Goldhaber and Brewer (2000) used a multiple regression analysis in order to examine different factors on student achievement. Within their study they examined whether the type of teacher certification had an effect, holding family background and school characteristics constant. The data used in the study was the National Educational Longitudinal Study of 1988, a large representative study of 8th grade students. Goldhaber and Brewer focused their study on those students who were in 12th grade. In order to determine the certification status of the teachers, they used a survey question asking "which type of math or science certification do you hold from the state where you teach?" The possible responses were: regular or standard, probationary, emergency, private school certification, or no certification. Neither the survey nor Goldhaber and Brewer distinguished whether "no certification" referred to any teaching certification or certification in the subject matter taught. In their study 82% of the teachers held standard certifications.

Similar to what Monk and King (1994) found, Goldhaber and Brewer (2000) found that student achievement was related to teacher's degree level for mathematics. Those teachers who had a Bachelors or Masters degree in mathematics had students who had higher test scores relative to those teachers reporting to have an out-of-field degree. However, in science no impact was seen for teachers with subject specific degrees. Therefore, mathematics students who are being taught by teachers who are certified out-of-field do worse on the standardized tests than those taught by teachers who are certified in mathematics.

In a study looking at the effect of course assignments on teaching efficacy, Ross, Cousins, Gadalla, and Hannay (1999) examined teaching outside of one's area of specialization. They gave a survey to teachers in nine secondary schools (*N* = 359). The main variable examined was teacher efficacy measured using a survey instrument created specifically for this study. The survey focused mainly on courses rather than subjects, since were the main work assignments for the teachers. A 6-point Likert scale was used for prompts beginning with “I feel confident in my ability to…”. These prompts focused on six instructional functions: (a) identifying important learning outcomes, (b) sequencing of course content, (c) explanation of key concepts, (d) anticipation of student difficulties, (e) evaluation of student progress, and (f) integrations of the course with other subjects.

A step-wise multiple regression analysis was conducted to answer the research questions with the criterion variable being teacher efficacy. The three predictor variables were course track, course grade, and match with the teaching specialization of the teacher. The between-teacher variables were gender, career experience, school leadership role, and teacher’s subject. The analysis showed that teachers have higher expectations in their ability to teach courses within their subject area. Ross et al. (1999) suggested that a teacher with higher teacher efficacy will be more willing to utilize teaching strategies beyond his or her comfortable abilities. They also suggested that since teaching out of one’s field has a negative effect on teacher efficacy, this might contribute to a downward spiral effect. Lower teacher efficacy could lead to the selection of less challenging instructional strategies when teaching out-of-field. This then might contribute to lower student achievement, which may lower teacher efficacy even further. Ross et al. cautioned that their results may not be generalizable due to their definition of “teacher’s subject area”. Their definition was the “subject of a teacher’s highest proportion of courses” (p. 798). This definition did not take into account a science teacher who might have been assigned mathematics courses at the time of the study, the possibility of teachers’ defining their own expertise within subjects, or with confidence in teaching within a single subject. Also, the findings accounted for a small amount of variance and therefore Ross et al. could not confidently claim that their research question had sufficiently been answered.

Recently, in the *Science and Engineering Indicators 2008* published by the National Science Board (2008), in-field and out-of-field teaching were defined in terms of four levels: in-field, related-field, general preparation, and out-of-field. The levels are defined as (Ch1, p. 30):

> *In-field*. In-field teachers have either a major or full certification in their main teaching field, or both. For example, a mathematics teacher is in field if he or she majored in mathematics or is fully certified in mathematics.
>
> *Related-field*. Related-field teachers have either a major or full certification in a field related to their main teaching field, or both. For example, a related-field mathematics teacher has a major or full certification in computer science, engineering, or physics.
>
> *General preparation.* General preparation teachers have either a major of full certification in general elementary, middle, or secondary education. For example, a physics teacher has general preparation if he or she has a

> major or full certification in general elementary, middle, or secondary education.
>
> *Out-of-field.* Out-of-field teachers have neither a major nor full certification in their main teaching field, a related field, or general elementary, middle, or secondary education. For example, a biology or life science teacher is teaching out-of-field if he or she has neither a major nor certification in biology, a related field (e.g., physics, chemistry, earth science), or general elementary, middle, or secondary education.

While these levels might reflect the different degrees to which a secondary teacher can be considered out-of-field, they do not support a very rigorous definition of an out-of-field teacher.

Starting with these definitions, “in-field” will be defined as a teacher with either major or certification in the subject area in which they are teaching. Therefore, an in-field physics teacher would have either a degree in physics or be certified in secondary physics teaching. This would indicate that the individual has taken 30-credit hours or more of physics coursework prior to entering the physics classroom. This will be identified as “In-field” throughout this study. A teacher who has the equivalent of a minor in physics (i.e. between 10- and 30-credit hours of physics coursework) will be identified as “Related field”. These are individuals, who through a major or certification for another science, were required (or chose) to take enough physics coursework to receive a minor in physics. These related fields are those such as, chemistry, engineering, astronomy, and other sciences (e.g. biophysics or geophysics). Individuals who took 10-credit hours or less of physics course work are considered to be “out-of-field” teachers. These majors or certifications include many life sciences and geologic science degrees.

While there has been much discussion regarding how to define an out-of-field teacher, the impact of an out-of-field teacher in the classroom is not well understood, and this is mainly due to the fact that “impact” is not something easily quantified, especially when measured by student scores on standardized tests, the most common measurement method. It has been suggested that an out-of-field teacher will rely heavily on the textbook and this might be what a standardized test best captures (Ingersoll, 1999). Therefore, if positive results on a standardized test are the measure of the success of teaching, it will not illuminate any negative learning outcomes present. Other consequences of out-of-field teaching suggested are: an inability to teach critical thinking skills, a lack of engaging student interest in the subject, a decrease in the amount of course preparation time a teacher has for other course taught, and having to cope with an addition to an already burdensome teaching load. These negative issues are more prevalent in fields that have higher than average out-of-field teachers. Since physics is typically cited as a field with a high number of out-of-field teachers (AAEE, 2005; Ingersoll, 2001; Neuschatz & McFarling, 2000) we would expect these issues to be present. However, the impact of out-of-field teaching in physics has not been an area of concern in the physics education research community.

Teaching Knowledge and Practices

Traditionally it has been difficult through research to show a link between a teacher's knowledge and classroom practices. This may be due to the fact that to a teacher what they do in a classroom and the different aspects of knowledge that influence those practices are already understood. (Schön, 1983). With many external pulls at a teacher (e.g. time, curricula, student achievement) it is not surprising that teachers do not connect their knowledge with their chosen practices.

Using interview data, Gunstone and White (1998) examined teachers' attitudes about physics classroom practice. They found three main influences that shaped physics teachers' attitudes towards teaching physics: beliefs about student learning, beliefs about the nature of physics, and beliefs about the purpose of education. The full study sample, described in Brass, Gunstone, and Fensham (2003), consisted of 14 secondary physics teachers in Australia. The sample contained a mixture of teaching experience (beginning and experienced), schools (public and private), and the number of physics teachers at each school (only teacher teaching physics and part of a team of physics teachers).

The interviews contained a series of 12 physics questions in which the participants were asked whether the question focused on "any aspects worth fostering" (p. 249). Interviewers first asked the participants to imagine their ideal secondary physics classroom in terms of student learning. After all 12 questions were asked the participants were asked to rank the questions in order of the quality of physics learning they demonstrated, and to place two questions on a continuum ranging from “utterly useless” to “absolutely terrific”, and were asked if there were any questions that should have been present and were not. The interviews were transcribed and a summary of participant responses was made for each of the twelve questions. The summaries were cross-checked in order to compare participant meanings for common expressions. For example, the phrase “linking physics to the real world” had different meanings for different participants. A set of aspects important to physics learning was settled upon after careful and repeated examination of the participant responses.

When the responses were examined in terms of attitudes towards physics classroom practice, the secondary teachers spoke mainly about their students designing and conducting their own experiments. They also mentioned the importance of linking physics concepts with students’ prior experiences outside the classroom. The types of classroom practices discussed by the secondary teachers represented a view of learning based in constructivism. To the secondary teachers the purpose of studying physics in high school was to develop an understanding of the world around them. For these teachers a view of learning is central. Gunstone and White (1998) briefly mentioned the impact of a teachers’ understanding of physics by making the general claim that “if a teacher’s knowledge is poor then his or her classroom practice is necessarily very limited” (Section D., p. 1). Tabanera (1996) found that, for university instructors teaching electricity, if they had a poor understanding of the concept themselves they used less analogies, avoided laboratories, used no student discussions, and no examples. Classroom practice for these teachers was limited to lectures taken from the textbook and demonstration of solutions to standard quantitative problems.

Summary

This study comes at a time when the conceptualization of what makes up PCK has settled on four main areas. These are a knowledge of: (a) science curricula, (b) assessment of scientific literacy, (c) instructional strategies, and (d) students' understanding of science (Lee & Luft, 2008). Thus the PCK framework for this study rests in a solid background of education research. However, when examining PCK within specific science disciplines, studies grounded in research are missing from the physics education literature. This study also fills a gap in the teacher education literature in looking at whether differences in PCK are present between teachers who are teaching in-field and those teachers who are teaching out-of-field. Due to the high number of physics teachers in this study who are teaching out-of-field, this study will contribute to the research bases of science education, teacher education, and physics education.

Chapter 3: Methodology

Overview

In his book on *The Foundations of Social Research*, Crotty (1998) lays out four basic elements of any research process: epistemology, theoretical perspective, methodology, and methods. Epistemology is defined as “the theory of knowledge embedded in the theoretical perspective and thereby the methodology” (p. 3). A theoretical perspective is a philosophical stance the researcher takes which informs the methodology and provides a context for the process. The methodology of the research program is the “strategy, plan of action, process or design lying behind the choice and use of particular methods” (p. 3). It also links those choices to the desired outcomes. Lastly, the methods are the techniques or procedures the researcher uses in order to gather and analyze data and are related to a research questions or a hypothesis. These four elements of the research process inform one another and this relationship can be seen in Figure 3.1, adapted from Crotty (1998).

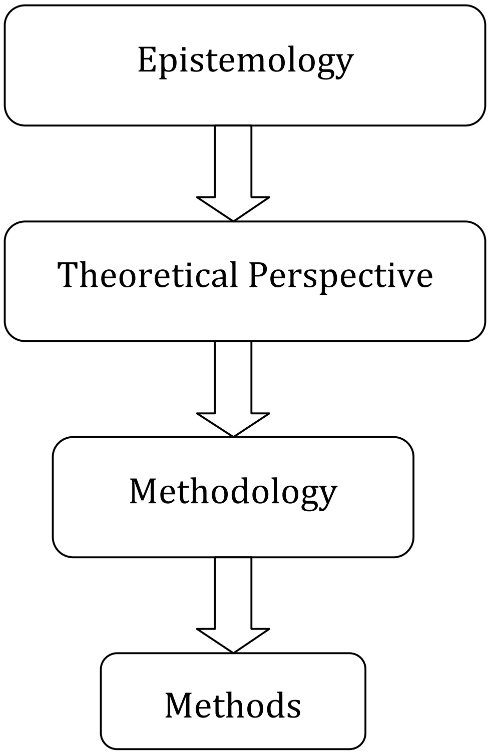


Figure 3.1. Elements of the research design process as conceptualized by Crotty (1998).

This study is framed under the epistemology of constructionism and the theoretical perspective of beginning teacher development. With a constructionist perspective, the assumption is that the subject interacts with his or her environment and this interaction fosters the development of the teacher. Crotty (1998) defines constructionism as “the view that all knowledge, and therefore all meaningful reality, is contingent upon human practices, being constructed in and out of interaction between human beings and their world, and developed and transmitted within an essentially social context” (p. 42). Knowledge is derived from everyday concepts and meanings (e.g. common sense terms and typical situations), whereby humans engage with their world, and in this engagement meaning is created. Human experience is therefore important in understanding an object, and the object cannot be described in isolation from the conscious experiencing it (Crotty, 1998). In order to understand the socially constructed meanings of participants, the researcher enters the everyday social world, reconstructs these meanings, and reports them in a social scientific language.

The theoretical perspective in this study is framed within early career teacher development. The model of teacher development that guides this work is based upon the continuum of early career teachers as suggested by Feiman-Nemser (2001). This model can be found in Table 3.1, which depicts the development of the beliefs, knowledge, and practices of an early career science teacher.

Table 3.1

Continuum of Professional Development Adapted From Feiman- Nemser (2001)

Preservice	Induction/Newly Qualified	PD
1. Examine beliefs critically in relation to vision of good teaching	1. Confront and revise/refine beliefs	1. Expand and fortify beliefs
2. Develop subject matter knowledge	2. Build coherent subject matter knowledge	2. Extend and deepen subject matter knowledge
3. Develop an understanding of learners, learning, and issues of diversity	3. Strengthen skill and dispositions to study and improve learning and teaching	3. Expand the ability to examine learning and teaching in a classroom, school or community
4. Develop a beginning repertoire	4. Enact a beginning repertoire	4. Expand and refine the repertoire for teaching
5. Develop the tools and dispositions for professional development	5. Develop a professional identity	5. Expand professional capacity and/or develop leadership skills

This model begins with the beliefs that potential teachers hold. There are several descriptions about beliefs, but they are often defined as personal constructs that are important to a teacher's practice; as they guide instructional decisions, influence classroom management, impact the representation of the content, and provide a lens through which to understand classroom events (Jones & Carter, 2007; Nespor, 1987; Pajares, 1992; Richardson, 1996). Even though the relationship that beliefs have to practice is not well understood, there is compelling evidence that beliefs should be considered early in one's teaching career in science (Jones & Carter). This can be attributed to the core and peripheral nature of beliefs (Rokeach, 1986). Peripheral beliefs emerge from core beliefs and are formed in response to new experiences.

The next component of the model pertains to the knowledge a teacher holds, which consists of content knowledge, context knowledge and PK. According to Abell (2007), who summarized the literature in science teacher knowledge, these three forms of knowledge are essential as teachers learn how to translate content into instruction. How these three forms of knowledge relate to PCK was discussed in Chapter 2.

For secondary science teachers, learning to teach one’s discipline occurs with opportunities to work with children in schools. These experiences are critical in learning how to transform content knowledge into appropriate learning experiences for children. Beginning science teachers build their PCK as they work in classrooms and are responsible for making instructional decisions based upon the learning of their students and the established standards (Lee, Brown, Luft, & Roehrig, 2007). In addition, as discussed previously, PCK can be general and address several content areas (general science), specific to one discipline (e.g., biology, chemistry), unique to a topic (e.g., heat, motion, evolution) (Veal & Kubasko, 2003). This variation is evident in beginning teachers, as they tend to build their discipline or topic PCK, while experienced teachers tend to hold a more general view of PCK (Carlsen, 1993; Sanders, Borko, & Lockard, 1993).

The methodology of a research study needs to be consistent with the epistemology and appropriate for the theoretical perspective. The methodology in this study will be a concurrent embedded mix-method design as discussed by Creswell and Plano Clark (2007). This methodology allows the researcher the freedom to use the most appropriate tools in order to make meaning within the data (Tashakkori & Teddlie, 2003), while also providing for the triangulation of data from different sources in order to enhance the richness of the data (Miles & Huberman, 1994). In this design (Creswell & Plano Clark, 2007; Plano Clark, 2005), a single method (e.g. exploratory or confirmatory) is used to develop the research question and guides the data collection. One primary type of data, either qualitative or quantitative is collected, with the other type of data providing a supportive, secondary role.

The chosen methods in this study consist of primarily qualitative data that will be quantized at certain points. These methods were selected as they provided a deep and rich characterization of the different teachers. When the qualitative data were quantized, it was possible to examine trends in certain areas. Data from both sources were ultimately merged in order to understand the development and differences of beginning secondary physics teachers.

The specific elements of the research process as conceptualized by Crotty (1998) and used in this research can be found in Figure 3.2, while the data collection and analysis can be found in Figure 3.3.

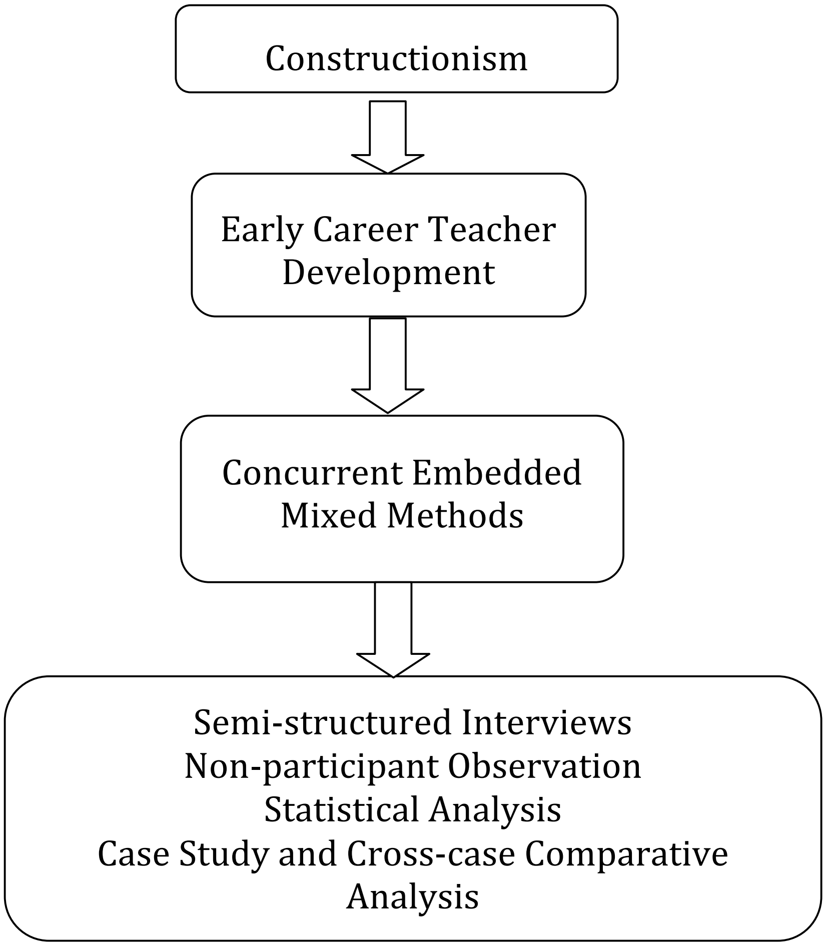


Figure 3.2. Elements of the research design process as conceptualized by Crotty (1998) describing the specific perspectives, methodology, and methods utilized in this study.

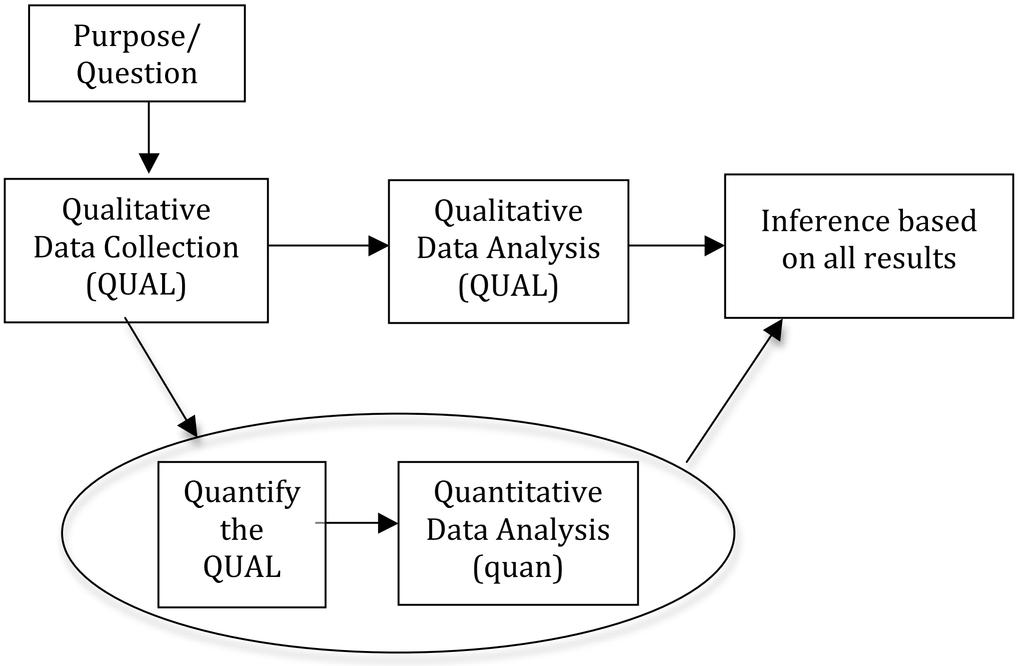


Figure 3.3. Concurrent embedded mixed method design, where the circle indicates the embedded piece and the all capital letters indicate the primary data source (based on Creswell & Plano Clark, 2007; Plano Clark, 2005).

Methods

Participants. This study is part of a larger study that is examining the effect of different induction programs on beginning secondary science teachers, however these conditions were not examined in this study. A description of this larger study was sent out to schools and districts in order to recruit participants teaching science in grades 8-12 in public, private, or charter schools in the summer of 2005. The study description included the purpose of the study and an explanation regarding the benefits of the study to the teachers. After indicating interest in the study a participant was contacted by a research assistant to gather a signature agreeing to participate in the study, and to describe the data collection process and the yearly stipend. Over 100 teachers were located in 2005.

From this pool of teachers there were 23 beginning secondary physics and physical science teachers. These teachers were located in the southwest, Midwest, and the west coast and taught in schools that have a varied number of English language learners and those receiving free and reduced lunch. The majority of the schools were public schools located in urban areas.

All of the teachers in this study taught physics at the high school level in either a physics or physical science course. A physics course is one in which physics topic and concepts are taught throughout the entire course. In a physical science course, physics is taught along with chemistry and often times earth and/or space science. The courses taught by the teachers were important, as the basis of classification of the teachers was based on their teaching assignments and their degrees. Teachers were classified into one of three categories based on their earned degrees indicating whether they were considered to be an in-field, related-field, or out-of-field physics teacher, as defined in Chapter 2. Additional demographic information for the participating teachers can be found in Tables 3.2 and 3.3.

