UNIVERSITY OF CINCINNATI

Date: May 13, 2004

I, Danielle E. Dani, hereby submit this work as part of the requirements for the degree of:

Doctor of Education

in:

Curriculum and Instruction

It is entitled:

The Impact of Content and Pedagogy Courses on Science Teachers’ Pedagogical Content Knowledge

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THE IMPACT OF CONTENT AND PEDAGOGY COURSES ON SCIENCE TEACHERS’ PEDAGOGICAL CONTENT KNOWLEDGE

A dissertation submitted to the
Division of Research and Advance Studies
Of the University of Cincinnati

In partial fulfillment of the
Requirements for the degree of

DOCTORATE OF EDUCATION (Ed.D.)

In the Division of Teacher Education
Of the College of Education, Human Services, and Criminal Justice

2004

by

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Abstract

The purpose of this study was to investigate how a professional development effort, which immerses teachers in learning science content by inquiry and models sound pedagogical practices, promotes change in teachers’ inquiry thoughts and actions. More specifically, the study first aimed to describe middle school science teachers’ beliefs and pedagogical content knowledge (PCK) for teaching middle school physical science. Second it examined how the Physics by Inquiry (PBI) course influenced their beliefs and PCK. And third, it investigated how the teachers’ beliefs and PCK influenced their practice. Participants in this study consisted of teachers who took part in Physics by Inquiry and who taught physical science in middle grade classroom following their participation.

The study followed a qualitative case study design and made use of in-depth interviews and observations to examine teachers’ knowledge, beliefs, and practice. The study drew on the theoretical framework of a knowledge base for teaching, especially the construct of PCK to create interview questions and formulate initial coding categories for analysis. Findings from this study indicated that the teachers differed markedly in terms of their PCK and coherence among its elements. The PCK of the teacher with 23 years of teaching experience was less coherent and integrated than the teacher with 3 years of teaching experience. Furthermore, Physics by Inquiry influenced teachers’ PCK in similar ways, namely their beliefs and knowledge about science teaching, student learning, and instructional strategies. The translation of the teachers’ PCK into their practice was mediated by several factors including contextual factors, beliefs about students, and concerns for coverage and control. Finally, the teachers’ PCK had roots in their early
experiences with science, college content courses, teaching experience, and *Physics by Inquiry*. 
Dedication

To my parents Elie and Therese Dani. Without your loving, multifaceted, and unending support, I would not be who I am or where I am today.

Thanks mom and dad…
Acknowledgements

The author wishes to express her appreciation to many individuals who were involved in some aspect of this study:

Dr. Keith Barton for answering all of my questions, reading all my drafts, and inspiring me with his academic excellence and integrity. His help and guidance have been indispensable. Keith, when I grow up, I want to be just like you!

Dr. Bob Burroughs for his thoughtful feedback and his practical advice, “right when I needed it.”

Dr. Annette Hemmings for teaching me what it means to let someone tell his or her story.

Dr. Glenn Markle for the insights he provided into what this work can lead to.

Dr. Helen Meyer, her feedback and insights were invaluable not only to this project but also on being a science educator and a faculty member in academe.

Dr. Piyush Swami, the chair of my committee, whose insights into all aspects of this work helped shape and refine the final copy. His faith in my ability and his constant support were key to my success. His advice was invaluable throughout my doctoral studies and will resound throughout my career.

My friends who gave me support, perspective, and their ears, including Sara Rombo, Debbie Kinne, and Kathy Koenig

My brothers, Michel and Eddy, and my family who patiently listened to me talk about this study over the past few years.

And most of all thanks to you Wael for encouraging and supporting me, providing help and prodding, throughout the entire dissertation process.
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CHAPTER 1: INTRODUCTION

The purpose of this study was to investigate how a professional development effort, which immerses teachers in learning science content by inquiry and models sound pedagogical practices, promotes change in teachers’ inquiry thoughts and actions. More specifically, the study first aimed to describe middle school science teachers’ beliefs and pedagogical content knowledge (PCK) for teaching middle school physical science. Second, it examined how the Physics by Inquiry (PBI) course influenced their beliefs and PCK. And third, it investigated how the teachers’ beliefs and PCK influenced their practice. Participants in this study consisted of two teachers who took part in Physics by Inquiry and who taught physical science in middle grade classroom following their participation. One taught in an urban setting and the other in a suburban setting. Data sources included standardized and semi-structured interviews, open-ended classroom observations, and a collection of classroom artifacts. The resulting data were examined with the intent of discerning influences on and changes in teachers’ beliefs, knowledge, and practice towards constructivist/inquiry based practices. Data was also examined to determine the factors that mediated change in teachers’ thoughts and actions.