Table 3.2

Background demographics of the study participants (N=23).

Total	
Male	9
Female	14
Type of school	
Urban	14
Suburban	4
Rural	5
Public	19
Private[1]	2
Charter[1]	2
Schools ≥ 30% ELL[2]	2
Schools ≥ 30% FRL[3]	11
Academic preparation	
BS/BA	4
MA/MS	11
PhD	1
Post-Baccalaureate	6
Number/type of preparations	
1	4
2	15
3	4
4+	0
Physics	9
Physical Science	16
Other Science	16
In-field	5
Related-field	7
Out-of-field[4]	11

Note: [1]A charter school is funded with public monies and freed from some of the rules, regulations, and statutes imposed on public schools (NEA, 2001), a private school is funded with private monies; [2]English Language Learners (ELL); [3]Free and Reduced Lunch (FRL); [4]Teaching out-of-field ≥ 50% of the time.

Table 3.3

Background of participants in the study

Pseudonym	Highest Degree	Degree Subject	Teaching Assignment	Teaching Status
Peter	B.S.	Physics	Physics	In-field
Sandra	B.S.	Physics	Physics*	In-field
Beth	B.S.	Physics	Physics/Phys. Sci	In-field
Jack	B.S.	Physics	Physical Science	In-field
Carl	B.S.	Physics	Physical Science*	In-field
Keisha	M.A.	Chemistry	Physics*	Related field
Celine	M.Ed.	Engineering	Physics*	Related field
Demetri	Ph.D.	Life Science	Physics*	Related field
Jessica	B.S.	Chemistry	Physical Science*	Related field
Lok	B.S.	Chemistry	Physical Science*	Related field
James	M.Ed.	Life Science	Physical Science*	Related field
Tyra	B.S.	General Science	Physical Science	Related field
Barb	B.S.	Chemistry Educ.	Physical Science*	Out-of-field
Jennifer	B.S.	Life Science	Physics/Phys. Sci*	Out-of-field
Daisy	M.Ed.	Life Science	Physics*	Out-of-field
Madeline	B.S.	Life Science	Physical Science*	Out-of-field
Tami	B.S.	Life Science	Physical Science	Out-of-field
Steve	M.Ed.	Life Science	Physical Science*	Out-of-field
Caleb	B.S.	Life Science	Physical Science	Out-of-field
Mandy	B.S.	Life Science	Physical Science*	Out-of-field
Dedra	M.Ed.	Other Science	Physical Science*	Out-of-field
Gavin	B.S.	Other Science	Physical Science*	Out-of-field
Caitlin	B.S.	Other Science	Physics	Out-of-field

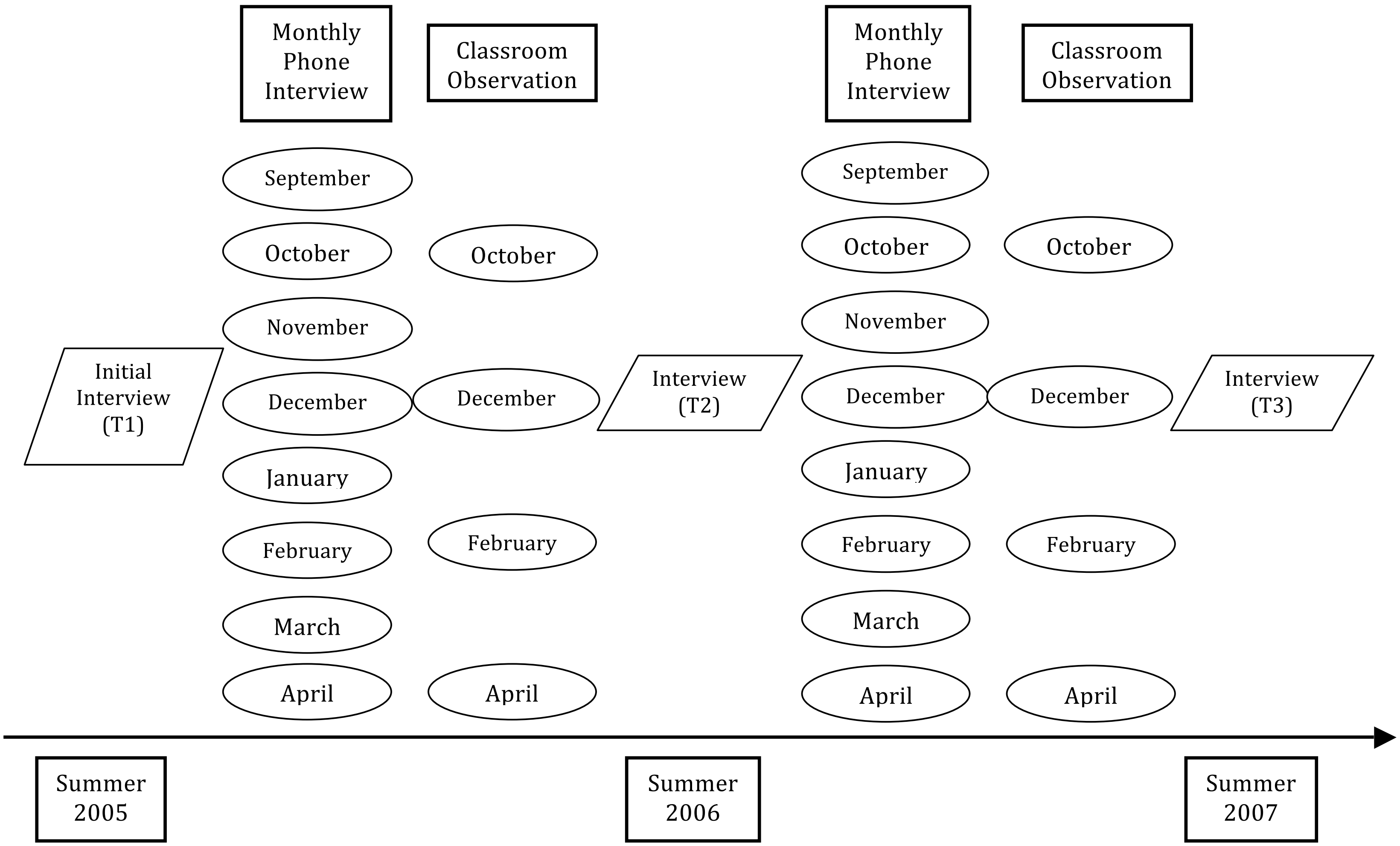
Note. * Teaches other subjects as well during the day (e.g. biology or earth science).

Data Collection Overview. The initial interviews in this study were conducted in the summer and before the teachers entered their classrooms for the first time. The same interview protocol was conducted during the summer in the following years.

Over the course of the year, each teacher in the study was observed four times and interviewed once a month. All of the observations and interviews occurred within specified two-week periods, in order to keep the data collection consistent. The observations were of one class period and the interviews about practices covered a week. At the end of each year there were 4 observations for each teacher and records of 40 days of practice.

A timeline for the research, including the data collection, can be found in Figure 3.4. Specifics on each type of collected data can be found in the next sections.

Figure 3.4. Data collection timeline.



Data Collection. There were several sources of data in this study, and they are described in the following paragraphs.

General Semi-structured Interviews. Research assistants conducted semi-structured interviews with the participants at the beginning of their first year of teaching (T1) and at the end of each subsequent year of teaching (T2, T3). Each interview included a set of general questions relating to the specific year of teaching. The interview before the teacher's first year focused on the teacher's educational background, degree program, mentoring program, new school and district, reasons for entering the teaching profession, and expectations of a new science teacher. The interviews after the first and second years of teaching focused on experiences during the year, reflections on the assistance provided throughout the year, and plans for the upcoming year. Participants answered these questions verbally with opportunities for the interviewer to ask follow-up questions. Each interview typically lasted between one and two hours and was digitally recorded. The different interview protocols can be found in the Appendix.

PCK Interview. During the summer interviews, PCK interviews were also conducted with the participants. The questions in the PCK interview were developed by Lee et al. (2007) and were part of the semi-structured interviews. The questions were designed to probe the instructional decision making process of secondary science teachers. The first question asks participants to describe what they think constitutes a good lesson in science. The second question asks participants to describe a successful lesson they have taught and probes for planning considerations, the content of the lesson, and the level of inquiry of the lesson perceived by the participant. The questions were subsequently revised during the main study, and the final protocol used in this study can be found in Appendix A. A description of the development of the interview questions can be found in Lee et al.

Concept Map. In order to assess the content knowledge of the teachers, concept maps were used. During each of the summer interviews, participants were asked to complete a concept map (see Novak & Gowin, 1986) corresponding to their degree subject. Specifically, all participants were given 10 words to use in the construction of the map, and instructions were given describing how to draw the concept map. The possible concept map subjects were physics, chemistry, biology, and earth science. Participants who received an elementary education degree were asked to complete the biology concept map. During the interview conducted in Summer 2007, participants were asked to complete a second concept map that included the original 10 words and up to 10 additional words of their own choosing. The protocol for this process can be found in Appendix B.

Weekly Update Interviews. Telephone interviews were conducted once a month during a two-week window. Participants were asked to describe five consecutive days of lessons for one specific class. The interviewer probed for the objective of the lesson, details of the activity (or activities) done on a given day, the organization of students during the activity, where the teacher obtained the lesson from, any materials or technology used in the lesson, and the types of assessment used. These topics corresponded to the observational protocol (see Lawrenz, Huffman, Appeldoorn, & Sun, 2002), which will be described in the following section.

During this interview, participants were also asked a number of semi-structured questions regarding their perceptions regarding teaching, professional activities, support, and/or usefulness of their preparation program. Probes included questions about how the participants generally felt things were going with their teaching that month, concerns they currently had, who they were currently receiving mentoring or support from, professional development activities they may have been participating in, whether their pre-service program had been helpful at that point in time, and for any additional comments they might wanted to add.

During the interview, the interviewer was allowed to ask additional follow-up questions regarding the lessons or in relation to any comments the participant made during the interview. During the data collection process, the data collection assignments were varied so that no individual collected all of the data from one teacher over a year.

Prior to the data collection process, all of the interviewers were trained to code interviews from the teachers. During this training, all interviewers had to achieve at least 90% agreement before interviews could be collected. All researchers were trained to identify the different instructional items to ensure validity. An example of this protocol can be found in Appendix C.

Classroom Observations. The research assistants observed participants four times during each school year. Each observation month, during a two-week window, research assistants visited several participants' classrooms. Only one period of class instruction was visited. Prior to visiting the classroom, participants were contacted to determine if a class was being conducted and the nature of the lesson. Observations were not scheduled for test days, days where the primary activity was a video or field trip, or shortened days. Any observations of this nature were rescheduled to a different day during the two-week window.

As the research assistant observed the classroom field notes were taken. These notes were descriptions of the instructional environment and often entailed the researcher sitting quietly in the back of the classroom watching and recording the events of the class. This protocol followed the recommendation by Bogdan and Biklen (2006). The field notes focused on the teachers' actions, the experiences of students, and the general events of the class. An example of the observation protocol can be found in Appendix D.

In this study, the author personally observed each of the teachers in one state in the southwest a minimum of one time. Given travel constraints, colleagues observed the participants located in the Midwest and the west coast.

Supplementary Materials. Whenever possible during the observations and after each weekly update phone call, supplementary materials associated with the lesson(s) were collected from the teachers. These supplementary materials included items such as handouts, worksheets, rubrics, and PowerPoint presentations. These materials served as support for the descriptions of the lesson(s) taught.

Qualitative Data Analysis.

PCK Interview Coding. Responses from the teachers from the PCK interview were coded according to a protocol suggested by Lee et al. (2007). This rubric rates PCK in two main categories:

1. *Knowledge of students*. This category includes consideration of students when planning a lesson and in teaching practice. This is expressed in terms of three sub-categories: (1) students' prior knowledge, (2) different levels of understanding, and (3) students' difficulties with specific science concepts (pre-existing misconceptions).
2. *Knowledge of instructional strategies, including science-specific strategies and topic-specific strategies*. This knowledge contributes to teachers' flexibility in adjusting their lesson plans to the classroom situations. It includes two sub-categories: (1) the quality of the inquiry that is present in the teacher's lessons and (2) how the phenomenon is represented in the classroom.

The rubric assigns interview responses a numerical value of 1, 2, or 3 for each sub-category, corresponding to a limited, basic, or proficient level of PCK respectively. In order to insure inter-rater reliability, two different researchers coded the question set and discrepant codes were resolved by discussion. Use of the coding rubric previously found an inter-rater reliability of 90% for the teachers and researchers used in that study (Lee et al., 2007). A discussion of this scoring process, the validity and reliability of the process can be found in Lee et al. (2007) and the PCK coding rubric can be found in Appendix E.

The results from this quantization process were analyzed with SPSS. A series of paired samples *t* tests were conducted to evaluate the effect of certification status (in-field versus out-of-field) and length of time (across two years) on the five PCK category scores. The dependent variable was the PCK rubric score (1, 2, or 3).

Concept Map Coding. In order to examine the teachers' physics SMK, the concept maps were analyzed in three areas: correctness, connectedness, and complexity. The coding scheme was developed by the research team during the summer of 2007, and followed the methodology of Hough, O'Rode, Terman, and Weissglass (2007). *Correctness* examines the general accuracy of the knowledge displayed by the teacher, and was determined by looking at the accuracy of each set of connected words. All links were assessed for correctness and were provided a rating between zero (the link was missing or incorrect) and four (the link shows a detailed and sophisticated understanding that is scientifically rich. The ratings were summed and divided by the total number of nodes to give a "correctness" value. *Connectedness* looks at the sophistication of the linkages between correct ideas, and was determined by first determining the number of correct "chunks". A "chunk" is defined to be a group of linked concepts for which the leading concept has at least two correct successors. The number of correct links for each chunk is then counted (cross-links are not included in this). In cases where links can be assigned to more than one node, the link that creates a chunk is always selected. Next the number of correct cross-links is determined and added to the number of correct chunk links. This sum is the "connectedness" value. *Complexity* is an evaluation of the depth and breadth of understanding of the 10 provided terms. This was determined by finding the "width" (the greatest number of concepts at one particular level) and the "depth" (the length of the longest chain) of the drawn map. A value for "complexity" was then found by multiplying the width, depth, and number of total cross-links found in the map. Therefore, with each assessment, three scores were given corresponding to each of the different areas of correctness, connectedness, and complexity.

In order to acquire the concept map scores, two different research assistants who have a background in physics, independently coded each concept map. With scores in hand, they met and shared their scores. When discrepant codes were identified, they were resolved through consensus (Miles & Huberman, 1994). An indication of the average link score was ultimately found by dividing the sum of the link scores by the total number of links. This process was based on the proposition accuracy and salience scores in Ruiz-Primo, Schultz, Li, and Shavelson (2001). The general rubric for the coding of the concept maps can be found in Appendix F.

In using this process, we were concerned with validity and reliability. The research group went through a process of discussion, testing, and refinement in the development of the rubric and then the determination of the values given to a particular concept map in the three different areas. By having two research assistants independently code each map we sought to ensure inter-rater reliability in the coding of the concept maps.

The concept map data were then examined in terms of correlations between the different measures for the sample of teachers. The teachers were sorted by their scores in each of the categories, as well as by the average link score per map. These sortings were then compared to the field groups each of the teachers were placed in based on his or her physics content preparation in order to look for consistency between the knowledge structure of physics of the teachers, as displayed by the concept maps, and physics content preparation.

Case Study Creation and Data Analysis. There were two different phases in the data analysis. The first phase involved the creation of case studies about the teachers in this project. Case studies attempt to shed light on a phenomenon by studying a single case example of the phenomenon in depth. The case can be an individual person, an event, a group, or an institution, and it can inquire into a phenomenon, population or general condition (Stake, 1995). This study looked at a collection of beginning secondary physics teachers in order to explore their knowledge, and how that knowledge is manifested in the classroom. The cases were bound by their being in-field, related-field, or out-of-field.

In creating the cases, all of the qualitative data were examined and placed into an analysis matrix following Miles and Huberman (1984). Each analysis matrix included different coding categories that were selected a priori to the data analysis or emerged during the reading of the data. The categories in the matrix that supported the development of the cases included:

- The support the teachers received from the induction program or mentors during the first few years.
- Indications of physics content knowledge: Information from the physics concept map and interviews regarding the teacher's knowledge of physics content.
- Salient information that pertained to the teaching circumstances of the teachers.
- Teacher's image of teaching physics: Thoughts about how to teach physics compiled from the general interview questions and the weekly update and/or PCK interviews.

Prior to putting the data into the matrix, an initial scanning of all of the data was first conducted to look for any additional areas to code. After an initial examination of the qualitative data another category was added, "teacher's image of teaching physics", in order to more fully understand how the teachers situate themselves in the profession of teaching physics. The data were then reexamined and organized within all of the categories in the analysis matrices.

A separate analysis matrix was composed for each year of the study (Year

1 and Year 2) ordered by field group. The next step entailed identifying emerging patterns within each group (LeCompte & Preissle, 1993). This involved comparing, contrasting, aggregating, and ordering of the collected data. The data between the field groups were also compared for what was different (LeCompte & Preissle, 1993; Miles & Huberman, 1994).

The reporting of each field case study followed Yin (1993). That is, a case description was developed as a framework for organizing the results. Through the description the most significant aspects of the case study will be addressed as well as basing the analysis on all relevant evidence. By using multiple sources of evidence patterns in the data were determined and reported. Following suggestions by Yin (1993) the cases are presented as a traditional narrative of multiple-cases within a single chapter (Chapter 4) with a chapter (Chapter 5) covering the cases as combined comparison. In this study the combined case comparison will be integrated with the quantitative results in Chapter 5.

In the second phase of the analysis, the data were quantitatively analyzed. These analyses were based on the second research question and specifically sought to understand how the different areas changed over time. The PCK interview data, coded according to the pre-designed rubric, were analyzed using descriptive statistics, a two-way analysis of variance (ANOVA), and paired samples *t*-tests in SPSS Version 10.0 for Macintosh and Microsoft Excel in order to look for significant changes in the five PCK categories across the two years. The weekly update interviews were analyzed using a frequency analysis in

Microsoft Excel. The results from the supportive quantitative analysis were integrated with the qualitative analysis results during the inference phase of the research.

Data Integration. As described in Creswell and Plano Clark (2007) the second stage of a concurrent form of analysis using an embedded design is to merge the two datasets. This integration of the data is done in a way in which "the supportive dataset can reinforce or refute the results of the primary dataset" (p. 136). In this study, the merging of the data was conducted through comparisons that were made among the datasets through examining the similarities of the quantitative and qualitative data results, and is reported through a discussion. In this way, Creswell and Plano Clark describe how researchers will report a theme and then provide quantitative results (or in reverse order). Chapter 5 will present the integration of the qualitative and quantitative data found in this study.

Validity and Reliability

In any research design there are potential threats to the validity of the conclusions. This is especially true in mixed methods research. Recommendations for reducing these threats by Creswell and Plano Clark (2007) include, collecting data from the same population, using unobtrusive collection procedures, and addressing validity issues in the quantitative and qualitative data. Each of these was followed during the design of the study.

In qualitative research, reliability is also known as dependability (Lincoln & Guba, 1985). Consistency of the qualitative data can be achieved by verifying the steps of the research through examination of the data, analysis, and process notes (Campbell, 1996). Lincoln and Guba (1985) and Patton (2001) have stated that reliability in qualitative research is a consequence of validity. All steps necessary were taken to ensure reliability and validity of the data collected.

There are different types of validity to consider in research and each was used to assess the quality of the conclusions made. Different types of data, qualitative and quantitative, have different types of validity associated with them because of the different ways in which the data are collected and analyzed. In general, we can look at four different types of validity: conclusion validity, internal validity, construct validity, and convergent validity. Each type of validity is concerned with a different methodological question. The validity concerns for this study included conclusion, construct, and convergent validity.

Conclusion validity is concerned with whether there is a relationship between the two variables. In this study, conclusion validity related to the validity of the relationship between the content knowledge of the teachers and the instructional practices they choose to use in the classroom. Internal validity asks, if there is a relationship is it a causal one. If no causal relationship exists, internal validity determines the rigor with which the study was conducted. Construct validity looks to assess whether an agreement is found between the theoretical concept and the measurements. In this study, I needed to determine whether the knowledge of the teachers (PCK and content knowledge) was actually measured as I set out to measure them. The different data sources allowed for convergent validity by examining whether multiple data sources produced similar results.

Limitations of the Study

There were three main limitations to this study. First, the teachers were recruited from the southwest, the Midwest, and the west coast. Therefore, there may be effects that are specific to these locations, which would make generalizing to all beginning secondary physics teachers difficult. Every attempt has been made to keep geographic differences from affecting the data through the data collection protocols, and it is believed that the teachers are all comparable regardless of his or her location.

Second, any inconsistencies found between the two types of data may be due to a few different issues. First, the interviews were coded by a number of researchers, in two different research groups and at different times. While every attempt was made to check the accuracy of the data by this researcher, not all inconsistencies were caught. By coding over a lengthened amount time, ideas about what the criteria were to place a response into one of the three levels of the rubric can and most likely did change. Especially difficult was the determination of the criteria for the categories of prior knowledge and student difficulties with specific science concepts categories, which was evident in the comparison of the results from the two data types. Future work with the rubric should include a richer description of what should be coded into each of the different levels so as to avoid ambiguity of coding.

Third, there is always a threat of researcher bias in the analysis of the data. Researcher bias can be introduced in the data analysis stage, especially with qualitative data. Since I have determined themes present in the data and compared responses between individuals and groups, my own bias may be reflected in the results. While every attempt has been made to remove researcher bias in the data analysis, it is possible that some remains. Any remaining researcher bias has been made explicit in the appropriate sections.

Chapter 4: Results

In the following sections, the analysis of the data will be presented. To begin with, the descriptive case of each field group is presented in terms of the results found through the analyses of the corresponding data matrix. The cases are presented in the following order: in-field teachers, related-field teachers, and out-of-field teachers. The quantitative data is then presented in the following order: PCK results, concept map results, and a summary.

Qualitative Findings

Case of the In-field Teachers. The in-field teachers were mainly characterized by geographical location, the degree subject, and their primary teaching subject (see Table 3.2). All of the in-field teachers were located in a Midwestern area, had degrees in physics with a post-baccalaureate certification, and taught introductory physics or physical science courses. The schools these teachers taught at varied from private schools (three of the five) to public schools in rural areas (two of the five). These characterizations changed slightly after the first year. Three of the in-field teachers remained in their schools the second year, however, the other two teachers switched schools after the first year. One teacher moved from being the only science teacher in a private school to teaching at a public school. The other teacher moved between two public schools due to issues he ran into with fellow science teachers and the courses the administration was asking him to teach the next year.

There were three main teaching behaviors the in-field teachers exhibited over the first two years of teaching. These behaviors reflected the physics content knowledge, PCK, instructional practices, and support systems of the in-field teachers.

1. The in-field secondary physics teachers had strong, consistent physics content knowledge that was evident in several settings.

While the number of physics courses was used to define the in-field group (and other two groups) of teachers, having participated in a physics class does not imply that one would demonstrate an appropriate level of understanding of physics concepts. Likewise, it does not preclude a teacher without the physics background through a degree program from having a correct understanding of physics. Therefore this group of teachers was examined for the level of physics content knowledge in the same way the other two groups of teachers were. Over the first two years of teaching, this group of teachers did demonstrate they had strong and consistent physics content knowledge. This was illustrated by the both the teachers' use of proper physics terminology and correct explanations to students, as seen in the concept maps, direct instruction, and in the answering of student questions. This was especially apparent through the observation notes as these teachers taught the content to their students. Many of the teachers presented material to the students in the form of notes, and the content in these notes was scientifically and physically correct.

For example, in his second year, Peter was having his students do a laboratory to calculate the spring constant for different springs. In order for students to accomplish the task they needed to understand how different forces sum to give a relationship of the force constant, k, to other variables. Peter correctly discussed with the students how to do this before they started the lab (Peter, Year 2, Observation 2). As indicated in the following transcript, the facts are correct and he presented the proper formulae in an efficient way.

> Peter: Before we begin, what forces are acting on the mass?
>
> Student: Gravity…
>
> Student: Spring force…
>
> Peter: What's the acceleration on that?
>
> Student: Zero…
>
> Peter: So if I'm going the spring constant on that…
>
> [He goes over the spring force and gravity force on the board]
>
> Peter: [writing the equation on the board]… "$F_s – F_g – 0$"… "-kx – mg = 0"… "m=kx/g". So that's how you get the slope… "y=mx".

Jack, another in-field teacher, also showed correct physics content knowledge when he went over the definition of work with his class (Jack, Year 1, Observation 2), albeit with a bit more humor and student engagement.

> Jack: Okay – who's big and strong? Okay Mike – c'mon up here. Try to push that wall over to the C-Wing. Looks like he's working pretty hard. Breaking a sweat. Was he actually working?

Student: No

Jack: Why?

Student: The wall wasn't moving.

Jack: In science, we define work a little differently than they do in the rest of the world. [He describes it in the business world] But in the science field, we define work differently – To put work on something, you have to be putting a force on something.

[Jack demonstrates by pushing a desk around]

Jack: To have that be work in the science way, there has to be force over a distance. Work is actually a very easy thing to calculate. It's a force multiplied by the distance. That's the official definition of a force in science. So we had Mike up here pushing as hard as he could. But there wasn't any work being done. Why not?

Student: There's no distance.

Jack: Right – the distance is zero. Force multiplied by zero is…zero. So in the official definition of work in science…it's not work.

Not only was the information presented correct, but the in-field teachers also organized information in thoughtful and logical progressions from lesson to lesson. The progression between topics in this groups' curriculum was indicative of an understanding of how major concepts in physics are related to each other and built upon one another. For example, when looking through the monthly interviews and observations, the in-field teachers generally began with motion (speed, velocity, acceleration, displacement, graphing, equations, projectiles, etc), then moved to forces and Newton's laws, and then work and energy. Some of the teachers chose to include other physics topics such as rotational inertia and angular momentum (Peter), thermodynamics (Carl), waves, light, and sound (Sandra), and electricity (Jack). Except for Sandra who started her year with properties of waves, light, and sound, the other topics were included after the main physics topics were covered, at the end of the unit.

While this may have been due to the particular curriculum the school's used this group of teachers often discussed how they had control over the organization of the curriculum, rather than having the topics scheduled out for them. This was most prevalent in Jack's discussion of he organized the topics over the course of the year. Even though Jack was provided the curriculum he was expected to cover, he had autonomy in how those topics were organized and taught, as he described in his first monthly phone interview, "there are curriculum that we have to cover – but it does not matter what order or how or how long I spend on stuff…rather teach physics first – start with energy and mechanics. Electron levels are hard – I don't know if kids know energy at all" (Jack, August 2006).

The concept maps backed up the observational and lesson plan information, since there were very few inaccuracies in the in-field group's maps. Any inaccuracies seen in the concept maps over the first year appeared to have been resolved by the end of the second year for the in-field teachers. Furthermore, the in-field teachers did not display many of the common physics misconceptions typically held by students, or even adults. For example, as seen in the concept maps, this group of teachers limited their idea of “heat” to being a form of energy or a way in which energy is transferred or changed. Only one teacher, Sandra, showed possible difficulties understanding heat when she described heat as having properties of waves and traveling through waves and fields.

The best example of the depth of physics knowledge in the in-field concept maps was how these teachers included the “fields” term into their maps. It was clear that the in-field teachers understood the connection between electric and magnetic fields with an electromagnetic wave, as well as the fact that fields are a commonly used as a visualization tool in physics. Jack consistently described waves as propagating in fields, Carl described electromagnetic fields as holding energy and oscillating to produce light, and Beth described how an electric current produces a magnetic field and a moving magnetic field produces a current. However, again, Sandra showed possible difficulties in understanding fields by connecting this term to heat. In her first concept map she described heat as an example of a field and in her second concept map she described heat as traveling through fields. Obviously, the maps, with their insistence on making connections between concepts, were a useful tool for the research.

Each participant drew three concept maps over two years. While maps revealed that this group of teachers understood physics, the maps also illustrated the range of abilities to organize the information. Carl was representative of an in-field teacher who showed the most complexity of knowledge organization across his first two years of teaching. His concept maps were nearly identical across his first two years of teaching and contained many complex phrases. Beth was representative of an in-field teacher who displayed a development in the organization of physics knowledge across her first two years of teaching. All three of Beth's maps were different from one another, showing changes in how she viewed the relationships among the given physics concepts. She moved from a very compartmentalized view of physics, where each of the given terms was simply topics under the main overarching concept of physics, to a more complex view of physics organized by Newton's Laws (T2) and Energy (T3). By the end of her second year of teaching, Beth showed a higher level of conceptual knowledge organization, as all in-field teachers did except for Carl. Sandra, however showed the least complex knowledge organization over her first year of teaching (she did not provide a concept map after her second year of teaching).

2. The general PCK of the in-field secondary physics teachers evolved over the two years of teaching and was impacted by the teachers working with students.

This second area of teaching behaviors with the in-field teachers concerns PCK – the ways it evolved over the two years studied and how student interaction affected PCK positively. It is clear that there is a progression from a concern of transmission of content and classroom management to a focus on student knowledge and learning. This progression was manifested by the teachers' improved ability to anticipate students' prior knowledge and difficulties in physics. However, this group of teachers showed more of a growth in the consideration of the difficulties students would have with specific physics concepts, while they did not grow as much in their ability to predict the prior knowledge students brought with them to the classroom.

While growth did occur in prior knowledge prediction, the progression for the in-field teachers was minimal. They did move from having a superficial understanding of student's prior knowledge to utilizing ways to probe students' prior knowledge that would inform their own teaching. Decisions about the prior knowledge held by students were made based on concepts previously taught in a prior unit, concepts assumed to have been taught by a previous teacher (either through conversations with other teachers or in consulting the standards for previous years), what the in-field teachers assumed students of a particular age should or would know about the specific physics topic, or through assumptions made regarding students prior life experiences. Language used by this group of teachers when speaking about students' prior knowledge revolved around how much they "assumed" the students knew.

For example, in the semi-structured interview before teaching his first year, when probed about whether he considered students' prior knowledge in teaching about momentum, Jack states that the students

> "had learned velocity and mass, and they knew it could be positive or negative…and they knew about it but hadn't had to deal with it

> before…other than that I assumed, maybe wrongly, that momentum was a term in students vocabulary" (Jack, T1).

After Jack's first year of teaching, when he spoke about the consideration of students' prior knowledge in terms of teaching electricity, he "assumed they had either no prior knowledge or many misconceptions. I didn't know what misconceptions…didn't probe. I used my own learning experience to design this part of the lesson. I didn't consult the middle school science curriculum to inform this" (Jack, T2).

When specifically probed on whether he considered his students' prior knowledge over his first year of teaching, Carl stated that he

> "didn't really assess for prior knowledge…I did a lecture and tried to ask questions about what they knew or not…I didn't assess for prior knowledge very much. It takes time and I always felt behind the 8-ball just planning for the next day" (Carl, T1).

By the end of his first year of teaching when Carl is asked about this same issue, he begins talking about how he incorporates students' prior knowledge by relating topics to real life examples and experiences. However, when pressed Carl states

> "Honestly, I don't consider prior knowledge that much. I probably should. I am grasping for straws here…it doesn't really go into my planning process much, evaluating prior knowledge or bringing it into play. But I guess it probably should, now that I think about it" (Carl, T2).

By the end of the second year this group of teachers was beginning to realize they could (and should) probe students for prior knowledge rather than making assumptions. This realization matured as this group of teachers worked with students over the first two years of teaching. As an example, Beth, who like Jack and Carl assumed students knew certain information when she taught her first year, was now able to think about probing her students' prior knowledge prior to teaching a lesson. As she described in the semi-structured interview after her second year of teaching,

> "Part of, at least in this lesson, um, my asking them to generate questions ahead of time. That really helped me get at not only what were they interested in, but a little bit of what did they already know. I asked them to write down something they remembered, but, you know, I could ask them to write something down that they remembered from the previous day and they'd all give me nothing. But getting them to ask a question really gave me a good indication, at least on some of them, about what they already understood." (Beth, T3)

Yet, even though this group started out having had difficulty in the consideration of students' prior knowledge, they were able to consistently identify areas in physics in which students would have difficulty with the subject matter, and after teaching for two years began recognizing this area as important to their teaching of physics the more time they spent with the students. As the teachers discussed the different student difficulties with specific physics topics, they also discussed different strategies used in their classrooms to address these difficulties with the students.

After the first year of teaching, the in-field teachers were able to move out of “survival mode” and begin to focus on their curriculum and their student’s learning. Carl recognized that he was acting mainly in a “survival mode” during his first year. At the beginning of his second year, when asked how this year was different than the previous year, Carl stated, “…I really want to get out of the survival mentality and really start modifying stuff and making really excellent lessons…” (Carl, Weekly Update 1, Year 2).

Throughout the second year when asked how things are going, Jack talks about how he is better able to focus on students, curriculum, and assessment rather than just surviving. Jack discussed the difference between his first year and the start to his second as one where he was able to think past classroom management and last minute curriculum changes. He describes himself as,

> More confident, in at least the management part. Still not where I would ideally have it be…it’s getting a lot better…um, I’m absolutely more confident in my curriculum as well…It’s a lot more smooth this year I think. And I’m able to change things now that last year I didn’t have time to change. I know better now what kind of…with the students, what hangs them up…concept wise, where their misconceptions are, I’m getting the hang of that a little better…um, and also, just general procedural things, you know, during lab and things like that…that’s a lot better this year.

> [Things that] make it easier to go home at the end of the day and say I did a good job. (Jack, Weekly Update 1, Year 2)

Continuing through the second year, Jack mentions many examples in the monthly phone interviews of his shift into focusing on students. In the second phone interview during the month of September Jack discusses his opinions on the new textbook the school had chosen. He believes it to be too advanced for the students and covering material in too much detail. Later in the year he moves to talking about feeling "comfortable moving at different paces with all my classes. I feel better able to see what the students needs and move at their pace" (Jack, Weekly Update 3, Year 2). This is not something considered by Jack, nor any of the in-field teachers, during the first year of teaching.

3. The in-field teachers initially drew upon experiences in their own physics classes as a model for teaching physics. Over the first two years of teaching, the focus of instruction began to shift from traditional physics instruction to more student-involved instruction and student understanding of physics. However, a disconnect emerged between how this group began to believe physics should be taught and traditional physics practices often pushed by district or school curriculum.

The in-field teachers displayed a change over their first two years regarding their image of what constituted the teaching of physics. Initially, this group of teachers began teaching physics in a very authoritative, transmissive manner. When discussing the relationships among different physics concepts, the in-field teachers relied heavily on mathematical relationships, rather than conceptual relationships. The physics units initially included a strong focus on practicing the solving of equations, data collection, and graphical and analytic analyses. While students were able to participate in activities that would be considered “hands-on”, the procedures for the completion of the activities were frequently given to the students. Assessments focused on summative measures of physics knowledge in the form of quizzes, multiple choice tests, and short answer questions.

Even by the end of their second year of teaching, there was still a strong focus on the mathematical relationships among the different concepts. While the planned activities began to reflect a movement towards a focus on what and how the students were learning physics, many of the homework assignments, worksheets, laboratories, and assessments were still dominated by problem solving practice. However, a change was seen in the in-field teachers’ practices through the way in which the teachers discussed material with their classes before and after these activities, and in the way in which questions were asked in the analysis areas of the activities. Questions presented to the students through class discussions and data analysis activities were more conceptual and open-ended after the second year of teaching. Students were also given more opportunities at this point to conduct their own research projects and through activities, which reflected more scientific inquiry practices, rather than directed inquiry or verification activities.

During his second year of teaching, Jack started one of his lessons on Newton’s Laws by having the students complete problems on whiteboards. After students attempt the first problem Jack goes over the solution by saying, “you have to use Newton’s second law…the equation is F=ma, so we need a mass and an acceleration” (Jack, Year 2, Observation 2). However, later on in the problem solving activity, Jack does realize that students are having a difficult time with the conceptual understanding of Newton’s second law, not just the mathematical understanding. He tries to give examples of velocity, force, and acceleration and then tells students that “the most important thing to think about is Newton’s second law says that if there is no acceleration, there is no force” (Jack, Year 2, Observation 2). Here Jack tries to push students into moving past the equation into a more conceptual understanding of the second law.

There thus appeared to be a disconnection between how this group of teachers spoke about their physics lessons and how they actually taught the concepts. Throughout the first two years of teaching, this group spoke at length in the interviews about incorporating different types of activities for students and including elements of scientific inquiry in the lessons. These different elements included students asking their own questions, developing their own procedures, putting together the information on their own, and coming up with their own conclusions based on their data. It was clear that this group of teachers struggled with how they had been taught physics throughout their own coursework and how, in their preservice and professional development programs, they were being "taught" to teach science.

Many of the teachers attributed influences in how they taught physics to their undergraduate physics coursework or their own experience in research. As Jack stated in the interview after his first year of teaching,

> I would say the research I did as an undergrad. It has a profound impact on how I view education. There were several projects I worked on as an undergrad (cosmic microwave background project)…I got a real sense of doing things more hands on. I had a lot of theory, now I could visualize the phenomena. This helps me to visualize and build more analogies, which helps my teaching. The lab provides me both the time and experience to make sense of things. I think the generic side of things comes from my research experience – Methods of Experimental Physics – not much resources, so we had to make it, and improvise. This had helped me think of making things for my class without many resources. This experience has enabled me to be the teacher I am. (Jack, T2, General)

When pressed however, in the context of teaching science, these teachers attributed their views of using inquiry or specific learning models (5E inquiry model or layered curriculum) to their education coursework. Throughout the first two years many of the in-field teachers struggled with the curriculum their schools used versus their vision of teaching physics and science. Carl discussed his curriculum struggles from the beginning of his second year of teaching. In his second phone interview during his second year of teaching (after moving to a new school), Carl describes the curriculum as “too cook-booky and uninspiring” and that the students just “learn facts and regurgitate”. He continues talking about how he would like to

> “try to modify next term, right now I don’t have time and I am in survival mode. I would like to do things that are more inquiry based, and inspiring. I can do the same material in more depth or assign more material. The other thing is being a first year teacher, I don’t want to just go in making change, in the first year I want to do okay and worry about myself, my content mentor has already done some stuff.” (Carl, WU2, Year 2)

Carl also drew on his own experiences in physics as an influential source in how he spoke about teaching physics. Carl talked about how he “loved solving complicated physics problems in his degree program” and that his “idea was to foster this problem solving ability” (Carl, T2) in his students because he “enjoyed it and it enhanced his understanding” (Carl, T2). These experiences influenced his “impression of what teaching was like and going to be more about”, and he was “more interested in teaching critical thinking and problem solving than actual science knowledge” (Carl, T2). In teaching physics, Carl’s goal was that he “wanted them to be able to explain physics concepts in their own words, solve simple problems, describe principles and how they are applied to worlds around them” (Carl, T2). He also wanted his students to be able to “design open-ended labs that were true demonstrations and application of their knowledge or using their knowledge for analysis" (Carl, T2).

Another example of the influence of previous physics coursework on how these teachers taught physics in their own classroom was described by Sandra. Sandra tried to "incorporate the activities that she has done and enjoyed" when teaching her physics class. She was originally in a general physics program when she decided to become a physics teacher. She reflected that once she had made the decision to teach she "didn't think that increasing her content knowledge would help her with teaching" like upper division quantum mechanics, "so she focused on other things" (Sandra, T2). Sandra believed that the "research classes would help her more in her teaching than upper level theoretical classes" (Sandra, T2). Her second year in the classroom Sandra made the decision, along with her fellow physics teachers, to change the order in which they taught the physics content. They "switched up the order" of how they did things and started with waves (sound then light) and optics the first trimester, moved onto mechanics the second trimester, and concluded with forces the third trimester. Sandra felt that by doing this "it seems to be better…not bogged down with math right away" (Sandra, T3), however this was her first time teaching waves.

It is clear that the in-field teachers evolved, albeit slowly, in PCK across their first two years of teaching. This was especially evident in their consideration of students' prior knowledge and difficulties with specific physics concepts. However, the in-field teachers were more likely to teach in ways that they had been taught physics throughout their educational career, which was contradictory to how they were taught to teach science through their pre-service certification programs and their professional development experiences. This group of teachers also started with strong, consistent physics content knowledge, which was manifested through many different settings (interviews, observations, and concept maps).

These characteristics were different when moving to the physics teachers who were exposed to less physics content instruction through their degree programs. The related-field teachers, defined to have essentially a minor in physics, displayed different behaviors when examining the issues of physics content knowledge, PCK, teaching practices, and views of teaching physics.

Case of the Related-field Teacher. The related-field teachers were also characterized by geographical location, the degree subject, and their primary teaching subject as seen in Table 3.2. The schools were varied in their demographics with some being large schools, some in high and some in low economic areas, two schools were located around a large Midwestern city with the rest located around a large Southwestern city, and all were located in urban areas. In the first year of teaching the related-field teachers were generally assigned to teach physics or 9th grade physical science. Five of the seven teachers were also asked to teach another science (chemistry, geology, or biology) class in addition to the physics or physical science class. One teacher was asked to teach mathematics in addition to the physics she was teaching. Four out of the seven teachers were teaching in a school that was on a traditional bell schedule with an average of 47 minutes available for physics instruction every day.

The teachers and school characterizations changed slightly after the first year. One teacher moved from a large, high economic area school on a semester block schedule to teaching at a smaller, lower economic area school on a traditional bell schedule. One teacher left the study after the first year because she moved into teaching only mathematics, while another teacher left the study halfway through the second year because she left teaching to go back to working in industry.

Indications of Physics Content Knowledge. Due to the nature of the concept map collection, most of the teachers completed a concept map for the discipline in which they had received their degree, rather than the course they were primarily teaching. Therefore only one of the related-field teachers completed a set of physics concept maps. Any indication of the level of physics content knowledge held by this group of teachers came from their description of their lessons in their weekly phone interviews, the classroom observations, and artifacts provided by the teachers relating to the lessons taught.

There were three main teaching behaviors the related-field teachers exhibited over the first two years of teaching. Just as was seen with the in-field group of teachers, these behaviors reflected areas of PCK, instructional practices, and images of teaching physics.

1. The general PCK of the related-field teachers showed very little evolution over the two years of teaching, especially in the teaching of physics.

The first area of teaching behaviors exhibited by the related-field teachers was related to PCK. For this group of teachers the consideration of students' prior knowledge in physics was either absent or only slightly considered. Like the in-field teachers, many of the related-field teachers made decisions on the prior knowledge held by students based on concepts that were previously taught by themselves or a previous teacher or what the related-field teachers assumed students of a particular age should know about the specific topic. For example, Demitri was told before he started that his "students were at a 3rd or 4th grade level…so approach as if they had no background knowledge" (Demitri, T1), and that is how he approached his students. However, different from the in-field teachers, this group of teachers also made decisions regarding prior knowledge based on the assumption that students had no knowledge before they started or that they had very particular knowledge about the concepts, especially in relation to equations and mathematical background.

One difference between this group of teachers and the in-field group was that a large fraction of related-field teachers spoke about ways in which they probed students during lessons during their first year of teaching. Common prior knowledge probing practices discussed and demonstrated by these teachers included having students make predictions before demonstrations, talking about prior knowledge during demonstrations, asking students questions during the introduction and writing student answers on the board (sometimes done the day before), and giving pre-tests.

Lok and James were unique in how they determined and used students' prior knowledge through their teaching. Lok used his own experiences to determine what his students' prior knowledge would be. He commented that "from his own experience of how he's learned to solve problems and experiences in teaching…can guess what they know from physical science, although he may need to re-teach it" (Lok, T1). James talked about a lesson planned by a group of teachers that used the students' prior knowledge in order to avoid having to lecture for the entire 90-minute block period. He commented that the reason they put the students into groups was "because I wasn't 100% sure what they would know…and as a group they were able to piece together from what they already knew" (James, T1).