The findings of this study indicate that, as a result of their participation in that program, first- and second- order changes occurred within the thoughts and practices of the participants. Furthermore, several cultural and political dilemmas that mediated the change process were identified. These dilemmas included beliefs about students’ abilities, concerns for coverage and control, depth of content knowledge, administrative support, availability of resources, and teacher autonomy. These factors facilitated or inhibited the development of pedagogical content knowledge and its adoption in practice. These
findings were compared with the existing literature on teacher change, beliefs and pedagogical content knowledge in an effort to more firmly establish a conceptual framework regarding the factors that influence the change process. Implications of these findings suggest that to promote lasting change, professional development programs should (a) explore teachers’ beliefs, (b) be situated in practice, (c) immerse teachers in learning content knowledge through inquiry, (d) emphasize and model the different aspects of inquiry-based instruction, (e) incorporate an action research component, and (f) acknowledge and tend to individual and contextual factors that mediate change by developing collaborations for support.

Background

Science Education is in a continual process of reform at the heart of which is scientific inquiry. Keys and Bryan (2001) stated, “Today’s reform rhetoric has revived the concept of inquiry as representing the essence of science education” (p.631). The goals of reform documents such as the National Science Educational Standards (NSES) (NRC 1996) center on the development of scientific literacy in students and promote inquiry as the “central strategy for teaching science” to meet those goals. Because teaching and learning science through inquiry promotes scientific literacy in students, these statements about the reforms in science education suggest that science teachers need to be teaching science though inquiry because this instructional strategy represents the essence of science as described in NSES. Since teachers are considered the most influential factor in educational reform intended to promote student achievement (Duffee & Aikenhead, 1992) and scientific literacy, it is not surprising that teachers, both inservice and preservice, have become the target of reform efforts. In recent years,
preservice education has undergone reform and is advocating more constructivist teaching strategies such as inquiry. Reform efforts that target inservice teachers are also underway. Recent literature suggests that, to meet the goals of the reforms, teacher professional development efforts need to immerse teachers in learning content knowledge through inquiry, should model inquiry practices, and would do well to address teachers beliefs as they construct a knowledge base for teaching science through inquiry.

Researchers in the field of science education believe that teachers, as professionals, are key players in any reform endeavors because of their traditionally central role in the curriculum process (Tobin et al., 1994; Clark & Peterson, 1986). A teacher as a professional is one who makes decisions based on information and data rather than on previous practice and tradition alone. This is in contrast to the public perception of teaching as a more or less natural activity requiring no special training or expertise (Hatch, 1999). The aspect of the professional teacher that is most relevant to the present study is specialized knowledge. Specialized knowledge is knowledge that is exclusive to the professional, the teacher, and is not possessed by laypersons. Shulman (1987) identified a professional knowledge base needed for good teaching that consists of seven categories: curriculum, content, general pedagogy, and pedagogical content knowledge, as well as knowledge of learners, educational contexts and educational aims.

In qualifying the knowledge base for teaching, the National Research Council (2001) states that teachers with differentiated and integrated content and pedagogical knowledge will have greater ability than those whose knowledge is limited and fragmented to plan and enact lessons that help students develop deep integrated understanding of the scientific enterprise. Similarly, Anderson (1987) defined good
science teachers as “those adequately prepared to help their students achieve an attainable form of high [scientific] literacy” (p.4). Such statements about the role of knowledge in teaching are supported by a body of research documenting that science teachers’ knowledge and beliefs have a profound effect on all aspects of their teaching (Hashweh, 1987; Smith & Neale, 1991), as well as on how and what their students learn (Bellamy, 1990; Magnusson, 1991). These statements highlight the role of preservice and inservice science teacher education. Not surprisingly, “ever since the birth of the science curricular reform movement in the late 1950s, a large portion of science teacher education has been connected in some way to attempts to introduce curricular change” (Anderson & Mitchener, 1994, p.36).

Several professional organizations, including the National Board of professional Teaching Standards (NBPTS), the Interstate New Teacher Assessment and Support Consortium (INTASC), and disciplinary societies such as the National Science Teachers Association (NSTA) recommend that teacher education programs in science, among other things:

- Unify, coordinate, and connect courses in science, mathematics, and technology with methods courses and field experiences;

- Teach content through the perspectives and methods of inquiry and problem solving, as well as illustrate and model in content courses, methods courses, and school-based field experiences a wide variety of effective teaching and assessment strategies that are consistent with the national education standards for science.
Significance