Given that many of the related-field teachers were already probing student prior knowledge during their first year there was a slight shift moving into the second year of teaching. After their first year teaching the related-field teachers talked about using opening questions in order to probe for prior knowledge, listening to the way the students talked every day, and by what they had just been taught previously. Similar to what Jessica was doing throughout the first year, James now spoke about how he had his students write down a prediction before showing a demonstration, and then having the students compare their prediction to the result after the demonstration. However, he did acknowledge that "their prior knowledge wasn't as important to him as how they were able to understand what was going to happen and why" (James, T2).

There was very little shift of the related-field teachers regarding prior knowledge after the second year of teaching. The teachers in this group continued to talk about students' prior knowledge in similar ways to how they did over the first year. Demitri spoke about how he probed his students through an anticipatory set, making as much of a discussion as possible, or giving quick true or false tests that he goes over as a class. He uses the information from these to know where he will need to spend more time on things his students didn't know. Tyra was an example of one of the teachers who used the students' knowledge of the world around them. She gave a specific example of using a video in order to connect the students' knowledge of the real world and link it to the atom. James, on the other hand, believed that his students "started out at such a basic level" that they only had "practical knowledge of Newton's Laws" (James, T3).

This last statement shows how consideration of students' prior knowledge is also connected to an understanding of student difficulties with specific physics concepts. As another example, Celine talked about the different things the students had already learned (systems, drawing bar charts, conservation of energy), but she also spoke about how students have difficulty understanding that energy is all the same, just in different forms. However, she did not mention how she knew this, whether it was an assumption or something she probed for.

The related-field teachers spoke about many different ways in which they considered students' difficulties with specific science concepts over their first year teaching. In relation to teaching atomic structure, Lok talked about how he "used visualization because he expects it to be difficult" for his students, and they "need to see the orbitals overlapping" (Lok, T1). He anticipated that the students were not going to be able to learn the material through reading alone, and made the comment that it was "hard for college freshman to even visualize" (Lok, T1). However, after the first year of teaching, when Lok was talking about planning his lessons, he reflected that he "didn't know how many misconceptions students would have" (Lok, T2). He thought that the project he planned "would bring out misconceptions" and that "the other groups would help bring understanding out". Lok also "built in time at the end of the unit to debrief and add what information he thought was missing" (Lok, T2).

Jessica spoke about a gas law lesson in the interview before she taught her first year and recognized that "gas laws are tough because you can't see molecules in the air or go to the moon to see less molecules" (Jessica, T1). Her strategy was to "bring in every day, real life experiences" in order to address difficulties. Jessica also stated that she came across misconceptions during class discussions, rather than planning for them ahead of time. After her first year teaching, Jessica acknowledged that she tried to figure out her students misconceptions as she went along because, like Lok, she "didn't know what would give them trouble beforehand" and "now she knows what will give them trouble in the future" (Jessica, T2). James also commented that he was not "100% sure" how his students would be able to handle the vocabulary when planning the lesson he described, and this was "part of the reason they were put into groups" (James, T1). After his first year of teaching however, James talked about how he would sometimes use a pre-test that would ask about the concepts he was going to present. He would then go through it with his students and "see what ideas they had and then talk about them" (James, T2).

Demitri initially started off his first year by "planning on the assumption they have no scientific knowledge" (Demitri, T1), however, by the end of his first year Demitri was able to identify specific places the students would have trouble, such and understanding why cells divide. Celine, like Demitri, started of her first year of teaching with only the "though about what the students had already been taught and should know" (Celine, T1). However, by the end of her first year Celine had included a section in her lesson plans that identified the common misconceptions that she was addressing with her particular lesson. Celine gave a specific example regarding students' ideas about energy in relation to the energy lesson she discussed in her interview. She commented on how her students believed that "energy changes from one form to another, when that is not really the truth" (Celine, T2). She stated that "energy is transformed or stored…energy is the same no matter where it is at…it is still energy" (Celine, T2). This is the misconception that she addresses in her lesson by having her students confront "the truth" through the activities. When prompted Celine states that she knows her students hold this misconception “by the way they talk about it…when they present their whiteboards” (Celine, T2).

After the second year of teaching the related-field teachers again refer to the different activities they do in their classroom to address student difficulties with specific science concepts. They do not comment specifically and where students might be having difficulties. James talked about how he “always questions to specifically bring to their attention” (James, T3) the misconceptions that they hold. Tyra spoke about how science is “probably a new language for them”, so as with “anytime teaching a new lesson” she utilizes strategies such as “memorization, name association, and memory games” (Tyra, T3). Demitri, knowing that students would have difficulty with “the whole idea of genes”, has a “day for independent work” that he uses “to meet individually with students to be sure they understand” (Demitri, T3).

2. Over the two years of teaching the related-field teachers demonstrated traditional approaches to teaching physics. These approaches included lectures, problem solving, reliance on equations, and textbook work.

The related-field teachers did not show much of a change over the two years of teaching in their approaches to teaching physics. Through the monthly phone interviews and the classroom observations it was clear that this group of teachers were most comfortable using traditional teaching methods when teaching a discipline which is only related to their discipline of certification. Through this data it was also clear that while the physics content may seem correct, these traditional teaching methods did not force the related-field teachers to fully understand the physics concepts they were teaching. For example, those that presented PowerPoint lectures could have correct material taken from various sources, such as the textbook, and just read the material to the students not fully understanding the material themselves. This was evident during the classroom observations of Lok over his first two years of teaching. Lok was observed teaching the concept of energy during both years of teaching. The first year he presented a PowerPoint lecture with definitions and equations. He had the students simply writing down the notes from the slideshow with a few examples in between slides. The students had previously done an activity taking measurements with trebuchets, and much of the lecture revolved around presenting the equations for the trebuchet calculations – weight, maximum potential energy, speed of the ball – with many of the calculations being very complicated.

His second year, Lok again presents a PowerPoint presentation of definitions and equations. When he presents the material this time, however, he talks more than in the previous year. He tries to put in many examples, but still ends up traditionally lecturing the class. Many of Lok’s examples also do not connect to one another during the lecture. For example, in the introduction to the energy lecture Lok is quoted as saying,

> The definition of energy is the ability to do work. The light bulb by itself cannot work without energy. Some of us, if we are starving and don’t have

> food, we can’t get up and go to work because we do not have energy. So like [student’s name] said, power and energy are related. But a powerful car cannot work without gasoline which is chemical energy. Work, what we see as work, is just changing energy. For example, you have a baby that does not grow, the body does no work. But you see the baby 5 years later, it is bigger, it is a kid, it has used food energy to grow. Energy is the ability to change over time. When you see something working, it is changing energy from one type to another. So the projector is putting out light, it is doing work; it is changing electrical energy to light energy. So what do we consider work? Just energy changing. The universe does not allow us to destroy or create energy most of the time, it changes. Doing work is the process of transferring energy. Think of energy like money. Nobody here wants to destroy their money. But if you go to another country, you want to change it into their money. If you go to Japan, you don’t want to rip up your money, you want to transfer it to Yen. (Lok, Observation 4, Year 2)

This example shows how even a teacher who is in a field related to physics, and therefore has enough coursework in physics that they essentially have minor in the subject and should understand the concept of energy, has difficulty understanding the material himself, teaching the material in an engaging way, and making connections for the students through his teaching. This was something that was seen throughout the related-field group of teachers.

Regardless of when this group of teachers was probed, through the monthly phone interviews and the classroom observations they demonstrated teaching methods that were traditional in nature. The related-field teachers showed many of the same common classroom practices as the in-field teachers over the first year of teaching. Those activities practiced by all related-field teachers were: general lecture (three used PowerPoint) with student discussion, verification and directed inquiry laboratories, and reading and working from the textbook. Five of the seven related-field teachers commonly used worksheets and demonstrations as part of their daily practice. Other practices used by this group in the first year included videos, skill-based and guided inquiry laboratories, and student presentations.

Over the second year of teaching this group of teachers showed similar most often used practices. All of the related-field teachers over the second year used: general lecture (three used PowerPoint) with student discussion and verification and directed inquiry laboratories. Five of the six teachers used worksheets in their daily practice. Other practices common to this group over the second year were skills-based and guided inquiry laboratories, demonstrations, reading and working from the textbook, and videos.

While the teaching methods demonstrated by the related-field teachers were mainly traditional, when probed in the semi-structured interviews the teachers focused on a greater variety of practices. The strategies mentioned included demonstrations, talking about the material, writing material on the board, lecturing, reading, laboratories, and direct questioning. Most of the teachers, like Keisha, felt that they wanted to "try to teach on all different kinds variations" (Keisha, T1) by "making sure [the students] have different opportunities to learn" (Keisha, T2). However, other teachers acknowledged that they did not really consider different variations in teaching physics, other than that they wanted to do something other than lecture.

There was a slight shift in the way that this group of teachers spoke about the different teaching methods they wanted to employ in the classroom after the second year of teaching. Most of the related-field teachers mentioned the same strategies they had earlier; however there was now an increased focus on visual and hands-on activities in their descriptions. For example, Demitri talked about how he always does PowerPoint so he has visuals, can tell the students the information, and can present in as many ways as possible. However, other teachers in this group believed the subject matter lent itself to traditional methods of teaching, and therefore they did not seek other ways to teach physics to their students. For example, James spoke about how he did not consider any variations in approaches to learning physics "because things were so straight forward" and that "he would like to see anyone who would do it otherwise with more success" (James, T3).

3. While it was difficult to determine this group's images of teaching physics due to the nature of the data, many of the teachers spoke about teaching physics at some point during their two years of teaching. Their comments

showed a struggle with teaching techniques they were being asked to consider and what they were experiencing in the classroom.

It was difficult to determine this group's images of teaching physics through the data used for this study. However, during the first two years these teachers were followed for the study, many of the teachers discussed struggles they were experiencing in teaching physics. These struggles revolved around issues such as classroom management and curriculum choices. Many of the teachers began to talk about different approaches to teaching physics by the end of their second year, however as previously mentioned in this section, there was no indication that the teaching practices of these teachers changed over the two years.

Lok spoke the most about his ideas for teaching physics through his first year in the classroom. In his seventh phone interview that year, Lok mentioned that "the cooperative groupings aren't working for me, so I will try something else" (Lok, March 2006). He felt that he needed to "have control in classroom management" and that what he was currently doing was allowing the students to be off task too much. Lok believed his main goal was to "help his students have a basic understanding of the content, topics, of things he teaches" (Lok, March 2006). During the interviews before and after his first year of teaching Lok spoke a lot about how topics, such as atomic theory, "needs to be very visual with lots of pictures and models to make it clear to the students" (Lok, T1). He believed that you "learn science best by doing or solving something" and that he "likes to have students learn by trial and error", by giving "easy examples or analogies", and that he "doesn't mind giving an explanation again eve if there are several people who got it" (Lok, T2). After his second year of teaching Lok reflected that he "feels more comfortable teaching physical science because the third time is easier" and that he would "like to incorporate more activities" (Lok, December 2006).

Celine's image of teaching physics comes from having taken physics modeling (Hestenes, 1987) workshops at a local university (a methodology for teaching physics). One reason she liked participating in the program was because "we go through the program like students and we can apply this in our classroom" (Celine, June 2006). Celine applied the modeling method very rigidly in practice. She took this curriculum as the only way that physics could be taught and did not deviate from it in her first year and a half of teaching. It is possible that Celine taught using only one physics curriculum because it was the one she was most comfortable using. However, while the modeling method of instruction claims to be focused on multiple representations of physics (including graphical, mathematical (algebraic), and diagrammatical), Celine tended to focus most on a mathematical representation over any of the other representation of physics. For example, many of her lessons involved hand-on activities or laboratories. These were always followed up with a worksheet, which focused on the mathematics of the physics concept.

In every one of Celine’s monthly interviews she mentions how much she liked this method of teaching physics. Yet, it was clear from the classroom observations that the students did not respond as Celine would have hoped using this method of teaching physics. In all of the observations, students in Celine’s classes were observed off task. Many would be doing something on one of the computers that lined the edge of the classroom while Celine was “teaching”. While this most certainly was a display of the level of classroom management Celine possessed, it also was a result of Celine so rigidly following the modeling curriculum. Many times during the observations it appeared as if Celine was just “going through the motions” rather than actively seeking to engage the students in the subject matter. At one point Celine even had trouble with a parent telling her that this method is “not teaching” (Celine, November 2005).

Because of the nature of this group of teachers it was difficult to tease out many of the same teaching characteristics as was found with the in-field teachers. This group of teachers were teaching more than just physics or physical science, and therefore talked about all of the subjects there were teaching, rather than focusing on just one class. However, through the analysis it was clear that this group of teachers considered prior knowledge in a more diverse way than the in-field teachers, had difficulty talking about specific problems students might have with physics topics, taught physics very traditionally, were more focused on specific curriculum rather than on developing their own activities or lessons.

These trends become more pronounced as we move to the out-of-field physics teachers in the next section.

The Case of the Out-of-field Teacher. The out-of-field teachers were also characterized by geographical location, the degree subject, and their primary teaching subject as seen in Table 3.2. The schools were varied in their demographics with some being large schools, some high and some low SES, three located in a rural area, and four schools were located around a large Midwestern city, with the rest located around a large Southwestern city. In the first year of teaching the out-of-field teachers were generally assigned to teach physics, 9th grade physical science, or a combined chemistry and physics (typically called chem/phys) class. Seven of the eleven teachers were also asked to teach another science (chemistry, earth science, or biology) class in addition to the physics, physical science, or chem/phys class. Five out of the eleven teachers were teaching in a school that was on a traditional bell schedule with an average of 47 minutes available for physics instruction every day.

Just as seen with the other two groups of teachers, the teachers and school characterizations changed slightly after the first year for the out-of-field group. Two of the out-of-field teachers were teaching at a new school. One moved from teaching at a rural Midwestern school on a semester block schedule to teaching at two urban public schools on traditional bell schedules. The other teacher was laid off from the school he taught at his first year and moved to another high school in the area. One teacher left the study after the first year because of lack of interest in participating any longer.

There were four main teaching behaviors exhibited by the out-of-field teachers over the first two years of teaching. Just as was seen with the other two groups of teachers, these behaviors reflected the level of physics content knowledge, PCK, instructional practices, and images of teaching physics.

1. The out-of-field secondary physics teachers showed a weak understanding of physics, with a large number of incorrect ideas regarding physics concepts.

Again, due to the nature in which the concept maps were collected, many of the out-of-field teachers completed a concept map for the discipline in which they had received their degree, rather than the course they were primarily teaching. However, out of the eleven out-of field teachers, five completed a physics concept map. The concept maps drawn before (T1) and after (T2) the first year of teaching were all linear in nature with very few crosslinks. The lengths of the linking phrases ranged from no words to a couple words and were very simplistic. The maps drawn after the second year of teaching (T3) remained linear in nature, however the number of crosslinks increased and the linking phrases became more complex. The maps that were drawn with the ten original provided words with words added by the participants became much more complex and were sometimes even hard to follow.

This group of teachers showed a larger number of incorrect links in the first concept map than the in-field or related-field teachers. However, by the second concept map drawn after their first year of teaching these teachers showed a much lower number of incorrect connections between words. This trend continued into the maps drawn after the second year of teaching, where the number of incorrect links remained low.

The words that were incorrectly linked by the out-of-field teachers showed similarities and differences to those seen in the in-field maps. Similar to the in-field teachers, common incorrect links seen in the maps of this group of teachers were between 'fields' and 'force'. For example, in all three of Steve's concept maps these two words were consistently linked incorrectly. The link in his first map described "force transmitted through fields" (Steve, T1). Steve's only incorrect link in his second map similarly stated that "force operates in fields" (Steve, T2). Again, in the two maps drawn after his second year of teaching, Steve stated that "forces occur within fields" (Steve, T3, map 1 and 2). Interestingly, Jennifer's only incorrect link on her second map was between these two words by stating that "fields" is an "example" of "force" (Jennifer, T2). However, Jennifer's first map was missing the term 'fields' altogether, so it is not clear whether she would have made this error in her first map as well.

However, this group of teachers showed a common set of incorrect links between the words 'fields' and 'heat' that was largely absent from the in-field group's maps. For example, all three of Dedra's concept maps showed an incorrect connection between these same two words, with this link being the only incorrect link in the maps before and after her first year of teaching. In her first map, before her first year teaching, Dedra described ‘heat’ as a “type of wave” (Dedra, T1). Dedra’s second map had a related incorrect link between ‘heat’ and ‘fields’ where she stated that “heat creates fields” (Dedra, T1). In the first map drawn (with only the ten provided words) after her second year of teaching, Dedra provided a sentence that incorrectly linked ‘heat’, ‘waves’, and ‘fields’. She stated that “heat travels as waves that produce fields” (Dedra, T3, map 1). Dedra had a very complicated second map obtained after her second year of teaching, drawn with her added words. In this map she stated that “waves travel as heat” (Dedra, T3, map 2). However, she also continued by describing that “heat produces work” and that “heat (and) light are not forms of matter” (Dedra, T3, map 2). All of these phrases are not consistent with an accurate representation of heat, fields, and waves.

Tami was another example of an out-of-field teacher who consistently, incorrectly connected the concepts of heat and fields. While Tami only provided a map from the two interviews before and after her first year of teaching, both of those concept maps showed an incorrect connection. In her first map she stated that “fields can produce heat” (Tami, T1), and in her second map she had ‘fields’ and ‘heat’ connected with no linking words between. Again, as seen within this group of teachers, there is a misunderstanding that somehow fields and heat are related to one another.

The maps drawn by Steve and Jennifer initially showed this misconception, however the misconception seemed to be resolved at certain points for each of these teachers. Steve's first map showed a connection between the terms 'heat' and 'waves', as he described that "heat propagates as waves" (Steve, T1). However, this connection did not show up in subsequent maps. Jennifer's only incorrect link in the maps drawn before her first year teaching and after her second year teaching was between these two words. In both maps she described that "heat travels in waves" (Jennifer, T1, T3). At some point between her first and second years of teaching this misconception was not present in the concept maps. In her map drawn after her first year of teaching Jennifer correctly lists "light measured in waves" and separately that heat is an example of energy (T2). It is not clear why Jennifer reverted back to her original misconception after her second year of teaching.

Daisy, a Plant Science major, showed one of the largest number of inaccurate (rather than incorrect) links, which were very different from any of the other maps, regardless of field group. She also had the most amount of words used in her linking phrases as if she were making sentences out of the given terms. Daisy had four inaccurate links in her first concept map between 'energy' and 'motion', 'motion' and 'waves', 'waves' and 'fields', and 'forces' and 'energy'. She described physics as being "all about energy of motion in waves and fields" (Daisy, T1). Her other inaccurate link was a crosslink that described "work is a measurement of energy and force" (Daisy, T1). Daisy's second concept map contained no linking phrases between words and only one incorrect link between ‘force’ and ‘conservation’. Without the linking phrases what she meant by that cannot be determined, and the protocol did not allow for follow-up regarding the drawn maps. In the maps drawn after Daisy’s second year of teaching she again provided inaccurate connections between words that were not seen in the other concept maps. In her first map drawn with the provided ten words Daisy incorrectly linked ‘Newton’s Laws’, ‘forces’, and ‘conservation’ by describing that “Newton’s Laws state that forces are in a state of conservation” (Daisy, T3, map 1). In her second map Daisy restructured her map by adding one extra word (electromagnetic), leaving ‘waves’ out entirely, and including the provided word ‘conserved’ within a linking phrase. She only had one incorrect link that described “force is conserved motion”. This was not a complete sentence, which made it difficult to determine the meaning, however force is not conserved by motion.

Tami’s maps also showed inaccurate links that other teachers did not have in their respective maps. In her first map she connected ‘fields’ and ‘light’ as well as ‘conservation’ and ‘work’ in an inaccurate way. Tami stated that “fields give us light” and “conservation of work” as well as the correct connection of “conservation of energy” (Tami, T1). In her second map, like Daisy, Tami included no linking words between terms. Therefore, without knowing exactly how Tami was thinking of the connection between the words when she drew the map, there were three incorrect links. As mentioned earlier, one of these was the common incorrect connection between ‘fields’ and ‘heat’. The other two incorrect links on Tami’s map were between ‘motion’ and ‘conservation’ and ‘energy’ and ‘force’. As previously stated however, Tami did not provide a map from the interview after her second year of teaching.

2. The out-of-field teachers’ idea of a successful physics or science lesson was mainly focused on processes, structure, and student engagement.

The PCK of the out-of-field teachers was mainly focused on processes, structure, and student engagement rather than on content or student knowledge of physics. Within this group of teachers many spoke about the process of teaching physics or science in general. Many times this description contradicted how these teachers were actually teaching physics. For example, Madeline gave a list of the different activities she believed made up a good science lesson. She spoke about wanting to “give an overview first” that was “not lecture so much, but an activity to explore the topic”. She then described how she presented the students with a question – “something to puzzle them, like a problem to think about the topic at hand” – which they then “discuss as a group” so that Madeline could “check-in to see where they are” and try to “point in the right direction”. It is important to her that her students come up with their own answers since she believes this is a “better way to learn”. Madeline would then “probably lecture after to give them the details, clarify any misconceptions for a deeper understanding” (Madeline, T1).

Other teachers spoke about teaching in terms of how structured the lessons were. If a lesson was well structured, then it was a good lesson. For example, Daisy and Gavin both specifically mentioned the less being “well planned” (Daisy, T1) and needing to “have an objective…know exactly what you need to do” (Gavin, T1). Tami also spoke about the characteristics of a good science lesson in terms of her own planning. She talked about how a good lesson for her is one written in a way in which she could “reach half of the students”. She also talked about a good lesson as one where she is able to “come up with ideas without using the same lesson”. In terms of what her students were doing in her idea of a good science lesson, Tami discussed that it was when she “has students saying what they are going to do that day” and to “go through the process of what they have to do and figure out how to answer the questions through lab or the Internet” (Tami, T1).