A case study that examines the influence of *Physics by Inquiry* on the beliefs and
PCK of science teachers, and the relationship between these two constructs and practice, is important for several reasons. First, the study echoes the major emphasis running through the recommendations of the professional organizations for the preparation and professional development of science teachers that consists of partnerships and collaborations between teacher education programs and science departments. Rubba et al. (1993) and Stake et al. (1993) emphasize the need for pre-service teacher preparation programs to pair or combine science content courses with science methods courses focused on teaching the same content. Little has been done to study the influence of such partnerships on the development of teachers’ knowledge and beliefs. Research has emphasized partnerships between K-12 science teachers, the community, museums, scientists, and engineers (Haakonsen, 1993; Ramey-Gassert & Walberg, 1994). Furthermore, professional organizations propose that science departments assume greater responsibility for offering college-level courses that provide teachers with strong exposure to appropriate content and that model the kinds of pedagogical approaches appropriate for teaching the content. This implies that science teachers need to experience, as learners, the instruction they are being prepared to use. Hence pre-service and in-service science teacher education programs should emphasize inquiry, construction and evaluation of students’ explanations, incorporate substantial classroom-based components in which students have meaningful teaching opportunities, and emphasize student reflection as well as instructor and peer support and feedback. Because it incorporates elements of these recommendation, this study has the potential of
Informing us about how such collaborative courses, which model inquiry and target teachers’ learning of the content through inquiry, impact the development of science teachers’ beliefs and PCK for teaching by inquiry. Findings from this study have implications for preservice science teacher education programs as well as future inservice programs.

Despite the above-mentioned recommendations and the emphasis in the *NSES* on inquiry, most teachers are inadequately prepared, in both content knowledge and scientific inquiry experiences, for the teaching of science through inquiry (Berns & Swanson, 2000). Findings from research studies on the professional development of science teachers echo the professional organizations’ recommendations. Several researchers have identified problems associated with professional development activities available to science teachers, including their short duration and lack of focus on content (Supovitz & Turner, 2000; Cohen & Hill, 1998). Supovitz and Turner (2000) identified six critical components of effective science professional development. Effective professional development efforts should (a) model inquiry teaching, (b) be intensive, (c) sustained, (d) be based on teachers’ experiences with students, (e) deepen content knowledge, and (f) be linked to other aspects of school change. This study investigates a professional development effort that incorporates most of the criteria for professional development. Its findings have the potential to provide empirical evidence for the importance of some of the criteria for effective professional development. Furthermore, it promises additional insights into the influence of specific professional development efforts on beliefs, knowledge, and practice, as well as the interaction between these elements.
Finally, several researchers called for longitudinal studies that focus on the day-to-day events in the real world of classroom life in regards to implementing inquiry-based instruction (Crawford, 2000; Supovitz & Turner, 2000). Such studies should emphasize the roles and knowledge of teachers as they implement inquiry practices (Keys & Bryan, 2000). For example, Keys and Brian state, “As yet, we have little knowledge of teachers’ views about the goals and purposes of inquiry, the processes by which they carry it out, or their motivation for undertaking a more complex and often difficult to manage form of instruction” (p. 636). A research agenda on teacher beliefs about inquiry should recognize the integral relationship between beliefs and actions (Keys & Bryan, 2001). This study is situated within this research agenda. Its findings will potentially shed light onto teachers’ views about the goals and purposes for inquiry, the processes by which they carry it out, and their motivations for undertaking this more complex and often difficult to manage form of instruction. As such, this study begins to address the gap in the research.

In conclusion, the purpose of this study is to investigate the influence of a physics course for teachers on the knowledge, beliefs, and day-to-day practice of science teachers. The *Physics by Inquiry* course combined in-depth study of physical science concepts with a way to teach the content, and was a result of a partnership between a science department and a college of education. The course set up was in compliance with the recommendations of the science reform documents, professional organizations, and effective professional development. This study has the potential to address the identified gap in the research on the influence of such partnerships on the development of teachers’ knowledge and beliefs. It further will add to our understanding of the relationship between knowledge, beliefs, and practice. Findings from this study have implications for
preservice and inservice teacher education, serving to inform the design and conduct of content and methods courses as well as effective professional development practices.

**Theoretical Framework**

This study is grounded in a transformational model of teacher reform that recognizes the importance of teacher change and teacher cognition. More specifically, this study is rooted in the normative-reeducative perspective on planned change strategies targeting individuals’ beliefs and knowledge that play an important part in guiding teacher actions and practices.

*Normative-Reeducative Change*

This study is rooted in Chin and Benne’s (1969) formulation of the normative-reeducative approach to individual and small group planned change strategies, as opposed to similar approaches that target organizational change or the empirical-rational and power-coercive approaches Chin and Benne describe. A normative-reeducative change strategy is voluntary and naturalistic in nature. It is based on the underlying assumption that change is enhanced through deep reflection on beliefs and practices, and it is focused on providing autonomy for and nurturing growth in the people that make up the system as well as increasing the problem-solving capabilities of the system (Richardson & Placier, 2001). Within this approach, dialogue between teachers or with the “other” (Fenstermacher, 1994) has been viewed as a critical element in the change process. The “other” consists of people outside the teacher’s classroom (e.g. change agents, staff developers, researchers etc.) who are concerned with helping the teacher change.

Several characteristics have been attributed to the change process that teachers go through within this approach. First, the direction of change originates in the individuals
partaking in the process such as the teachers themselves and the “other” they are collaborating with. Second, teachers change all the time and over their careers (Richardson & Placier, 2001). Their change could take the form of first-order change or second-order change (Cuban, 1988) and might be “prompted, promoted, or supported by discussions with other teachers, and evaluation by an administrator, a workshop, experience with an often-tried activity that no longer works, an article in a practitioner or research journal, a new grade level or population of students, etc.” (Richardson & Placier, 2001, p. 908). First-order changes consist of minor changes in the organization of the classroom, the curriculum, and other factors. Second-order changes entail different ways of thinking, teaching, and learning.

Central to the normative-reeducative perspective on change is an emphasis on teachers’ cognition and constructivist learning and teaching. The emphasis on cognition reflects an interest in different groups of cognitive constructs; ones that influence the change process, ones that are acquired within it, or ones that affect its outcomes (Richardson & Placier, 2001). An example of cognitive constructs that influence the change process consists of teacher perspectives (Zeichner, Tabachnic, & Densmore, 1987). Examples of constructs acquired within the change process include pedagogical content knowledge (Magnusson, Krajcik, & Borko, 1999; Grossman, 1990; Shulman, 1987) and content knowledge (Borko, Lalik, & Tomchin, 1987). Examples of cognitive constructs that affect the outcomes of the change process include beliefs (Richardson, 1996) and metaphors (Tobin, 1990). The present study is concerned with two of the above-mentioned constructs, namely beliefs and pedagogical content knowledge. The importance of these constructs is magnified within a constructivist view of learning and
teacher change where beliefs and knowledge are thought of as critical in terms of what and how teachers make sense of what they are studying and as guides for instruction (Richardson, 2003a; 2003b; Resnick, 1989; von Glaserfeld, 1989). The following sections describe the constructs of beliefs and pedagogical content knowledge.

Teacher Beliefs

Several researchers maintain that beliefs are precursors to change and that the teacher is the “crucial change agent in paving the way to reform” (Haney & McArthur, 2002). In that respect, beliefs become the focal point of change efforts. This is not surprising since several researchers suggest that beliefs may constitute stumbling blocks in the reform of k-12 classroom instruction.

Because beliefs play a crucial role in educational change and reform, it is fitting to define beliefs and characterize them. Richardson (2003b) defines beliefs as “psychologically held understandings, premises, or propositions about the world that are felt to be true” (p. 2). Nespor (1987) stated that beliefs are deeply personal, stable, lie beyond individual control or knowledge, and are usually unaffected by persuasion. Furthermore, there is a general agreement that beliefs are not necessarily logically structured (Richardson, 2003b), but may be clustered into belief structures or systems. Rokeach (1968) compared the belief structure to an atom and explained that some beliefs form the nucleus in a central-peripheral system. The central beliefs are more important and therefore more resistant to change. The central beliefs hold the less important peripheral beliefs together to form the belief structure. Centrality of a belief is related to its connectedness to other beliefs held by an individual. Finally, Green (1971) suggested that an individual may possess beliefs that are incompatible or inconsistent. When this
occurs, incompatible beliefs are held in different clusters. Green further proposed that this incompatibility will not be resolved unless the beliefs are set side by side and examined for consistency. As such, this process of investigation has become a component in professional development programs that attempt to develop and change beliefs (Richardson, 2003b).

Several terms are used interchangeably with beliefs, and are referred to as beliefs in disguise (Pajares, 1992). These terms include attitudes, values, judgments, opinions, ideology, perceptions, conceptions, conceptual systems, dispositions, implicit theories, internal mental processes, action strategies, rules of practice, and perspectives. An important distinction to be made in this study, one that remains a point of disagreement in teacher cognition studies, is the differentiation between the constructs of belief and knowledge. The study takes the philosophical stance adopted by Richardson (2003b) whereby beliefs are propositions that are accepted as true by the individual holding the belief, but, as opposed to knowledge, they do not require epistemic warrant. In that respect, the major goal of education becomes to develop, modify, and transform beliefs and belief systems (Green, 1971), and might be facilitated in part through inviting students to question their beliefs and allowing them to interact with knowledge.