The rest of the out-of-field teachers were concerned with the students being engaged in the lesson. Barb spoke about her lessons as being “something to grab their attention and interest” (Barb, T1), while Steve described his as one in which “students are actively working on stuff rather than passively listening” (Steve, T1). Steve also spoke about how the lesson should “relate to other topics students know about”, which is why, for the lesson he was specifically speaking about, he tries “to relate the cycling of energy to the properties of matter” (Steve, T1).

After the first year of teaching, the out-of-field group was still talking about a successful lesson as one that includes student engagement, having a structure, and related to a process, however many of the teachers focused on student engagement. For example, Caleb spoke about using a “teaser or hook” before a “brief exploration into a concept or topic” where you “give something to explore related to what you teach” (Caleb, T2), while Tami talked about her lesson as one that “grabs attention” which “leads to the main part of the lesson” (Tami, T2). Related to student engagement many of the teachers in the out-of-field group spoke about how the lesson needed to relate to the students every day life.

Just as he mentioned in the interview before he started teaching his first year, Steve talked about how a lesson should “tie into the rest of the stuff they are talking about or some other sort of science…make it part of their past experiences if you can, make it exciting” (Steve, T2). Dedra also discussed how a lesson should be one where the students could talk about what they had seen in real life that related to the topic they were learning about. Jennifer was very concerned with her students being engaged throughout the lesson and especially “one that captures students’ attention right away”. She also spoke about the lesson needing to “directly pertain to their everyday life…and what they need for science” (Jennifer, T2).

Those teachers that spoke about the process of a good science lesson after their second year now spoke about the process of science, rather than a process of lesson planning. They talked about how a successful lesson needed to have students engaged in hands-on activities. For example, Dedra talked about her lesson beginning with a question and having the students participate in an “investigation or activity” and then having them “discuss what happened…relating back to what they have seen in the real world” (Dedra, T2), while Caitlin’s idea of a good science lesson after her first year of teaching was one that includes a “clear objective, problem solving, analyzing, asking why, a lot of questioning, practicing, group work, and experimentation” (Caitlin, T2).

Madeline was an interesting case regarding teaching physics and science after her first year of teaching. She showed the most development in terms of how she spoke about best practices for teaching science and was now talking about successful science lessons needing to have an inquiry component. She remarked that the students “ideally should come up with the question or problem” because they “get the most out of the lesson that way”. The process that Madeline spoke about after her first year was very similar to how she envisioned a good science lesson before she began teaching. She would first introduce the topic and “let them mull it over” and the lesson was “best when it is an on-going discussion because that’s what science is”. Madeline believes she accomplished this by having “each group come up with a different way to solve the problem”, which she said “tells her they are interested and learning”. For her, a goal of her lessons is for her “students to know how to problem solve” (Madeline, T2).

After the second year of teaching the out-of-field teachers were mainly concerned with the engagement of their students in the lesson, having the lesson apply to the students' lives, and having the students be responsible for much of their own work and learning. As an example, Tami believed that "it all depends on the students" and that it is most important "that kids remember". She therefore believed that it was best to use "activities, hands-on, a good lab…that get students working" because a good lesson is "what they get involved with" (Tami, T3). Caitlin also described a successful lesson in this way, now not only talking about having "to include a type of hands-on, lab or discovery" activity, but that her role was "not just delivering information" (Caitlin, T3).

Jennifer was and example of one of the most reflective out-of-field teachers after her second year of teaching. She described in detail the aspects that she believed made up a successful science lesson, and also related it to her own planning of science lessons. Just as she talked about over her first year Jennifer believed that a good science lesson was "one that keeps her students engaged". However, she now explained that this was

> why you have to change directions so many times…if her students are going to come into her room and sit at their desks and do table work all day, every day…going to have the good students who work ahead and then they are just sitting there goofing off…or going to have the ones that just hate it and completely tune it out…I look at the activities I have and then it's like putting a puzzle together…will do one day of lecture and

> then got to kind of throw in something else in there…will bribe them…
>
> (Jennifer, T3)

Jennifer also talked about how the lesson needed to relate to what they have been doing previously and have some relevance to the students. She therefore would sequence her lessons so that it would keep her students', or at least the majority of students', attention.

Mandy was the only teacher to talk about a good science lesson as being mainly teacher oriented after her second year of teaching. She talked about how she would have an "opening to get the kids thinking…a question", followed by a "small activity". She then talks about how she would "go through notes first" and give an "information worksheet to think about the idea" they are learning about. After the students look at the notes Mandy would then determine if the students can "take what they learned and apply to a small question or lab". After this she would have a "closure to bring everything back together" (Mandy, T3). As will be described later in this section, Mandy was the most traditional teacher in terms of teaching physics, relying on the materials provided to her by the previous teacher and not modifying her practices over the first two years of teaching. It is interesting to note however, that Mandy did attempt to change her practices when teaching in her field of certification, biology.

3. In terms of PCK, the out-of-field teachers considered students' prior knowledge in physics starting in the first year of teaching, however this knowledge was not typically probed before the lesson was taught. This

> group of teachers usually only talked about students' difficulties with specific topics in the field of study closest to their degree, and therefore rarely considered student difficulties with specific physics concepts.

The out-of-field group of teachers all considered students' prior knowledge before teaching in the classroom for the first time, however to various degrees and most often in their in-field teaching subject. Some teachers considered what students had previously been taught, either in that class or a prior class. Other teachers considered the knowledge students would need in order to be successful with the lesson they were describing. Still others talked about probing students to see what they already knew about specific content. After their first year of teaching these teachers considered prior knowledge in the same ways, however they also spoke about what students had previously experienced in their everyday life. More teachers considered specific knowledge students would need to be successful in the lesson after the first year of teaching than had before they started teaching.

Before their first year in the classroom, the majority of the out-of-field teachers all considered the knowledge students previously had or did not have when they talked about their lessons. For example, Mandy commented that, in the lesson she described, "this was not the first time students had done this" (Mandy, T1), while Daisy considered "what is fact and what is fiction" when teaching about diseases in Africa (Daisy, T1). During a lesson using animals on cards, Steve considered the prior knowledge of his students "in the sense that most students didn’t know the information on the cards”, otherwise he “didn’t really think there was a whole lot else they needed to know” (Steve, T1). Dedra “had been forewarned that students didn’t know what a mole was” so instead she “considered what they did know, like a ‘dozen’”, as well as “how students had seen the idea of the mole in their lives” through different quantities (Dedra, T1), while Caitlin based her considerations on comments from the students who most of the time would say “we never learned this” (Caitlin, T1).

Unlike the teachers in the other two groups, a few of the out-of-field teachers even spoke about probing students to determine prior knowledge when starting their lessons. As an example, Gavin probed his students about what they knew about earthquakes during his lesson, and commented on how “they remembered the tsunami” (Gavin, T1). Barb talked about how she “probed with opening questions, asking students what they knew about the names and functions about certain organic substances”, while also using “what they had already previously covered” (Barb, T1), while Jennifer “probed prior knowledge before and when doing the introduction to the lesson or unit via a class discussion” and asking questions (Jennifer, T1). It was interesting that once again, these lessons were in the field that these teachers were certified in, not in the field of physics. It was not clear that this group of teachers considered students’ prior knowledge when teaching the physics lessons.

After the first year in the classroom, the teachers spoke more about knowledge that the students had previously gained, although many still made assumptions about what the nature of that knowledge was and where they had learned the material. For example, Madeline spoke about basing her understanding of her students' prior knowledge "on what they had done in the past couple of days and on answers to questions asked in class" (Madeline, T2). There were a few teachers, including Madeline, who considered the knowledge students would need in order to be successful in the lesson they were describing. Madeline, who was doing a lesson where students gave an opinion about different statements on genetics, commented that her students "had to know what the things were in order to have an opinion". She reflected that they "had covered topics previously in formal projects and lectures" but the students "had never had the opportunity to express opinions" (Madeline, T1). Since she had covered it in class, her students should know the material. Tami, on the other hand, considered her students' knowledge of the periodic table, which they had been studying. Knowing the students' comprehension of the material she moved "from the easiest to the hardest units" (Tami, T1) in her lesson.

The consideration of what knowledge students needed in order to be successful with a particular lesson continued through the second year of teaching. For example, in a physics lesson on Power, Jennifer spoke after her second year regarding the specific concepts her students would need in order to be successful. She commented on the fact that students "can't do power without work", so she "started with velocity and acceleration, then force, and then work", and that she "felt good enough about their prior knowledge that they could do the lab" that she had planned. Jennifer continued by saying that the class had first “talked it over” and then she moved onto “short notes at the beginning” where she “talked about power and formulas”. She also mentioned that she had “talked through the lab quite a bit beforehand as well” (Jennifer, T2).

Contrary to the interviews before and after their first year of teaching, the majority of the out-of-field teachers talked about how they did not consider students’ prior knowledge when planning their lessons in the interview after their second year of teaching. A few of the teachers, like Caleb, discussed how, even though he did not consider prior knowledge when planning, it “came out in the lesson anyway” (Caleb, T3). Usually Caleb “asked what they know to get their interest” and to determine his students’ understanding of the material, yet this was not a main consideration when he planned his lessons. On the other hand, Caitlin mentioned that she usually considered it “if it was something she taught them”, that she used “bell work and open-ended questions” (Caitlin, T3) to accomplish this, and that she “talked about it at the beginning of the lesson” (Caitlin, T2) with her students in order to assess prior knowledge. Mandy was an example of an honest teacher who rarely considers prior knowledge and only “considers the knowledge she’s given them so far…because it comes out when doing notes” (Mandy, T3). Mandy is an interesting example, because she went through a university-led science teaching program, which stressed inquiry and assessing students’ prior knowledge. Yet, even after her second year of teaching this was not something that she felt was an important thing to plan into her lessons.

The out-of-field teachers tended to speak either generally about how and if they considered students' difficulties with specific science concepts, or they commented on concepts specific to the field closest to which they received their degrees. Over the first year in the classroom this group of teachers had varied ways in which they considered students' difficulties. Mandy waited for her students to tell her their misconceptions and said that she "knows with their questions and with her extra questions" (Mandy, T1) where student difficulties lie. On the other hand, Tami looked at assessing student difficulties as a way to make accommodations for her ELL students. She "put all possible questions on the board that students don't understand" and then tried "to address them through the notes" (Tami, T1). Many of the teachers were not able to determine what specific difficulties students had, especially in physics. Even after his first year of teaching, Caleb was "still learning what these would be for a teacher" and that "being new he still needs to know these" (Caleb, T2).

A few of the teachers spoke about students' difficulties in relation to a specific science. As an example, in chemistry Barb commented that she "wasn't aware of what misconceptions students hold in organic chemistry" (Barb, T1). In biology Steve spoke about trying "to dispel the notion that individuals were changing" (Steve, T1), and he thought that was the only misconception his students had. After his first year, in terms of physics specifically, Steve talked about his students having only one misconception, which was "that in general potential energy is thought of as potential energy – not as broken down into different kinds like gravitational or chemical”. He believed that it “ends up causing more problems in the end if you don’t specify it” so he “tried to keep them separate or clearly described” (Steve, T2).

Jennifer was an example of an out-of-field teacher who spoke very generally about her student difficulties, talking about how her “students have difficulty thinking outside the box…they are not abstract thinkers” (Jennifer, T1). She handled this by having gone “slow and explained it a few times and in a couple of different ways”. In her lesson, Jennifer “called out students who sat back by giving a specific bone and making them determine the similarities and differences” (Jennifer, T1).

After the second year in the classroom, the out-of-field teachers, just as with students’ prior knowledge, once again did not consider students difficulties with specific science concepts or misconceptions as they had during the first year. As an extreme example, Mandy talked about how she “never thinks of misconceptions, like prior knowledge”, however she does “think about difficulty a lot” and in doing so she “tries to make sure she knows about the concept” (Mandy, T3). She would usually have her students do a “lab first to bring up misconceptions…then go through a PowerPoint” (Mandy, T3) which she felt should clear up any misconceptions. On the other hand, now that she had taught for two years, Tami did not consider her students’ difficulties because she was “confident that they knew” (Tami, T3) the material.

Some of the teachers did not realize the difficulties students would have with specific concepts until they were in the middle of teaching a lesson. As an example, Madeline did not consider her students' difficulties when planning her earth science lesson, however she "realized once into the lesson that they didn't get the concept of layers and deposition". She had "thought it was simple, but hard to explain…it is abstract so kind of lose them" (Madeline, T3). Jennifer explained that her students' difficulties with the science concepts were "why she is always circulating and available…if struggling they need to ask". Her role was to "make sure they were doing what they needed to do be doing and why" so she "watched them and gave a few prods during the first trial" (Jennifer, T3) of their experiment.

4. The out-of-field teachers tended to teach physics very traditionally and spoke openly about their influences in teaching physics. This group of teachers was also very vocal about their feelings regarding teaching a subject that was very different from their field of certification.

Over the first year of teaching the out-of-field teachers showed practices that were common across the group. All of the teachers used general lecture (some with class discussion), verification and directed inquiry laboratories, and worksheets. Six of the eleven teachers used demonstrations and guided inquiry laboratories. Other practices seen over the first year of teaching in these teachers were simulations, reading and/or working from the textbook, problem solving, videos, skills-based and inquiry laboratories, and student research projects and presentations.

Over the second year of teaching this group of teachers again mainly used general lecture (some with class discussion), directed inquiry laboratories, and worksheets. Three of the eleven teachers used demonstrations and skills-based laboratories, and four teachers used verification and guided inquiry laboratories. Other common practices seen in this group over their second year of teaching were inquiry laboratories, videos, student research projects, reading from the textbook, simulations, and problem solving.

The out-of-field teachers spoke frequently throughout their first two years about teaching physics and how they were feeling about it. Some of the teachers were more vocal than others. Barb, who majored in chemistry education, talked about how all of her science teachers in college were very traditional, teaching "all cookbook" (Barb, T2). She reflected that because of this she "never thought science could be taught in any other way until her science methods instructor…modeled inquiry" (Barb, T2). She also mentioned that "doing research helped with what she does with students" (Barb, T2). During her first year of teaching Barb reflected on how knowing the content she was teaching was essential to being able to teach when she said,

> I think that its essential to know the content really well, a strong content background allows you to focus on the classroom rather than what to teach. I felt my methods class was invaluable, the other education classes

> were a waste of time. (Barb, November 2005)

After his first year of teaching Steve, who had a degree in biology, reflected on his role in the classroom compared to his students. He talked about how his “year started out with him doing a lot and not necessarily having the students do as much work or learning”. Throughout the year he “tried to push it to students actually learning and doing the stuff…by turning away from lecture…and making it more project based” (Steve, T2). Steve felt that “being a first year teacher and teaching physics without a license for it, and having three different preparations” he thought “the year went pretty well” (Steve, T2).

By her second year of teaching Dedra, originally a geology major, was concerned with how much content she was being asked to cover in her class and how that was affecting the way she was teaching the subject. The fall of her second year Dedra talked about the “new physical science course” and how frustrating it was. Because of this request she could not teach the way she wanted to teach. She was asked to “cover all of the chapters so she ends up assigning text readings a lot and is not enjoying her teaching”. In the spring of her second year, Dedra was still feeling this same way about teaching physical science. However, at this point she reflected about how she did not like the content she was teaching. She reflected that she was

> Still frustrated with how much we do – two sections a day, not hitting them too hard. Myself and the other science teacher, the principal told us to hit everything in the book, but its not in the test. We do more of just

> covering it in class, not going through stuff, doing just vocab. It would help if I liked the topic, but I don't. (Dedra, March 2007)

Caitlin, who specialized in biochemistry, reflected during her second year about how "teaching chemistry is easier because it's her major". However, unlike the previous year she "has time to prepare this year", mostly due to the fact that she "put together the whole first month of physics over the summer" (Caitlin, October 2006).

Jennifer, another biology major (with zoology emphasis), was the most reflective about teaching physics as an out-of-field teacher. During her first year teaching Jennifer talked about how she felt about teaching. When asked how things were going during her third month of teaching she said,

> It's gone pretty smoothly…the biggest thing in chemistry and physics that's a concern is staying a couple days ahead of the kids…but I don't have time to get anything extra to bring to the class…I'm grasping at strings just to refresh my memory. The labs we do do are not fabulous labs, just what I have available. Biology is my field…so biology is easier, but I haven't had chemistry or physics in like three years, so it's tough. I can plan on the weekend what we'll be doing, but then we need worksheets and all that stuff. I'd like to make it more interesting and more fun for the kids, but I spend all night just relearning the material…it should be easier after the first few years. (Jennifer, October 2005)

At one point, getting on towards the end of her first year teaching, Jennifer became worried about whether she was able to teach physics correctly. She reflected,

> sometimes I'm worried 'Am I teaching this correctly?' chemistry I'm not so worried about, but physics is…I struggle. I do physics all weekend. That should be better this summer. (Jennifer, February 2006)

After her first year she commented on how all of her "experiences in teaching science dealt with biology…so I had to learn a lot about chemistry and physics…the methods are similar, but the content is very different" (Jennifer, T2). She said she "was really nervous about chemistry and physics, but really likes it now…more open to it" (Jennifer, T2). During her second year of teaching Jennifer continued to reflect on teaching chemistry and physics as an out-of-field teacher.

> I feel confident in the subject matter this year but the time (due to the split) is tight. I wonder if I am getting my upper level kids adequately prepared for college? (Jennifer, September 2006)

Quantitative Findings

PCK Data Results.

Descriptive Statistics. The PCK interview asked the teachers to talk about a lesson they had taught that they felt was successful. Since this study was interested in teachers who were teaching physics, an examination of the topic of the lessons chosen was done. A note was then made as to whether the lesson the teacher chose to speak about was an in-field or out-of-field lesson. Most teachers who were teaching classes both in and out of their area of specialization chose a combination of lessons in the two areas across the three interviews. For the second interview, T2, an additional question was asked based on the teacher's primary teaching assignment. If a teacher was teaching physical science, they had the option to answer for physics, chemistry, and sometimes earth science. The lesson topics (chosen by the teachers) for the three interviews can be found in Table 4.1.

Once it was determined whether the chosen lessons were in or out of the teacher's area of specialization, the total PCK scores were examined. It was found that for teachers who chose to speak about lessons out of their area of specialization, the PCK scores tended to be lower than when speaking about lessons in their area. Because of this discrepancy, the PCK interviews were recoded to be sure that the scores were accurate. The PCK scores with an indication of the lessons that were out-of-field can be found in Table 4.2.

Table 4.1

List of lesson topics chosen by participants during each interview.

	T1	T2	T2 (Additional)	T3
Beth	Static electricity	Astronomy unit	Physics	Astronomy unit
Jessica	Gas laws	Acids and bases	Chemistry	Acids and bases
Barb	Organic chemistry	Waves (Physics)*	Chemistry	Introduction to the atom
Sandra	Pendulums	Newton's laws†	Did not ask	Momentum and impulse
Jennifer	Skeletal system	Power (Physics)*	Physics*	Titrations*
Jack	Momentum	Electricity	Chemistry*	Atomic structure*,†
Lok	Atomic theory	Energy resources	Chemistry	Atomic structure†
Dedra	Mole*	Acids and bases*	Chemistry*	Atomic structure*,†
Carl	Magnetism and field	Bernoulli/Pressure	Physics	Heat transfer
Peter	Balancing forces	Newton's laws†	Did not ask	Polarization
Steve	Charac. of life	Energy*	Physics*	Projectile motion*
Caitlin	Chemical equations	Acceleration*	Physics*	Electricity*
Keisha	Acids and bases	Gravitation*	Physics*	**
Celine	Energy	Energy	Physics*	**
Gavin	Earthquakes*	Titration*	Chemistry*	**
Caleb	DNA modeling	Forces*	Did not ask	HR diagram*
Mandy	Fish dissection	Motion equations*	Biology	Arthropods
James	Cycles (Biology)	Newton's laws*	Did not ask	Force/Newton's laws*
Daisy	Spreading disease	HR diagram*	Physics*	Gattica (Biology)
Demetri	Scientific method	Cancer lesson	Earth Science*	Genetics
Tami	Chemical reactions*	Measurement*	Did not ask	DNA
Tyra	DNA*	Physical charact.	Chemistry	Atoms
Madeline	Genetic engineering	Scientific method	Biology	Grand Canyon*

Note. *topic is out-of-field for the teacher; †topic was requested by the researcher, not chosen by the participant; **no longer in study

Table 4.2

PCK scores for each participant for each interview with out-of-field lesson indication.

	T1	T2	T3		T1	T2	T3
Beth	7	8	9	Demetri	8	10	7
Jack	11	13	9*	Daisy	10	7*	10
Peter	6	10	8	Caleb	8	7*	8*
Carl	6	12	6	Caitlin	7	13*	10*
Sandra	9	9	11	Steve	9	11*	10*
Lok	5	8	6	Jennifer	8	9*	6*
Jessica	10	12	10	Mandy	7	7*	5
James	10	10*	6*	Madeline	9	7	7*
Tami	7*	7	5	Tami	10*	7*	7
Keisha	5	11*	**	Dedra	7*	8*	8*
Celine	10	8	**	Barb	8	12*	12
				Gavin	5*	7*	**

Note: *topic is out-of-field for the teacher; ** no longer in study at time of interview

The interviews chosen for re-code were: Daisy (T2), Jennifer (T3), Peter (T1), Jack (T3), Demetri (T2), Caitlin (T1), Carl (T2), James (T3), Beth (T1), and Keisha (T1 and T2). For three of these participants (Jennifer, Jack, and Keisha) the re-coded scores were different from the original coding. To ensure accuracy of the new codes another researcher in the group was asked to also re-code the same interviews. It was found that the re-codes were accurate, and therefore the scores were changed before any statistical analysis was conducted.

The individual categories in the PCK rubric were not designed such that the individual code scores could be summed. Therefore the categories needed to be examined separately over the two years. The means and standard deviations for the scores in each of the five PCK categories for each of these groups over the three interviews can be found in Tables 4.3, 4.4, and 4.5.