Finally, beliefs are rooted in vivid memories of past experiences. Richardson (1996) suggests these past experiences consist of personal experience, experience with schooling and instruction, and experience with formal knowledge.

**Pedagogical Content Knowledge**

The term pedagogical content knowledge (PCK) was introduced by Shulman (1987) as part of his conceptualization of a professional knowledge base needed for
teaching. A major contribution of Shulman’s formulation of the knowledge base was its acknowledgement of the importance of subject-specific knowledge in effective teaching, namely PCK, and its role in the transformation of subject matter. Without such transformation, teachers’ knowledge and understandings will remain tacit and unavailable for teaching, and hence they would not be able to help students develop the desired understanding of science (Anderson, 1987).

Shulman (1987) defines PCK as “that special amalgam of content and pedagogy that is uniquely the province of teachers, their own special form of professional understanding” (p.8). It is a teacher’s understanding of how to help students understand specific subject matter. Simply, PCK is concerned with the ways of representing and formulating subject matter that make it comprehensible to others. It provides teachers with an understanding of how particular subject matter topics, problems, and issues are organized, represented, and adapted to the diverse interests and abilities of learners, and then presented for instruction (Shulman, 1987). PCK enables teachers to translate complex or difficult ideas into concepts that students, as novices, could grasp (Kennedy, 1998), that is, it refers to teachers' interpretations and transformations of subject matter knowledge in the context of facilitating student learning (van Driel et al., 1998).

Several researchers have described the components of PCK. Shulman (1987) identified two dimensions of PCK: knowledge of research on students’ misconceptions, and knowledge of representations of subject matter. Based on Shulman’s two elements (i.e. knowledge of comprehensible representations and knowledge of learner difficulties), several conceptualizations of PCK exist in the literature. Scholars have included other aspects of Shulman’s knowledge base for teaching within PCK. For example, Grossman
(1990) perceived PCK as consisting of knowledge of representations and strategies, student learning and conceptions, curriculum available for teaching, and purposes for teaching a particular subject. Similarly, Marks (1990) added knowledge of curriculum and media as a component of PCK. However, this scholar also included subject matter knowledge within PCK. In a similar fashion, Cochran, DeRuiter, and King (1993) included subject matter in their conceptualization of PCK. Based on a constructivist view of teaching, these scholars renamed PCK as pedagogical content knowing (PCKg) to acknowledge its dynamic nature. Compared to Shulman’s formulation, their definition of PCKg was broader and included “a teacher’s integrated understanding of four components of pedagogy, subject matter content, student characteristics, and the environmental context of learning” (Cochran et al., 1993, p.266). The notion of integration was also central to Fernandez-Balboa and Stiehl’s (1995) conceptualization of PCK. They identified knowledge of subject matter, the students, instructional strategies, the teaching context, and one’s teaching purposes as components of PCK. Finally, Magnussson, Krajcik, and Borko (1999) conceptualized PCK for science teaching as consisting of five categories, building on Grossman’s (1990) definition and Tamir’s (1988) work on assessment. In this model, components of PCK included orientations toward science teaching, knowledge about science curriculum, knowledge about students’ understandings of specific science topics, knowledge about assessment in science, and knowledge about instructional strategies for teaching science. Smith (1999), and Carlsen (1999) added knowledge of the nature of science as a component of PCK. Even though there is no universal conceptualization of PCK, there is general agreement as to its nature and its inclusion of Shulman’s two key elements. van Driel et al. (1998)
conclude that all scholars agree that PCK refers to the teaching of particular topic and thus may differ considerably from subject matter per se.

Finally, Shulman’s differentiation of PCK from content knowledge has recently been questioned on epistemological grounds (Segall, 2003; McEwan & Bull, 1991). For example, McEwan and Bull (1991) contend that all subject matter is pedagogical in some real and important sense. These authors critique the view that pedagogical content knowledge is an area of teacher expertise separate from content knowledge. Along these lines, Marks (1990) discussed some ambiguities in PCK and presented examples in which it is impossible to distinguish PCK from either subject matter knowledge or general pedagogical knowledge. Despite these critiques, I agree with Doster, Jackson, and Smith’s (1997) view that the vast majority of teachers, science educators, and scientists who have shaped science teacher education believe that PCK is sufficiently justified by the practical value it has had in organizing our thinking and planning for program development. Similar to them, “whether or not PCK exists as a philosophical ‘reality,’ we have chosen to act as if it does” (Doster, Jackson, & Smith, 1997, p. 54).