Table 4.3

Means and standard deviations for the scores in each of the five PCK categories for the in-field group (N=5).

	T1		T2		T3	
PCK category	M	SD	M	SD	M	SD
Prior knowledge	1.2	.45	1.8	.45	2.0	.71
Variations in approaches to learning	1.2	.45	2.4	.55	1.6	.55
Students’ difficulties	1.6	.55	1.8	.45	1.8	.84
Scientific inquiry	2.0	1.0	2.0	1.0	1.6	.55
Representations	1.8	.45	1.8	.45	2.0	.71

Table 4.4

Means and standard deviations for the scores in each of the five PCK categories for the related-field group (N=5).

	T1		T2		T3	
PCK category	M	SD	M	SD	M	SD
Prior knowledge	1.4	.55	1.6	.55	1.4	.55
Variations in approaches to learning	1.6	.55	2.0	.00	2.0	.00
Students' difficulties	1.8	.55	1.6	.55	1.0	.00
Scientific inquiry	1.8	.45	2.0	.71	1.4	.89
Representations	1.8	.45	2.2	.45	1.8	.45

Table 4.5

Means and standard deviations for the scores in each of the five PCK categories for the out-of-field group (N=10).

	T1		T2		T3	
PCK category	M	SD	M	SD	M	SD
Prior knowledge	1.5	.53	1.6	.70	1.6	.70
Variations in approaches to learning	1.9	.32	1.8	.79	1.7	.48
Students' difficulties	1.3	.48	1.4	.52	1.5	.53
Scientific inquiry	1.7	.48	2.0	.67	1.7	.68
Representations	1.9	.32	2.0	.47	2.0	.47

An average coding score for each individual over the five PCK categories was also found in order to get an indication of the level of and change in PCK each teacher exhibited over each of the first two years of teaching. An average coding score of 1 indicated that the teacher exhibited a limited level of PCK, on average. An average coding score of 2 indicated a basic level, and a score of 3 indicated a proficient level. Before the teachers in this study entered the classroom for the first time to teach physics, 60% of the teachers exhibited a basic level of PCK and 40% exhibited a limited level. The majority of the teachers showed a basic level of PCK in the areas of variations in approaches to learning, scientific inquiry, and use of representations in the classroom. When broken down into the three field groups, in the first year the in-field physics teachers clump into one coding or another. The other two groups were more evenly split amongst a limited and a basic level of PCK. For example, in the area of considerations of students' prior knowledge before the teachers entered the classroom, 80% of the in-field teachers were scored at a limited level, but 43% and 55% of the related-field and out-of-field teachers, respectively, scored at a limited level. The percentages of teachers who scored in each of the three levels in the rubric, for each of the five categories before their first year of teaching can be found in Table 4.6.

After the first year of teaching a very slight shift in the teachers' PCK can be seen. On average, 8% of the teachers moved to an overall PCK level of proficient. The same amount of teachers was rated at a basic level and there are fewer teachers in the limited level. Looking further into an individual teacher's average PCK rating, one teacher moved from a limited level, and one from a basic level to the proficient PCK level. Because only two teachers made this shift, and because the shift was not consistent in terms of starting levels, this may not be a typical or "real" effect in terms of the teachers' knowledge. By the end of the second year the in-field teachers moved from being almost evenly split between a limited and basic level to the majority of teachers shifting to a basic level (no teachers at a limited level). The related teachers made a similar shift, and the out-of-field teachers shifted downward from a majority of teachers at the basic level before teaching to a majority at the limited level after teaching for one year.

When looking at the individual areas of PCK that were rated, overall, the majority of teachers showed a basic level of PCK in all five areas. Areas that shifted up from a limited to a basic level of PCK were: prior knowledge and student difficulties with specific science concepts. The other areas remained at a basic level.

Table 4.6

Percentage of teachers scoring in each of the three PCK levels, in each of the five PCK categories, overall and by field group, before teaching for the first time (T1).

	Limited				Basic				Proficient			
PCK category	Overall	In-field	Related-field	Out-of-field	Overall	In-field	Related-field	Out-of-field	Overall	In-field	Related-field	Out-of-field
Prior knowledge	57	80	43	55	43	20	57	45	0	0	0	0
Variations in approaches to learning	35	80	29	18	65	20	71	82	0	0	0	0
Students' difficulties	61	40	57	73	39	60	43	27	0	0	0	0
Scientific inquiry	30	40	14	36	61	20	86	64	9	40	0	0
Representations	17	20	14	18	83	80	86	82	0	0	0	0

All three field groups exhibited a shift into the proficient level of PCK for the areas of scientific inquiry and classroom representations, however while the in-field and related-field teachers were heavily grouped in the basic and proficient levels in all areas, the out-of-field teachers were more evenly split between a limited and basic level of PCK for all five areas. The percentages of teachers who scored in each of the three levels in the rubric, for each of the five categories after their first year of teaching can be found in Table 4.7.

By the second year of teaching, the majority of teachers (60%) again exhibited a basic level of PCK, with no teachers moving to the proficient level. The in-field teachers remained at a basic level, while the related-field teachers shifted downward to a limited level. The out-of-field teachers moved back up to a majority of teachers exhibiting an overall basic level in PCK. When looking at the five areas, overall the teachers moved to a more even grouping between the limited and basic levels. The related-field teachers mainly exhibited this shift, where the majority of the teachers moved downward from a basic to limited level. The percentages of teachers who scored in each of the three levels in the rubric, for each of the five categories after their second year of teaching can be found in Table 4.8.

At this point, in order to have equal and larger sample sizes for the statistical analyses, the in-field and related-field groups were combined into a single in-field group. The data were then examined in terms of two main PCK categories in the rubric.

Table 4.7

Percentage of teachers scoring in each of the three PCK levels, in each of the five PCK categories, overall and by field group, after their first year of teaching (T2).

	Limited				Basic				Proficient			
PCK category	Overall	In-field	Related-field	Out-of-field	Overall	In-field	Related-field	Out-of-field	Overall	In-field	Related-field	Out-of-field
Prior knowledge	39	20	29	55	57	80	71	36	4	0	0	9
Variations in approaches to learning	26	0	14	45	57	60	86	36	17	40	0	18
Students’ difficulties	39	20	29	55	61	80	71	45	0	0	0	0
Scientific inquiry	30	20	43	27	52	60	43	55	17	20	14	18
Representations	4	0	0	9	78	60	86	82	17	40	14	9

Table 4.8

Percentage of teachers scoring in each of the three PCK levels, in each of the five PCK categories, overall and by field group, after their second year of teaching (T3).

	Limited				Basic				Proficient			
PCK category	Overall	In-field	Related-field	Out-of-field	Overall	In-field	Related-field	Out-of-field	Overall	In-field	Related-field	Out-of-field
Prior knowledge	45	20	60	50	45	60	40	10	10	20	0	10
Variations in approaches to learning	45	40	80	30	55	60	20	0	0	0	0	0
Students' difficulties	60	40	100	50	35	40	0	0	5	20	0	0
Scientific inquiry	50	40	80	40	40	60	0	10	10	0	20	10
Representations	15	20	20	10	75	60	80	10	10	20	0	10

Table 4.9 shows the means and standard deviations for the two field groups (in-field and out-of-field) by PCK category (student learning and instructional categories) at each of the different interview times (T1: before teaching for the first time; T2: after the first year of teaching; T3: after the second year of teaching).

Table 4.9

Means and standard deviations for the PCK categories by field group.

	PCK category	T1		T2		T3	
		M	*SD*	*M*	*SD*	*M*	*SD*
In-field (*N*=10)	Student learning	4.20	1.32	5.60	1.17	4.5	1.65
	Instructional strategies	3.70	1.06	4.30	1.06	3.40	1.07
Out-of-field (*N*=10)	Student learning	4.70	.82	4.80	1.62	4.80	1.14
	Instructional strategies	3.60	.70	4.00	.94	3.70	1.06

ANOVA and Statistical t tests. A repeated measures 2x3 ANOVA was conducted to compare the effect of field group on total PCK score over the three interviews. The dependent variable was the total PCK score. The within-subjects factors were the field group with two levels (in-field and out-of-field) and time with three levels (T1, T2, and T3). There was no main effect of PCK score over time, $F(2,17) = 3.257$, $p = .06$, partial $\eta^2 = .28$. A non-significant interaction between field group and PCK score over the three interviews was also found, *F* (2,17) = 1.59, *p* = .23, partial η^2 = .16. Based on this initial examination of the data it was not convincing that there was any effect across the three times. However, it was acknowledged that the groups used in this study were small (N = 10 per group), and therefore the results may be more stable when combined across groups.

Due to the lack of differences between groups, three paired samples *t* tests were conducted to evaluate whether PCK changed over the first year and/or second year of teaching for each of the field groups. Differences in total PCK score were significant for the in-field group over the first year of teaching, *t* (9) = -3.25, *p* = .01. Table 4.10 shows the mean differences and *t* statistics for the total PCK score over time for the two field groups.

Table 4.10

Mean differences and t statistics for the total PCK score by field group.

	T1 – T2			T2 – T3			T1 – T3		
	MD	*t*	*p*	MD	*t*	*p*	MD	*t*	*p*
In-field (*N*=10)	-2.00	-3.25	.01*	2.00	2.54	.03*	0.00	.000	1.0
Out-of-field (*N*=10)	-.500	-.535	.61	-.300	-.287	.78	-.20	.580	.58

Note. * = significant at the *p* < .05 level.

To be thorough, given the significant differences seen in the total PCK score over the first and second years of teaching, three paired samples *t* tests were conducted for each of the two subscales that make up the total PCK score in each of the field groups. Differences in PCK score in the main category for “knowledge of student learning in science” were significantly different for the in-field group over the first year of teaching, *t* (9) = -3.77, *p* < .05. Table 4.11 shows the mean differences and *t* statistics for the PCK scores by subscale over time. This is one and a half of a coding category, moving from just above a “limited” level to just below a “basic” level of PCK. The elements in this category that show a significant difference over the first year for the in-field teachers were the prior knowledge (*t* (9) = -2.45, *p* < .05, *MD* = -.4) and variations in students’ approaches to learning (*t* (9) = -4.00, *p* < .05, *MD* = -.8) categories. While the in-field teachers did not show a significant difference over the first year in the main category of “knowledge of instructional strategies”, they did show a significant change in the element of representations, *t*(9)=-3.00, *p*<.05, *MD*=-.5. The out-of-field teachers showed no significant differences in either of the main categories or in the elements that comprise those categories over the first two years of teaching. Given the small sample sizes of the group these results are recognized as being exploratory.

Concept Map Results. Two researchers, who have a background in physics, independently coded the concept maps. Of the participants in the study, all of the in-field teachers, two of the related-field participants, and five of the out-of-field participants completed a physics concept map. The rest of the participants completed the chemistry (four related-field and four out-of-field teachers) and biology (3 out-of-field teachers) concept maps. Each concept map was coded in three main categories utilizing the protocol developed by the

Table 4.11

Mean differences and t statistics for the PCK categories by field group.

		T1 – T2			T2 – T3			T1 – T3		
	PCK category	MD	*t*	*p*	MD	*t*	*p*	MD	*t*	*p*
In-field (*N*=10)	Student learning	-1.4	-3.8	.004*	1.1	2.2	.06	-.30	-.61	.56
	Instructional strategies	-.10	-1.3	.22	0.0	2.2	.05	-.10	.90	.39
Out-of-field (*N*=10)	Student learning	-.60	-0.15	.88	.90	.00	1.0	.30	-.22	.83
	Instructional strategies	-.40	-1.1	.31	.30	1.2	.28	-.10	-.36	.73

Note. * = significant at the .05 level.

research group during the summer of 2007 and based on the methods reported by Hough, O'Rode, Terman, and Weissglass (2007).

When looking at the average link score given by the researchers, it is clear, that on average the in-field teachers received higher scores. This indicates that the in-field teachers provided links that were more correct, and included more linking words between the two concepts. For example, Peter, an in-field teacher with an average link score of 2.2 on his second physics concept map, had a total of 13 links, 61% of which scored a 2 and 30% of which scored a 3. He used directional arrows between nodes and descriptions such as, "work → transformation of → energy". The in-field teachers also showed more connections between the given physics topics by their use of crosslinks. Carl used 11 total crosslinks in his map showing that the 10 given words, in his view of physics, were very connected. The in-field concept maps also tended to be more like webs, rather than a hierarchically drawn map, and a few were very complicated.

The out-of-field teachers showed a lower average link score, indicating the links were incorrect, drawn without any linking words, or very basic in their connection. For example, Tami, an out-of-field teacher with an average link score of 0.7 on her second concept map, had a total of nine links, 66% of which scored a 1 (correct but no linking words present) and 33% of which were incorrect. These maps tended to have very simple connections between the nodes and very few, if any, crosslinks present. The out-of-field concept maps also tended to be drawn very linearly in a typical hierarchical fashion. A summary of the over-arching concepts, average link scores, and number of crosslinks in the physics concept maps can be found in Table 4.12.

Summary of Quantitative Data

Overall, the quantitative data showed the in-field teachers started with a higher PCK score than the other two groups. The paired samples *t*-test showed a statistically significant difference over the first year of teaching in the PCK category of “knowledge of student learning in science”, with a one and a half category change from just above a limited level to just below a basic level. Specifically this group of teachers showed a change in prior knowledge and variations in student’s approaches to learning. The out-of-field teachers showed no significant differences in either of the main PCK categories or in the elements that comprise those categories over the first two years of teaching.

In looking at the concept maps, the in-field teachers showed higher scores in each of the three categories – correctness, connectedness, and complexity. They also used a smaller number of over-arching concepts (most often "energy"), had higher average link scores, and used more crosslinks in their maps. The results presented here in this chapter will be discussed integrated together in the next chapter.

Table 4.12

Over-arching concepts, average link scores, and number of crosslinks in the physics concept maps.

		Over-arching concept			Average link score			# Crosslinks (correct or not)		
		T1	T2	T3	T1	T2	T3	T1	T2	T3
In-field	Beth	Physics	Newton's Laws	Energy	2.2	1.4	2.1	1	9	2
	Jack	Energy	Physics	Energy	1.9	2.0	2.1	0	2	1
	Carl	Energy	Energy	Energy	2.0	1.4	2.0	7	11	3
	Sandra	Physics	Energy	N/A	2.0	1.7	N/A	3	6	N/A
	Peter	N/A	Physics	N/A	N/A	2.2	N/A	N/A	3	N/A
Out-of-field	Celine	Physics	Physics	N/A	1.9	2.2	N/A	0	1	N/A
	Dedra	Newton's Laws	Newton's Laws/ Energy	Energy	1.8	1.8	1.6	2	2	1
	Daisy	Physics	Physics	Physics	1.0	0.9	1.5	1	0	1
	Jennifer	Kinematics	Physics	Physics	1.8	1.6	1.0	2	1	3
	Tami	Physics	Energy	N/A	1.1	0.7	N/A	0	0	0
	Steve	Energy	Energy	Physics	1.3	1.9	1.9	2	1	0

Comparison of Quantitative and Qualitative Data

Trends in Physics Content Knowledge. An effective physics teacher needs to have knowledge of the physics concepts, the relationships among them, and the methods of acquiring this knowledge (Etkina, 2005). This study sought to determine to what extent the teachers possessed an accurate knowledge of physics and the relationship among certain physics concepts.

At the start of this study there were two assumptions made regarding the physics content knowledge of the teachers in this study. The first assumption made was that over the first two years of teaching the physics content knowledge of the teachers as a whole would increase and move towards a more accurate representation of the field as they worked through the material and taught it to their students. Through the data this was not shown to be an accurate development of the teachers in this study. The data examined did not provide a clear indication of physics content knowledge increasing any of the teachers over the two years of teaching physics. Qualitatively they did not speak about understanding the content in more meaningful ways, and the quantitative data from the concept maps showed both rises and declines in the correctness of the links between physics concepts for all teachers over the first two years of teaching.

The lack of development seen in the physics content knowledge for these teachers could be the result of a couple different possibilities. First, other than the concept maps, the data collected was not designed to specifically look at the development of content knowledge over multiple years of teaching. The concept maps provided significant insight into the content knowledge of the teachers. However, the study was not designed such that the concepts explored in the concept maps matched with what the teachers' taught in the classroom. This may account for the fluctuation seen in the qualitative data in terms of the physics content knowledge of these teachers. Second, this may very well be a valid result, whereby teaching physics does not increase the content knowledge of the teachers who are teaching the subject. Both these possibilities will be examined further with a more thorough study that focuses only on the physics content knowledge of secondary physics teachers over a period of time, and uses multiple measures of content knowledge. Multiple measures of content knowledge are necessary in order to probe for different types of content knowledge as discussed in the physics education research (PER) literature, which spans factual knowledge through conceptual knowledge of the discipline.

The second assumption was that the in-field group would show the most accurate physics knowledge compared to the other two groups, followed by the related-field group, and then the out-of-field group. The in-field teachers demonstrated that, through classroom observations and the concept maps, they held a more accurate representation of physics than the other two groups. The maps drawn by these teachers showed more complex organizations of physics, as demonstrated by the number of crosslinks in the maps. In addition, the majority of the in-field teachers organized their maps by one of the most major physical principles – energy. This group also showed fewer misconceptions in their understanding of the physics content as seen in the classroom observation data, which was supported by the high average link scores given to these teachers on the concept maps.

The in-field group is in stark contrast to the out-of-field group of teachers, which showed many traits of knowledge held by a novice in physics. The teachers without a background in physics drew concept maps that were very linear in nature, contained few to no crosslinks, and typically used the general term of "physics" as the overarching organizing principle. This group also demonstrated many of the common misconceptions held in physics in both their concept maps as well as during their instruction. Quantitatively they had very low average link scores as related to the accuracy of physics concepts. This group of teachers also tended to present physics content that was either taken directly from lesson plans given to them or the class textbook, or the content was presented inaccurately, also showing a lack of physics content knowledge.

When looking at the difference in physics content knowledge it is no surprise that the in-field group showed a higher level of physics understanding than did the out-of-field teachers. However, the out-of-field group of teachers in this study reflects the national trend of physics in secondary schools being taught by teachers who are not adequately prepared to teach physics.

Trends in PCK. There are PCK knowledge areas needed in order for a teacher to effectively teach physics. As described in Chapter 2, an effective physics teacher needs to have knowledge of: (a) the physics curricula, (b) student difficulties in physics, (c) effective instructional strategies for a particular concept, and (d) knowledge of assessment methods (Etkina, 2005). This study sought to determine to what extent the teachers displayed knowledge of student prior knowledge in physics, student difficulties in physics, and effective instructional strategies for a particular physics concept.

From this study it is evident that the representation of physics concepts in the classroom is impacted by a teacher's content preparation. Specifically, those who are teaching in a field different from their content specialization in their first years of teaching seem to have trouble identifying students' difficulties with specific science concepts. Due to the significant difference found for the in-field group in the quantitative analysis of the PCK scores, this study implies that teachers who are teaching a subject they are knowledgeable in are able to focus on teaching in ways that improve their PCK. This also supports other studies that have shown a teachers' PCK to change as they work within the classroom over the year (Lee et al., 2007). While the Lee et al. (2007) study did not differentiate teachers by their field of certification, this study provides a new direction to examine the development of PCK as teachers work in the classroom and helps to refine the results that have been previously found regarding all beginning science teachers.

Overall, the majority of the teachers (60%) in this study began with PCK that was considered "basic" (as measured by the PCK rubric). This was primarily seen in the PCK areas of: variations in approaches to learning, scientific inquiry, and the use of representations in the classroom. In the two PCK categories focused on in this study (prior knowledge and student difficulties in physics) the teachers overall began with a lower level of PCK understanding ("limited"). After the first year of teaching a slight shift began to emerge, with 9% of the teachers in the study moving into the highest level of PCK understanding. By the end of the second year of teaching, the percentage of teachers being coded at the proficient level remained about the same (7%). However, when broken down into the different field groups, the PCK coding appears to be inconsistent. These inconsistencies will be specifically discussed further in relation to the qualitative results in the three PCK categories below.

Consideration of students' prior knowledge. While the group of teachers in this study as a whole had difficulty in identifying student prior knowledge in physics, they developed this skill in different ways, with the in-field group evolving more over the first two years of teaching compared with the other two groups. When looking at the quantitative data, the in-field teachers showed a significant change in the first main category of PCK, knowledge of student learning in science (which includes knowledge of students' prior knowledge), yet this result did not support the qualitative results as might have been expected. The in-field teachers showed a movement in PCK, with the majority of the teachers (80%) moving over their first year of teaching from the lowest level of PCK to a basic level of understanding. Then, after the second year of teaching, the majority of teachers' PCK was considered at a basic (60%) and proficient (20%) level of understanding (see Tables 4.6, 4.7, and 4.8). However, when looking into the qualitative results from the semi-structured interviews, most of the teachers over their first two years, regardless of field group, assumed they knew the prior knowledge their students brought to their lessons, or they did not consider their students' prior knowledge. Overall, there seemed to be a mismatch between the quantitative coding and the qualitative results, as the in-field teachers seemed confident in their knowledge of physics and they thought they could predict the prior knowledge of their students, rather than specifically probe their students for knowledge they had previously learned in school. This is in contrast to the quantitative results, which showed no significant change over the first two years in the area of prior knowledge for the in-field teachers.

The quantitative results of the related-field group showed an even split between being at the lowest (43%) or mid-level (57%) of the PCK rubric for consideration of their students' prior knowledge (see Tables 4.6, 4.7, and 4.8). The qualitative results indicated that these teachers rarely considered students' prior knowledge in physics. When they did consider students' prior knowledge, it was often based upon assumptions that they students already had the required physics knowledge necessary or no knowledge about the concepts a priori to the lesson. If the teachers did probe students for prior knowledge they usually used common techniques such as making predictions and asking students questions during the introduction to the lesson and writing the answers on the board. The qualitative data also demonstrated that this group of teachers only slightly modified their consideration of students' prior knowledge, which is supported by the quantitative data. This again, supports the findings of a novice teacher in PCK (Lee et al., 2007; Meyer, 2004).

The out-of-field data showed nearly no change across the three interviews quantitatively for the prior knowledge category. Again, as seen with the related-field teachers, this group was split fairly evenly between a limited (55%) and basic (45%) coding for this category with the PCK rubric before they began teaching their first year. This stayed fairly consistent after the first year of teaching with the majority staying at the limited level (55%), however a small percentage of the teachers seemed to shift (9%) from the basic level to the highest level of PCK coding, proficient, after their second year (see Tables 4.6, 4.7, and 4.8). This may be due to Jennifer, who was the most reflective of the out-of-field teachers, and seemed to change the most over her first two years of teaching. After the second year the percentage of the out-of-field teachers who were coded by the PCK rubric at each of the different levels remained at about the same.

However, a discrepancy was found when comparing the quantitative results to the qualitative results. Many of these teachers in the first interview discussed how they probed students' prior knowledge through questioning or how they based their knowledge of their students on what they previously taught in the class, rather than what had been taught in prior instruction either by themselves or in a previous grade level. While the out-of-field teachers did not specifically mention consideration of students' prior knowledge while planning their lessons, it was clear from the qualitative data they were considering this type of knowledge more than the in-field or related-field teachers did over the first year of teaching. However, this was not evident in the statistical data. The majority of these teachers was continually scored at the lowest level on the PCK rubric, and did not show any quantitatively significant change over the first two years of teaching. This group also considered students' prior knowledge most often in their in-field teaching subject, rather than when discussing physics lessons.

Students' difficulties with specific science concepts. The one category that did not show any significant differences quantitatively across the first two years of teaching was in the area of students' difficulties with specific science concepts. By the end of their second year of teaching, most of the in-field and related-field physics teachers, when probed, were able to identify student difficulties with physics concepts in relation to the specific lesson they discussed in the interview. By the end of the second year all of the in-field teachers discussed areas in which students had difficulties with specific physics topics. This was reflected in the percentage of the majority of in-field teachers who were coded at the basic level in this category using the PCK rubric (60% before the first year of teaching and 80% after the first year of teaching). After the second year of teaching the in-field teachers were evenly split between the limited level of coding (40%) and basic (40%), and there was shift towards proficient for 20% of the teachers.

When the related-field teachers mentioned specific difficulties students might have with the topic of their described lesson, they were describing a lesson that was in their field of study. If these teachers were describing a lesson that was out of their field of study, they spoke very generally about finding out where students had difficulties by “asking questions” or “assuming they have no scientific knowledge”. This was reflected in the percentage of related-field teachers coded at each level of the PCK rubric. Before the first year of teaching this group of teachers was fairly evenly between the limited (57%) and basic (43%) categories. After the first year this group shifted, with a majority of teachers were coded as basic (71%).

The out-of-field teachers quantitatively and qualitatively showed no change across the first two years of teaching in the area of student difficulties with specific science concepts. Before their first year of teaching, the majority of these teachers were, on average (73%), coded as limited in the PCK rubric. By the end of their first year of teaching this group were evenly coded as limited (55%) and basic (45%), indicating a shift in consideration for students’ difficulties with science concepts. The qualitative data and the quantitative data were in agreement after the first year. From the start, this group of teachers were split between assuming what students would have difficulties with and where students, in general, might have difficulties with the lesson. However, when examining this group of teachers’ responses it was clear the ones who talked about not knowing where students’ might have difficulties with the material were in relation to a lesson being described out of their field area. When this group of teachers described lessons that were in their field area they were more likely to talk about or have assumptions regarding the specific difficulties students might have with the material. After the second year of teaching, all of the teachers who described a lesson in an out-of-field area talked about how they did not consider students' difficulties with specific concepts. This was reflected in the quantitative data where half of the teachers were coded as limited on the PCK rubric after their second year of teaching.

Trends in Classroom Practices

The practice data (weekly updates and observations) were examined to determine the practices the teachers primarily used in their classes over the first two years. The data showed that over the first year of teaching all of the beginning physics teachers struggled with how to teach physics in their classroom. Most of the teachers showed or talked about difficulties in classroom management, which supports the research on beginning science teachers (Feiman-Nemser, 2001) that understanding students does not come until later. All of the beginning teachers struggled with understanding how inquiry fit in their instruction, the different difficulties students would have with physics concepts, and the prior knowledge about physics students bring into the classroom with them. Therefore, it should not be a surprise that all of the teachers showed similarities in the classroom practices that were common across the two years of teaching and across the different teachers.

The common practices across the groups were mainly teacher-directed (e.g. lecture, working and reading from the textbook, problem solving, verification and directed inquiry laboratories, demonstrations, or worksheets). This should have been an expected result in terms of a beginning secondary science teacher (Angell, Ryder, & Scott, 2005), however it was hoped that the in-field teachers might utilize a variety of classroom practices and activities, including trying out different forms of inquiry in the classroom due to their comfort level with their physics content knowledge.

While this was not the case in terms of the common practices seen across the different field groups, the number of total different practices tried within the different groups was greatest for the in-field teachers. The in-field teachers typically used, on average, a total of ten different types of classroom practices over their first and second years in the classroom, some of which were student directed (such as student research projects and presentations, open inquiry laboratories, and student led discussions). The related-field teachers only used an average of seven the first year and eight the second year of teaching, while the out-of-field teachers used seven the first year and six the second year of teaching, all of which were teacher directed.

Teachers' Images of Physics Teaching

Etkina (2005) lists five areas that compose a teachers' PK. These areas are a knowledge of: (a) brain development, (b) cognitive science, (c) collaborative learning, (d) classroom discourse, and (e) classroom management and school laws. While this study did not specifically probe the teachers' PK it did examine the teachers' all-a-round idea of what it means to teach physics.

Throughout the school year, many of the physics teachers in this study showed a focus in their instruction around problem solving and using equations.

Many of the teachers showed tendencies of “teach as you were taught”. However, while this may have been expected to have been seen more from the in-field teachers, given that they had had many more physics content courses in their preparation, most of these teachers used more student directed methods of delivering the problem solving. Students worked in groups to solve the problems and at times good science discourse could be seen in these groups. The out-of-field teachers tended to present a single method of solving problems to the students, and some teachers didn’t allow the students to find their own way to a solution. However, there were in-field teachers that presented physics problem solving in this way as well.

This study also showed that the in-field teachers and the out-of-field teachers thought about physics teaching over the two years more than did the related-field teachers. The in-field teachers reflected on how they thought teaching was going to be in their first year, how their physics courses in their degree programs influenced their ideas of teaching physics, relations with their fellow physics teachers in terms of understanding the physics content, how much physics content was needed to teach physics, the order in which they taught the content, and the different techniques and strategies they were using in the classroom.

When it came to the out-of-field teachers, these teachers were also very reflective regarding teaching physics. While a couple of these teachers exactly followed the materials given to them by their mentors to teach the physics content, a few of the out-of-field teachers reflected on how previous experiences in science effected their science teaching and about the type of activities they were doing in the class. These teachers also spoke about the differences in teaching courses that were in their field of expertise versus teaching physics out of their areas of expertise. The general feeling of these teachers was that teaching physics was much harder for them due to the content involved.

The related-field teachers did not reflect much on teaching physics. When they did it mainly referred to how they were structuring the students in their class during the activities and classroom management. One teacher made the comment that “physics was not her passion”, and after the first year that teacher moved to teaching mathematics full time. Only one teacher reflected on how, in her second year, she felt more comfortable teaching physical science, because it was going to be the third time she had taught the course and she would like to incorporate more activities.

It is interesting that the study conducted by Sanders, Borko, and Lockhard (1993) found that in-field teachers were able to develop their lessons because they knew the resources and materials available to help them, however the out-of-field teachers searched for outside help to plan their lessons. The out-of-field teachers in that study also showed difficulties in deciding the important key concepts and in planning because they did not know how long lessons would take and how much content to cover. These are the same issues seen in the related-field and out-of-field teachers in describing their physics lessons. However, the most reflective related-field and out-of-field teachers saw this as a learning experience, rather than in a negative light. They used their experience in the classroom teaching physics over their first year to inform how they taught physics over their second year.

Chapter 5: Conclusion, Future Directions and Implications

This study set out to answer two questions regarding the knowledge and practices of beginning secondary science teachers:

- How do the content knowledge, pedagogical content knowledge, and practices of beginning secondary physics teachers change over two years?
- How does being in- or out-of-field impact these areas for this group of beginning physics teachers?

Using the models suggested by both Abell (2007) and Etkina (2007), as discussed in Chapter 2, the study identified areas of difference between the teachers in this study. Specifically, being in- or out-of-field impacted the content knowledge, certain areas of PCK, and the practices within teaching the discipline of physics. Both models for the structure of knowledge emphasized content knowledge as not only knowing the concepts, but also the relationships among those concepts. This then translated into PCK in the classroom, where the teachers were compared in their understanding of student difficulties in physics, the prior knowledge of students, and the pedagogical strategies chosen to appropriately teach the physics material.

When examining the qualitative and quantitative results together, three main conclusions can be drawn. First, these results support previous findings that beginning physics teachers have trouble understanding physics concepts themselves, and therefore have trouble identifying where students' will have difficulty in physics (Halim & Meerah, 2002). Halim and Meerah (2002) found that the knowledge teachers had of students' difficulties in physics and the strategies they chose to explain these concepts were dependent on the teachers' understanding of the physics content knowledge themselves. This finding is consistent with the results found in the current study, where the teachers who were most confident in the identification of student difficulties in physics were the in-field group of teachers.

Therefore, this study did indicate, as would be expected, that the out-of-field beginning physics teachers struggled with teaching physics in part due to a lack of physics preparation. This supports what Reynolds et al. (1988) found where teachers who were more confident in their knowledge of the subject matter were more likely to depart from the organization of the content found in the textbooks. However it was interesting that other comments during the different interviews with the out-of-field teachers showed a similarity to the other teachers in the different areas of PCK by the end of their second year of teaching.

It is possible however, that the ability for the teachers in this study to be able to identify student difficulties in physics a priori may have to do with the confidence the different groups had in their own physics content knowledge. Those that were more confident tended to make more assumptions about their students, disregarding common science education inquiry strategies, whereas those teachers that were less confident in their own knowledge of the subject tended to rely on probing their students for knowledge and understanding, rather than making assumptions. This seems to contradict what Ross et al. (1999) found in his study of teaching efficacy. In the Ross et al. (1999) study teaching out of one's field of expertise had a negative effect on teacher efficacy. The current study seems to indicate that this may not hold true for these beginning physics teachers. More often than not, it was the out-of-field teachers who showed higher teaching efficacy in teaching physics. These teachers showed the same characteristics as those with high teacher efficacy, where they seemed to be more willing to utilize teaching strategies beyond their comfortable abilities. However, there were still teachers in the out-of-field group who solely relied on the materials provided to them to teach their physics content, rather than planning appropriate lessons, and this may have been due to a lower teacher efficacy.

Second, in terms of the development of PCK, the quantitative results showed a significant movement of the combined in-field and related-field groups from just above a "limited" level of PCK understanding to just below a "basic" level of understanding for the main category of "knowledge of student learning in science", with no significant change for the out-of-field group in this main category. This has been seen in other studies, such as the one conducted by Angell, Ryder and Scott (2005), who examined how content knowledge was expressed in a pedagogical context, specifically in teachers' identification of misconceptions, prior knowledge, and the sequence of answers. Their study suggested there was no difference between a beginning and expert teacher in terms of the content understood by the teachers, however there was a significant difference in the pedagogical aspects. Specifically, a teacher in their framework could have a good understanding of the content, but less knowledge regarding the teaching strategies that might be used to teach the content. This was illustrated in this study when the in-field group of teachers were specifically examined.

There were many instances where the in-field teachers showed a strong command of physics content, but less of a command regarding how to teach the content. This was when the in-field teachers displayed characteristics of teaching how they were taught. While, Angell, Ryder, and Scott (2005) found no significant difference between the in-field and out-of-field teachers in either content or pedagogy, the teachers in this study showed a difference between the groups in terms of content, with less of a difference in terms of pedagogy. Regardless of the field group, this study showed that beginning science teachers are more likely to know about students' misconceptions, prior knowledge, and the strategies and representations that work well for teaching particular topics through their teaching in a classroom and working with students, rather than from their pre-service preparation (Grossman, 1990; Lee et al., 2007; van Driel, Verloop, & de Vos, 1998).

Third, when discussing the relation of physics teacher knowledge to the students they are teaching, the most important finding is that there does not appear to be a quantity and quality issue when discussing the PCK of in- and out-of-field physics teachers, as suggested by the quantitative results. There were examples of teachers in each of the three field groups who showed a quality of PCK that overall seems to allow them to adapt their instruction to better meet the needs of their students. Contrary to other studies of physics instruction (Gunstone and White, 1998, Tabanera, 1996), this knowledge does not seem to be a result of the physics content preparation in these teachers. The quality of PCK developed in these "special" teachers allowed them to adjust their instruction to represent science to their students in ways that were conducive to learning physics. However, for a majority of the out-of-field teachers and some of the related-field teachers, the results of the data suggested that overall, as a group, PCK was concentrated in one area and did not expand into other areas that would have suggested the ability to modify their instruction to better meet the needs of their students. For these teachers, the lack of robust PCK is probably related to the lack of physics knowledge that they hold. In either case, it is clear that areas of PCK most ready for change are directly related to the teachers' background knowledge, and that areas in PCK which are more conceptual are less likely to change in beginning physics teachers. The necessary change, and the direction of change, would be different depending on whether the teacher was in-field or out-of-field.

Future Directions for the Research

This study revealed many new questions that warrant further research. First, it might be worthy to exclusively use the PCK model suggested by Etkina (2005) in physics education to guide the next study of the development of PCK in physics teachers. The use of this model would provide four guiding areas for the collection of data: physics curriculum, student difficulties in physics, effective instructional strategies for particular physics concepts, and knowledge of assessment. With this in mind, there are six directions that this research could move towards in the future.

First, it would be interesting to specifically probe both the in-field and out-of-field teachers throughout the year regarding their beliefs about teaching physics, and the ways in which they handle their insecurities or confidences in the classroom. This study was able to speak to teachers teaching physics outside of their field of certification regarding both the in- and out-of-field classes they were teaching. A further study would include also include teachers who are certified to teach physics and are teaching another course outside of their area of expertise. This would provide an idea of how these teachers view teaching physics compared to other subjects, complementary to the findings from the out-of-field teachers in the current study.

Second, the results of this study indicate that the examination of the practices these beginning teachers employ in their classroom needs to extend further into the third year of teaching and beyond. This will allow the ability to discern any divergence in the types of practices the different field groups utilize to teach physics as the teachers are moving away from the “beginning teaching phase” of their careers, and are more able to concentrate on their students, rather than classroom management and administrative issues. This would fit well into the call for research from Duit, Neidderer, and Schecker (2007) on examining whether instructional practice in physics improves over time, especially if physics teachers are able to access current research findings and reflect on the teaching and learning of physics.

The third area for future research relates to an area of classroom practice that was not anticipated a priori to this study. The teachers in this study presented similar ways of solving physics problems to their students. The methods employed were very linear in nature and focused on a single methodology for solving problems. This phenomenon was not limited to the related-field and out-of-field teachers, as many of the in-field physics teachers showed a similar process of solving physics problems to their students. Since physics problem solving is an on-going research area in physics education in terms of how students employ problem solving (Sabella & Redish, 2007; Redish, Scherr, & Tuminaro, 2006) and how teachers employ problem solving techniques in the classroom (Heller & Hollabaugh, 1992; Heller, Keith, & Anderson, 1992; Larkin & Reif, 1979; Reif, 1981), more examination of secondary physics teachers' problem solving pedagogy is warranted in light of this study.

Fourth, a similar study could be conducted with master secondary physics teachers who have similar content preparation to the sample of beginning secondary physics teachers. These would include master teachers in each of the three field categories (in-field, related-field, and out-of-field) in order to compare to the beginning physics teachers. This lends to an interesting question of whether master physics teachers follow the same pedagogical practices as other master science teachers. Do master physics teachers include more student directed science inquiry practices in the classroom? If not, then are we unfairly judging the beginning physics teachers against a generally accepted view of how science should be taught?

A fifth area in which this research could lead is into the preparation of physics teachers who teach at higher levels of education. The result of this research has an impact on how physics undergraduate and graduate teaching assistants are (or are not) prepared to teach physics, as well as future physics professors. This group of physics teachers has good content preparation, but very little pedagogical preparation. There are many programs that have been developed around the country that provides structured teaching experiences for undergraduate and graduate students enrolled in a science degree program. Some of these programs have the intent to recruit students who might be interested in becoming teachers into a teacher preparation program, with the intent to supplement the low turn out of secondary science teachers from teacher education programs (e.g. The University of Colorado CUTeach and Teaching Assistant programs or the NSF Noyce Teaching Scholarship programs). Research with a focus on PCK development of these other groups with varying levels of content and pedagogical preparation could lend itself to the development of a continuum of knowledge in teaching physics. This would be a two-way continuum of physics content knowledge and PK, where PCK would be described and measured along this continuum of physics teaching. Once this has been accomplished then teacher effectiveness at each of the different areas of this continuum can be examined and addressed.

Finally, one last area that is missing from this current research is the student side of the equation. This study was focused on the beginning science teacher, and not the students in these teachers' classrooms. To really identify the impact of the level of physics content preparation and the level of PCK development for beginning physics teachers, the students should also be included in the research, similar to the study conducted by Goldhaber and Brewer (2000). The Goldhaber and Brewer study found that student achievement was related to the teacher's degree level in mathematics, where teachers with a Bachelors or Masters degree taught the higher scoring students. However, that study also found no impact for teachers with subject specific degrees in science. Including this aspect into future studies could confirm or disconfirm the Goldhaber and Brewer results and examine the effectiveness of membership in the different field groups on student understanding of physics can be examined. Without including this aspect in the research it is possible that regardless of whether the teacher is in-field or out-of-field, if the same practices are being used as this study found, the students are learning at the same rate. In this case whether the teacher is in- or out-of-field is not as important as providing professional development for good science inquiry teaching.

It is clear that this study is not only timely given past and future national legislation regarding the preparation of secondary science teachers and science education, but has also illuminated many other questions and paths for future research. This study is just the beginning of an intricate problem in teaching physics and one that can contribute to the research on the preparation of physics teacher education at all levels of teaching physics.

Implications for Physics Teacher Education

This study is of value to the field of secondary science teacher education and the physics education communities. How a beginning physics teacher represents physics to their students is important for maximization of student learning. Because of recently passed national acts calling for highly qualified teachers in the classroom and the production of a scientifically literate society, it is important to examine the extent to which secondary science teachers are prepared to teach out of their content area. This has implications for physics teacher education due to the high number of secondary science teachers being asked to teach physics when they do not have a certification or background to do so. Ultimately, this will impact the methods used to retain physics teachers in the classroom, providing physics specific mentoring to teachers teaching out of their content area, and the effectiveness of these teachers in teaching physics content to their students.

This study has brought to light three issues that are directly effected by the content knowledge preparation of secondary physics teachers. First, while it is not surprising that the in-field physics teachers showed a greater knowledge base of physics concepts, the concept maps showed that all of the teachers had difficulties with certain topics in physics (waves, heat, force, and fields). Since these are also some of the main topics that are taught in a secondary physics course these topics should be ones given extra attention in the physics content preparation of secondary physics teachers. It should also be the topics in which extra support is offered to those teachers teaching physics out of their field of expertise. This support needs to be extended from the preservice years through the first few years of teaching in the classroom, so as to provide a continual support base for beginning physics teachers as they progress through the stages of a beginning teacher moving from classroom concerns to the concerns of their students.

Second, this study could extend into the novice/expert research of secondary physics teachers quite easily. This research in physics education has shown that experts tend to have extensive, highly organized knowledge that they use efficiently in problem solving situations (NRC, 1999). Much like what was seen in the in-field concept maps, Chi and Glaser (1981) found that the organization of expert knowledge is hierarchical, and that the top level of the hierarchy contains the major principles or concepts of the domain (Chi & Glaser, 1981; Mestre, 2001). Chi, Feltovich, and Glaser (1981) found that novices in problem solving would categorize according to superficial attributes of the problem, jump immediately to the quantitative aspects of the solution, and discuss equations used for solving the problems rather than a justification and procedure for how to solve the problem (Mestre, 2001). This was not a focus of this research project, however, based on the results it is clear that using this type of framework as a lens for examining the effect of physics content knowledge on how beginning teachers approach teaching physics in the classroom might better illuminate any differences between in-field and out-of-field physics teaching. Theoretically the out-of-field teachers, who are novices themselves in the area of physics, are teaching novices of physics. It is unclear whether any effects of this would be larger than the effects of simply being a beginning secondary science teacher alone.

Third, this study also has implications for the preparation of undergraduate and graduate teaching assistants. It is clear from this research that a balance between physics content and pedagogical preparation is necessary to teach physics in ways commensurate with current research in cognitive science, physics education, and science education. The pedagogical preparation of physics teaching assistants varies widely across the country, and this research provides support to how this preparation effects the ways in which these teachers might be teaching. This study was just the beginning at examining differences between teaching in and out of an area of expertise. The other side of the research should be examining those who have the content knowledge but are teaching with varying levels of pedagogical preparation. This research therefore can contribute to the research on not only the preparation of secondary physics teachers, but also the preparation of graduate teaching assistants and future physics professors.

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APPENDIX A

PEDAGOGICAL CONTENT KNOWLEDGE INTERVIEW PROTOCOL

Participant		Interviewer	
Induction Group		T1/T2/T3/T4	
Date		DSS Recording Time	

1.	What do think constitutes a good lesson in science?
2.	Can you briefly describe a lesson or unit you taught that you thought was successful?
a.	What did you consider when planning your lesson/unit?
If not explicitly mentioned – use the following probes	
i.	Did you consider prior knowledge? If so, how?
ii.	Did you consider variations in students' approaches to learning? If so, how?
iii.	Did you consider students' difficulty with specific science concepts (misconceptions)? If so, how?
iv.	Is this a good example of inquiry in science? Why or Why not? If not, how would you change this lesson to reflect inquiry?