This study uses an adaptation of Magnusson, Krajcik, and Borko’s (1999) conceptualization of PCK for science teaching, as theoretical framework. Hence, for the purposes of this study, PCK consists of knowledge about science curriculum, knowledge about students’ understandings of specific science topics, knowledge about assessment in science, and knowledge about instructional strategies for teaching science.

Relationship between Beliefs/Knowledge and Practice

This study subscribes to Clark and Peterson’s (1986) reciprocal theory of the relationship between the domains of teacher thought and action. These researchers
propose that teachers’ actions are in large part caused by teachers’ thought processes, including beliefs and knowledge, which are in turn affected by teachers’ actions. However, Richardson (2003b) affirms that the question remains unanswered as to whether beliefs guide actions, actions guide beliefs, or that they interact such that beliefs or actions may be dominant and affect the other depending on other factors. Other factors may include the physical setting or external influences (e.g. school, principal, community, and curriculum), degree of autonomy (flexibility in planning), teacher empowerment, and task demands (Clark & Peterson, 1986).

A Model of Change

I propose a model of change that incorporates aspects of each of the study’s theoretical frameworks, highlighting the relationships among them. The model presented in Figure 1 was developed by adapting and modifying Magnusson, Krajcik, and Borko’s (1999) conceptualization of PCK to represent the framework of the study. The model depicts each of the four domains discussed previously and which are central to the change process. These are (a) professional development, (b) PCK, (c) teachers’ beliefs, and (d) teachers’ practice. Professional development programs instigate change and promote the development of the PCK and its components. PCK does not constitute the sum of its parts. Rather it represents a synthesized whole that results from the transformation of its parts and their integration in practice. This implies that professional development programs should be based on teachers’ authentic practice with students, especially because contextual factors play an important role in the development of PCK and translation to practice. Finally, teachers’ beliefs represent a lens through which new knowledge is acquired, synthesized, and integrated into practice. Beliefs are an essential
aspect of this model of change because they influence or shape the change process. The model will be used to assist the reader in visualizing the several parts of the research literature on teacher change and the role of beliefs and knowledge in the process.

Conclusion

The constructs of teacher beliefs and PCK have the potential to define important dimensions of expertise in science teaching that can guide the focus and design of pre-service and in-service teacher education programs. We need to know about the role of teachers’ conceptions and alternative conceptions about the teaching of science on the teachers’ knowledge, understanding, and practice to be able to consider emphasizing and addressing these conceptions in teacher education programs (Magnusson et al., 1999). This is important because teachers’ knowledge and beliefs act as important filters through which they come to understand the components of PCK and, just as students’ existing knowledge and beliefs serve as starting points for their learning, are important resources and constraints for the implementations of the current reforms. Pajares (1992) asserted that beliefs are “the best indicators of the decisions individuals make throughout their lives” (p. 307). Such views are grounded in a transformational model of science teaching reform. This model recognizes the importance of teachers’ beliefs, acknowledging that teachers will experience tensions in the change process, encouraging teacher reflection, and creating interactive environments for fostering conceptual connections (Bryan & Abell, 1999; Parke & Coble, 1997). Additionally, Nespor (1987) stated that teachers rely on their core belief systems rather than academic knowledge during decision making because educational environments are ill-structured and not amenable to step-by-step problem solving.
Finally, research on naturalistic normative-reeducative change process is complex and focuses on teacher change. It makes the assumption that change is present and attempts to answer questions similar to what Richardson and Placier (2001) propose: How do teachers change? In what direction? And why and when do teachers change? Are there different approaches to change, and what affects those differences? As those researchers claim, these questions are designed to inform theories on individual change. Remaining true to this perspective, the present study attempts to answer questions relating to how and why a professional development effort, following a naturalistic normative-reeducative approach, influences the beliefs and PCK of science teachers, and in turn, how and why the teachers’ beliefs and PCK influence practice.

Looking Ahead

The purpose of this study was to examine how a university-based *Physics by Inquiry* course influenced the PCK and practice of middle school science teachers. The course involved learning physics subject matter through inquiry, and engaged participants in activities intended to promote change in their practice. The study specifically aimed to investigate the influence of *Physics by Inquiry* on PCK, and the relationship between PCK and practice.

The study is grounded in the theoretical tenets of a knowledge base for teaching. It follows a qualitative case study research design characterized by the use of several data collection strategies and iterative interpretative analyses. These processes serve to provide in-depth understandings and conclusions to inform the theoretical framework of PCK and its sources.
Before moving into a detailed discussion of the methods and findings of the study, it is fitting to review the extant literature on PCK, the methods used to study it, and the relevant research findings. The next chapter targets research on the components of PCK, professional development efforts addressing them, and their relationship to practice.
Figure 1. A Model of Change. Adapted and modified from Magnusson, Krajcik, and Borko, 1999.
CHAPTER 2: LITERATURE REVIEW

In view of the goals of the science education standards and of researchers’ and professional organizations’ recommendations for teacher education, this study is concerned with teacher change. More specifically, the study is concerned with promoting beliefs, knowledge, and practices consistent with advocated reforms. In that respect, I aim to investigate the influence of a professional development effort on inservice science teachers’ beliefs, PCK, and practice. The professional development effort in question consists of a course focused on learning and teaching physics through inquiry. This chapter will present past research that addresses teacher change with a focus on studies emphasizing science inservice professional development, followed by a discussion of research targeting teacher beliefs, PCK, and the relationship between these two constructs and practice. The latter part of the review is organized according to the model proposed in chapter 1 of this manuscript. In that sense, it will begin with an overview of the various methodologies used to study beliefs and PCK, followed by research on teachers’ beliefs of science, science teaching, and science learning, and research on PCK. In each of the sections of the review, studies that influence the relationship of each of the domains to practice will be highlighted. The chapter ends with a conclusion that summarizes the findings from the reviewed studies and presents implications for future research.

Professional Development

Past research on professional development programs intended to promote teacher learning and effect changes in their practice suggests that such efforts are ineffective (Smylie, 1989; Guskey, 1986). A lot of the failure is attributed to a top-down approach,
which disregarded the teacher as a professional and in most cases consisted of the following steps (Van Driel, Beijaard, & Verloop, 2001):

1. The core elements of the innovation were defined by curriculum developers or policy makers.

2. A description was made of the teaching behavior expected of teachers who would loyally implement the innovation, or of the skills teachers should acquire.

3. A series of training sessions or supervision activities were designed, aimed at developing the desired teaching behavior. In particular, “single shot interventions,” like inservice workshops, were used to achieve this aim.

4. Usually, the teachers did not adopt the implementation in the manner intended, or initially observed changes in the teachers’ behavior did not persist.

5. The preceding four steps were repeated, but in a modified manner, or after the innovation itself had been redefined.

There have been many efforts to improve on this model of professional development, and, in recent years, researchers and educators “have forged a remarkable level of national consensus about what may constitute effective science professional development (Supovitz & Turner, 2000, p. 964; Loucks-horsely, et. al., 1998; Abdal-Haq, 1995; Little, 1993; Sparks & Loucks-horsely, 1990; Fullan, 1991). They propose that professional development can most likely be considered of high quality if it includes a set of six components, namely it; (a) immerses participants in inquiry, questioning, and experimentation and therefore models inquiry forms of teaching, (b) is intensive and sustained, (c) engages teachers in concrete teaching tasks and is based on teachers’ experiences with students, (d) focuses on subject-matter knowledge and deepening
teachers’ content skills, (e) is grounded in a common set of professional development standards and shows teachers how to connect their work to standards of student performance, and (f) is connected to other aspects of school change.

The majority of the research in this area addresses large-scale systemic change initiatives that investigate the relationship between professional development and teaching practices (Supovitz & Turner, 2000; Allen & Lederman, 1998) and workshops targeting teachers’ learning of specific inquiry oriented science curricula (e.g. Yerrick et al., 1997). These efforts target organizational change or represent compulsory short-term curriculum-based workshops. As such these studies will not be reviewed in this chapter. Rather, consistent with the study’s theoretical framework and intent, this part of the literature review will focus on reform-oriented individual or small group science teacher professional development efforts, within the normative-reeducative approach, that reflect effective professional development practices. Six journal articles and one research document within this category were identified in the literature. The following sections describe the different purposes of these studies, their characteristics, populations and sampling methods, the instruments used, data analyses, findings, and limitations.

**Theoretical Frameworks and Purposes**

Several researchers have investigated the influence of individual and small group professional development efforts designed to promote change in teacher beliefs and practices toward reform-oriented, inquiry-based instruction (Bell et al., 2003; Posnanski, 2002; Westerlund et al., 2002; Luft, 2001; Hogan & Berkowitz, 2000; Supovitz et al., 2000; Radford & Ramsey, 1996). These studies used a variety of theoretical frameworks including von Glaserfeld’s (1989) framework of constructivism (Posnanski, 2002;
Westerlund et al., 2002; Radford & Ramsey, 1996), Cobb and Yackel’s (1996) social constructivist perspective (Hogan & Berkowitz, 2000), Gilmore et al.’s (1996) conceptualization of contextual learning experience (Westerlund et al., 2002), adult learning theories (Luft, 2001), transformation models of teacher reform (Hogan & Berkowitz, 2000), and various models of teacher education, professional development, and theories of practice (Posnanski, 2002). This reliance on a multiplicity of theoretical and conceptual frameworks is not surprising when we consider the variety of conceptual alternatives that guide teacher preparation (Feiman-Nemser, 1990).