APPENDIX B

PHYSICS CONCEPT MAP PROTOCOL

How to make a concept map for Physics

You are being asked to prepare a concept map for your science content area. Concept maps are two-dimensional visual organizers used to represent concepts related to a certain theme or topic.

Procedure for creating a concept map:

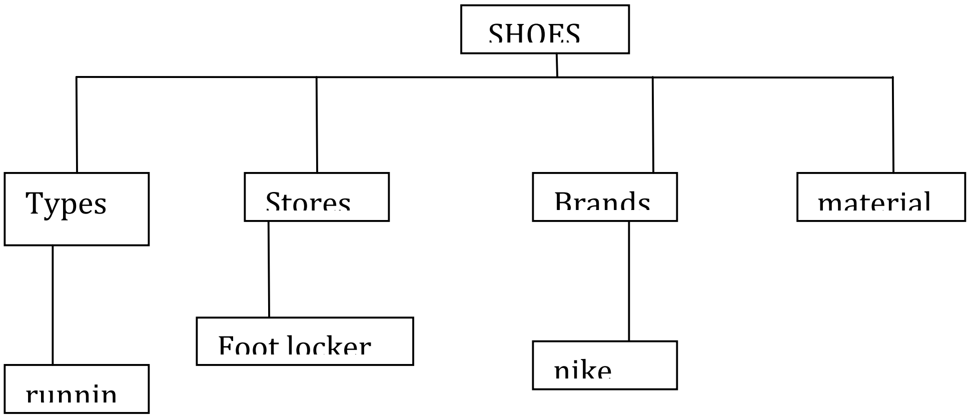
1. Categorize the words into groups:

Types of shoes:	Stores	Brands of shoes	Shoe materials
Running	Foot Locker	Nike	Leather
Boots	Marks	Adidas	Plastic
Sandals			Rubber

Creating groups allows you to see the connection between the words.

2. Create a hierarchy using the groups and words that have been provided.

Below is a map that represents a hierarchy. The term on top encompasses the greatest number of topics, while the terms below are more specific.

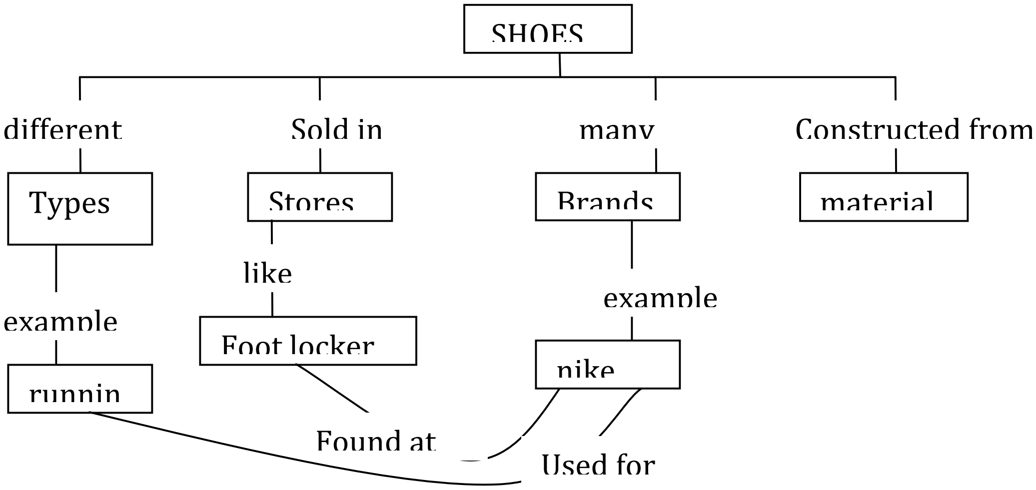


Creating a hierarchy demonstrates the relationship of larger concepts to smaller ones.

3. Use linking words and cross-links in your map. Use linking words that describe the relationship between the concepts, and can be thought of as creating sentences between concepts. For example, Shoes are sold in Stores, Shoes come in different Types. Use cross-links to show the relationships

between concepts that are not directly related. For example, Nike shoes can be found at the Foot Locker.

The example concept map below has a hierarchy, cross-links and linking words.



Here are the 10 words to use for your own concept map. You should not use any resource when you are drawing this map, only your understanding of the domain.

Physics terms

Energy
Motion
Newton’s Laws
Force
Conservation
Waves
Fields
Work
Heat
Light

You can scan and email the completed map back to us, fax the completed map to: 480-787-6558, or mail the completed map to:

Julie Luft
P.O. Box 870911
Science Education
College of Education
Arizona State University
Tempe, AZ 88287-0911

APPENDIX C

WEEKLY UPDATE TELEPHONE INTERVIEW PROTOCOL AND CODING RUBRIC

Teacher Name: Interviewer:

Grade/Subject: Date:

Schedule Type Traditional (< 60 mins) Block (> 60 mins)

Class meets: Daily 2-4 days a week

Update# 1 2 3 4 5 6 7 8` 9mu

Protocol:

Before

- Read participant file before calling participant --if you are not familiar with the participant.
- Call/e-mail ahead of time to set a time to talk. Follow-up frequently if you don't get a response right within 48 hours.
- Decide which class to collect information on (refer to teacher's schedule). Updates should reflect the composition of classes (e.g., 75% bio/ 25% physics= 6 interviews in biology and 2 interviews in physics).
- Make sure you have the audio recorder and that it is set correctly, and that you have checked the batteries.

During

- Have the teacher describe the lessons and clarify what they taught each day, how they taught it, the origin of the lesson, and what materials they used.
- Block schedule- code a block day for two days
- Type this review, if possible.
- Make sure you ask for the artifacts from the lessons at the end of the interview – establish how you will get these.

After

- Upload file to the computer, mark interview as complete, and file the update sheet. Check board indicating that interview was completed.

Interview questions (on even interviews, ask question 4)

1. How did things start this year? Compared to last year?
    a. As teacher talks about events, ask for more details.
    b. If good points are presented, ask about what is not going well? Or, if bad points are presented, as what is going well.

The goal of this probe is to capture the current issues for the teacher in terms of instruction

2. What are you looking forward to most in terms of your teaching science? Least?

The goal of this question is to understand the developmental concerns of the teacher at this time.

3. What types of professional development activities did you engage in over the summer that you didn't tell us about? What type of professional development activities are you engaged in currently or have plans to participate in?

4. Have you taken on any new responsibilities this year? If so, what are they? Were there any responsibilities that you declined this year? If so, what are they?

5. Is there any additional information that you would like to share regarding your teaching that we have not talked about, that would be helpful for us to know?

DAY	OBJECTIVE	ACTIVITIES / STRATEGIES	MATERIALS	ASSESSMENTS
MONDAY DATE______				
TUESDAY DATE______				
WED DATE______				
THURS DATE______				
FRIDAY DATE______				

	Mon	Tues	Wed	Thurs	Fri
Lesson consisted of: Date:					
• Bell-work/Opening activity					
• Teacher-led lecture without discussion					
• Teacher-led class discussion					
• Teacher directions					
• Teacher-led demonstration					
• Teacher-led simulation					
• Teacher-led review activity- For test					
• Teacher-led review activity- hwk/prev. day					
• Teacher-led review activity of class assignment					
• Inquiry laboratory/activity					
• Guided inquiry laboratory/activity					
• Directed inquiry laboratory/activities					
• Verification laboratory/activity					
• Process / skills laboratory/activity					
• Student research project					
• Students reading assigned material					
• Students work/reading from a textbook					
• Students complete a worksheet					
• Student presentations					
• Video/film/DVD					
• Homework assigned					
• Homework collected					
• Out of class experience/field trip					
• Admin task					
• Non-science instruction					
• Interruption					
• No class					
• Other					
Classroom organization:					
• Individual					
• Whole group					
• Small group, 2-4 students					
• Cooperative learning					
• Lesson from previous year					
• Lesson from published source					
• Lesson is from school/district curriculum					
• Lesson from mentor/colleague					
• Lesson created by teacher					
• Lesson from Internet					
• Other					
Materials/Technology used:					

- Laboratory – Professional equipment
- Laboratory - Common items

- Computer - Internet
- Computer - Software
- Computer - PowerPoint
- Probeware
- Other

Assessments used: Date:

- District/State assessment
- Department assessment
- End of Unit/Chapter Test (formal test)
- Quiz
- Rubric
- Lab report
- Interactions with students (questioning)
- Multiple choice
- Matching
- Fill in the blank
- Short answer
- Essay
- Lab journal/notebook/logbook
- Other

Examples of Other codes:

Lesson	Organization	Materials	Assessments
• Addressing student concerns • Concept maps • Review (games)		• Lab journals • Office supplies	• Vee maps • Concept maps

Descriptions:

<u>Under "Lesson consisted of"</u>

Bell work – To get students settled and focused, lasting a short period of time (approximately 5-10 mins), and having a set procedure (e.g., copying information from the board).

Teacher-led lecture without discussion – When the purpose of dialogue is to disseminate information. It includes questions by teacher and answers by student. Used as verification by teacher.

Teacher-led class discussion – When purpose is to promote dialogue between teacher and student. In this dialogue questions are open-ended and lead to discussion, interaction, and brainstorming.

Teacher led review – For test – This activity allows the students to review for the test and may include games, review discussions, or written review activities.

Teacher-led demonstration –To provide students with a visual or auditory experience to see a phenomena or event that they would otherwise not observe. Demonstrations can be conceptual or teach a skill.
Teacher-led simulations- Students apply concepts, analyze situations, solve problems, or understand different points of view. Typically, situations, concepts or issues are provided in a condensed and simplified form.

Reading assigned material – Students are reading materials that the teacher copies off, school magazines related to science, or articles. This is not coded when reading a textbook.

Inquiry laboratory/activity – The students develop their own question to explore, along with determining the experiment and modes of data collection.

Guided inquiry/activity – The teacher provides the question, and the students are free to answer the question as they see fit.

Directed inquiry laboratory/activity – The teacher provides the question and the mechanism to answer the question.

Verification laboratory/activity – The students are told or know the concepts they will see during the activity. They follow written/verbal guidelines to identify the concept.

Skill-based laboratory/activity – The laboratory/activity involves the learning of some basic skill (e.g. learning measurement).

Assignment – Discussion is of an assignment to be done outside of class (e.g. homework).

Administrative task – Large amount of time is spent in taking care of administrative tasks (e.g. stamping journals without another activity going on).

Non-science instruction – Large amount of time is spent on instruction that is not related to science.

Under "Classroom organization"

Individual – Students are working individually on a task (e.g. worksheet). The only interaction is with the teacher.

Whole group – Students are groups together as a class. This is coded with lecture or class discussion.

Group work 2-4 students – Students work together in groups of 2-4.

“Lesson from” – This should be coded who regard to who or what supplied the lesson. For example if a mentor teacher supplies a textbook lesson, it is coded as a mentor teacher.

Lesson from published source – Lesson is from outside of the school or district.

Under “Assessments used”

Lab journal/notebook/logbook – Used to assess students but is not used just in the scientific sense of the term “lab journal”. Also used for questions, reflections, etc.

APPENDIX D

CLASSROOM OBSERVATION PROTOCOL

I. Background Information

Teacher Name: ___________________________ School: ________________

Subject Observed: _____________________________ Grade Level: ______

Observation is (circle one) in-field/ out-of-field based on major & content

Start Time: _______ End Time: ______ Date :_______

Schedule Type Trad (45-60mins) _____ Block (60-over) ______

# of classroom meetings a week 5______ 2-4 __________

Observer: _______________________ Observation # (circle one) : 1 2 3
4

Number of students in class ____

Brief description of students in class:

Socio-Economic Status
M/F Ratio
school uniforms
ethnic breakdown
etc

Protocol regarding the observational coding:

- The first priority should be to take notes about the lesson. This will be recorded under III. Description of events over time.
- Record the most salient event during the 5 minute data collection periods. For example, students may work individually and the may work in groups. If they spend more time individually, then code the 5 minute segment as individual.
- Under cognitive activity, code what happens and not the intent of the lesson.
- At the end of the lesson code the 10 items for “quality” of instruction.
- Try to observe a variety of classes that represent the content areas that are taught.

II. Contextual Background and Activities

A. Objective for lesson (ask teacher before observing):

B. How does lesson fit in the current context of instruction (e.g. connection to previous and other lessons)?

*write down agenda

C. Classroom setting: (space, seating arrangements, room for the lesson, if desks are fixed or moveable, posters (science vs. non-science), student work, is it conducive to lab work (or teaching science) etc. Include a diagram).

D. Any relevant details about the time, day, students, or teacher that you think are important? Include diagram. (i.e.: teacher bad day, day before spring break, pep rally previous hour, etc.)

III. Description of events over time (indicate time when the activity changes)

Make sure that you describe the activity. If you can, collect artifacts.

Time	Description of events

IV. Evaluation of the class in 5-minute increments

Code the prevalent activity during the 5-minute increment (3+ minutes out of the 5).

Time in minutes	0-5	5-10	10-15	15-20	20-25	25-30	30-35	35-40	40-45	45-50	50-55	55-60
Instruction												
Organization												
Student												
Cognitive												

Key ---*Note:* Type of Instruction - requires two codes: type of activity and organization (Ind, Group etc.)

Activity codes

B	bellwork
Lec	teacher led lecture w/o discussion
LWD	teacher-led class discussion
Dir	teacher directions
Dem	teacher-led demonstration
Sim	teacher-led simulation
RT	teacher-led review -test
RH	teacher-led review – homework/ previous day
RI	teacher- led review – in-class assignment
LI	inquiry lab/activity
LG	guided inquiry lab/activity
LD	directed inquiry lab/activity
LV	verification lab/activity
LP	process/skills lab/activity
RP	research project
SR	student reading assigned material
TB	students work from textbook
WK	students complete worksheet
SP	student presentations
V	video/film/DVD
HA	homework assigned
HC	homework collected
FT	out-of-class experience (field trip)
AD	administrative task
Q	quiz
I	interruption
NS	non-science instruction
O	other ________________________ (please specify)

Organization Codes

WG	whole group
SG	small group
CL	cooperative learning (ex: roles, individual accountability, etc.)
Ind	students working individually on assignments

Student Attention to Lesson

LE	low attention, 80% or more of the students off-task. Most students are obviously off-task – heads on desks, staring out of the window, chatting with neighbors, etc.
ME	medium attention, 50% of students are attending to the lesson.
HE	high attention, 80% or more of the students are attending to the lesson. Most students are engaged with the activity at hand – taking notes or looking at the teacher during lecture, writing on the worksheet, most students are volunteering ideas during a discussion, all student are engaged in small group discussions even without the presence of the teacher

Cognitive Activity –This should be coded for the students who are participating (not for the intention of the lesson)

1 Receipt of Knowledge--(i.e., lecture, reading textbook, etc.) Students are getting the information from either a teacher or book. This generally includes listening to a lecture, going over homework or watching the teacher verify a concept through a demonstration or working problems at the board. The critical feature is that students are not doing anything with the information.

2 Application of Procedural Knowledge-Students apply their knowledge (from Bloom's taxonomy: Use a concept in a new situation or unprompted use of an abstraction. Applies what was learned in the classroom into novel situations in the work place.). This typically involves students using what they have learned, doing worksheets, practicing problems, or building skills. The critical feature is simple application of information or practicing a skill.

3 Knowledge Representation-organizing, describing, categorizing. Students manipulate information. This is a step beyond application. Students are re-organizing, categorizing, or attempting to represent what they have learned in a different way – for example, generating a chart or graph from their data, drawing diagrams to represent molecular behavior, concept mapping.

4 Knowledge Construction-higher order thinking, generating, inventing, solving problems, revising, etc. Students create new meaning. Students

might be generating ideas, or solving novel problems. For example generating patterns across three different data sets, drawing their own conclusions, articulating an opinion in a discussion or debate.

5 Other-e.g. classroom disruption, no science in the lesson, administrative activity

APPENDIX E

PEDAGOGICAL CONTENT KNOWLEDGE RUBRIC (LEE ET AL., 2007)

Category 1: Knowledge of Student Learning in Science

Elements	Level		
	Limited	Basic	Proficient
Prior knowledge	Teacher has limited or no acknowledgement of students’ prior knowledge, or is cognizant but does not incorporate it into lesson plans.	Teacher recognizes students’ prior knowledge and uses it in a limited way.	Teacher draws upon students’ prior knowledge and constructs lessons that build upon this knowledge.
Variations in students’ approaches to learning	Teacher has limited or no consideration for variations in students’ approaches to learning, and frequently uses one type of approach to instruction.	Teacher acknowledges variations in students’ approaches to learning while planning lessons and uses different approaches without student contributions.	Teacher acknowledges variations in students’ approaches to learning and allows students various opportunities to engage in science learning in their own way.
Students’ difficulties with specific science concepts	Teacher has limited understanding about students’ learning difficulties associated with lessons, and makes few or no attempts to minimize those difficulties during planning or instruction.	Teacher recognizes students’ learning difficulties and modifies the lesson to a limited degree.	Teacher considers students’ learning difficulties during the process of planning lessons and addresses these in the lesson.

Category 2: Knowledge of Instructional Strategies

Elements	Level		
	Limited	Basic	Proficient
Scientific inquiry (Science-specific strategies)	Teacher implements a lesson that verifies a previously covered concept or directs the student in how to proceed through the lesson. None of the essential features of classroom inquiry are present (NRC, 2000),	Teacher adopts scientific inquiry for teaching lessons and addresses some (2-3) of the essential features of classroom inquiry, which includes having the learner: engage in scientifically oriented questions; give priority to evidence in responding to questions; formulate explanations from evidence; connect explanations to scientific knowledge; communicate and justify explanations.	Teacher adopts scientific inquiry for teaching lessons and incorporates most (4-5) of five essential features of classroom inquiry into lesson.
Representations	Teacher uses representations (e.g. illustrations, examples, models, analogies, and demonstration) and materials that are ineffective, scientifically inaccurate, or are not linked to students' knowledge and/or experience.	Teacher uses representations and materials that are pedagogically limited and/or scientifically undeveloped or limited, with an attempt to link to students' prior knowledge and experience.	Teacher uses representations that are pedagogically effective and scientifically accurate and are well- linked to students' prior knowledge and experience.

APPENDIX F

CONCEPT MAP CODING PROTOCOL (UNPUBLISHED)

Developed and modified based on:

Hough, O'Rode, Terman, & Weissglass (2007). Using concept maps to assess change in teachers' understandings of algebra: a respectful approach. *J Math Teacher Educ*, 10, 23-41.

In proposing this type of analysis, we acknowledge that there are word restrictions (provided words and limitations on the words provided), a value on the coherence of knowledge represented in the map, and differentiation among participants in creating their concept maps.

With this said, we propose 3 areas:

Correctness – the accuracy of *all* of the links that are written down

> This area addresses the question: What does the teacher know accurately?

Connectedness – an evaluation of the correct cross-links and chunks within the concept map

> This area addresses the question: What is the sophistication of the linkages between the correct ideas?

Complexity – an evaluation of the structure of the presented knowledge, with no regard to correctness

> This area addresses the question: What is the depth and breadth of understanding with the provided terms?

Definitions

Node – a word/concept linked to one or more other words/concepts
Link – a direct connection between two nodes on successive levels
Cross-link – a connection between two nodes on either the same level or other levels
Successor – a linked word one level down from a node
Width – the greatest number of concepts at one particular level on the map
Depth – the length of the longest chain on the map
Chunk – a group of linked concepts for which the leading concept has at least two *correct* successors

Correctness

1. All links are assessed for correctness (cross-links and links)
2. The following rating is provided for each link (L_i):

   0 = the link is missing or incorrect

   1 = a link is present, but there are no words or propositions on the link

   2 = the link is represents a basic or superficial idea that while acceptable shows limited or "scientifically thin" knowledge

   3 = the link represents an idea that is scientifically acceptable, but more could be added to clarify the connection

   4= the link shows a detailed and sophisticated understanding that is "scientifically rich"
3. All of the scores are added for each link and cross-link, and the final score is divided by the number of nodes. This corrects for the fact that some teachers chose to add extra nodes. The formula is:
   $((L_1) + (L_2))$/total number of nodes = Correctness

Connectedness

1. The correct chunks are determined. A chunk is a group of linked concepts for which the leading concept has at least two *correct* successors. The number of correct links for each chunk are counted (do not include cross links in this count). This is the number that is used in the equation for connectedness and is given the abbreviation of 'CNL'. Procedural note: in cases where links can be assigned to more than one node always select the link that creates a chunk if applicable
2. The correct cross-links are determined (CCL).
3. A score for the connectedness is:
   nCCL + nCNL=connectedness

Complexity

Procedural note: when redrawing the map in hierarchical form nodes are assigned to a hierarchical level based on their distance from the overarching concept.

1. The width of the concept map is assessed (W). This is the greatest number of concepts at one particular level on the map.
2. The depth of the concept map is assessed (D). This is the length of the longest chain on the map.
3. The number of cross-links are counted (CCL).
4. The formula:
   (W x D) x CCL =complexity

BIOGRAPHICAL SKETCH

Jennifer Jean Neakrase was born in Evanston, Illinois, on June 16, 1975. She received her elementary education at Lions Park Elementary School, and her middle school education at Lincoln Junior High School. Her secondary education was completed at Prospect High School in Mt. Prospect, Illinois. In 1993, Jennifer entered Indiana University, Bloomington, Indiana, majoring in astronomy/astrophysics with a minor in mathematics. She graduated with honors from the Astronomy Department. In August 1997 she entered graduate studies in astronomy at New Mexico State University, Las Cruces, New Mexico. After two years, she transferred to Arizona State University, Tempe, Arizona, continuing her study of astronomy. While in this program, Jennifer received an NSF Graduate (GANN) fellowship. She graduated with a master in science in physics in May 2003. At this time she continued graduate studies with the College of Education, pursuing a doctorate in curriculum and instruction in science education. She was a student member of many organizations, including the Astronomical Society of the Pacific, the American Association of Physics Teachers, the National Association for Research in Science Teaching, and the American Educational Research Association. Jennifer was also a member of the Phi Kappa Phi honor society.