Just as these studies used a variety of different frameworks, they had various purposes. Study purposes included the impact of professional development on teachers’ beliefs (Luft, 2001), knowledge (Bell et al., 2003; Radford & Ramsey, 1996), attitudes (Supovitz et al., 2000), and self-efficacy (Posnanski, 2002) toward inquiry-based instruction, their use of inquiry-based instruction (Bell et al., 2003; Luft, 2001; Hogan & Berkowitz, 2000; Supovitz et al., 2000), and professional development factors that affect teachers’ practices (Hogan & Berkowitz, 2000).

**Characteristics, Populations, and Sampling**

The development programs described in the studies had a variety of characteristics, targeted different populations, and relied on various sampling technique to determine study participants. The professional development programs reviewed in this study exhibit one or more of the following five program characteristics. First several professional development programs included a focus on content, modeling of inquiry practice, and participation in inquiry activities (Bell et al., 2003; Supovitz et al., 2000; Radford & Ramsey, 1996). Second, some programs involved teacher participation in
authentic research experiences in various content areas (Westerlund et al., 2002; Luft, 2001; Hogan & Berkowitz, 2000; Supovitz et al., 2000). Specific content areas targeted in these studies include life science, environmental science, ecology, physics, and a mixture of school-curriculum based topics. Third, several programs focused on identifying teachers’ beliefs or helping teachers explore and reframe their knowledge, beliefs, and inquiry practices (Bell et al., 2003; Posnanski, 2002; Luft, 2001). Fourth, a lot of the programs emphasized individual or collaborative reflection on program experiences and resulting practices (Bell et al., 2003; Luft, 2001). Finally, two programs involved collaborations between scientists and science educators (Radford & Ramsey, 1996) or scientists, science educators, and local teacher leaders (Hogan & Berkowitz, 2000).

These studies also targeted a variety of populations. Populations targeted in the professional development programs included elementary teachers (Hogan & Berkowitz, 2000), middle level teachers (Bell et al., 2003; Radford & Ramsey, 1996), induction and experienced secondary teachers (Westerlund et al., 2002; Luft, 2001) and teachers from all levels (Posnanski, 2002; Supovitz et al., 2000). Study participants from these populations were selected through convenience sampling. The only difference occurred in the case of Hogan and Berkowitz’s (2000) study involving 14 similar professional development efforts at various sites. In this study, 4 sites were purposefully selected as cases based on demographic variability. Sample sizes in the various studies ranged from less than 25 (Bell et al., 2003; Westerlund et al., 2002; Luft, 2001), to 31-45 (Hogan & Berkowitz, 2000; Radford & Ramsey, 1996), to 90 (Posnanski, 2002), to 1,475 (Supovitz et al., 2000).
**Design and Data Sources**

The professional development studies presently reviewed rely on pre and post quantitative (Supovitz et al., 2000), qualitative (Bell et al., 2003), phenomenologic (Westerlund et al., 2002), and mixed methodological designs (Posnanski, 2002; Luft, 2001; Hogan & Berkowitz, 2000; Luft & Pizzini, 1998; Radford & Ramsey, 1996). Data sources for the studies included fixed choice (Posnanski, 2002; Westerlund et al., 2002; Hogan & Berkowitz, 2000; Supovitz et al., 2000; Radford & Ramsey, 1996) and open-ended response (Bell et al., 2003; Westerlund et al., 2002) surveys. Open-ended response surveys targeted the understanding and use of inquiry teaching and the impact of the professional development effort. Fixed-response survey items targeted program effects, attitudes, and comfort with science teaching and knowledge about ecological topics. These surveys relied on 5-scale rating. Other data sources included content tests, journals, learning logs, portfolios, interviews, and classroom observations. Interviews consisted of structured and semi-structured protocols. For example, Luft (2001) used both a semi-structured interview protocol targeting teachers’ beliefs and a structured interview consisting of 8 questions from the Teacher Pedagogical Philosophy Instrument (Richardson & Simmons, 1994) targeting teachers’ didactic, transitional, conceptual, and constructivist beliefs about teaching science. Similarly classroom observations were either open or protocol-based. Of the studies, Luft (2001) and Hogan and Berkowitz (2000) relied only on protocol-based observations. For example, Luft used the 5-scale Extended Inquiry Observation Rubric (Luft, 1996b) to score field notes resulting from open observations. A score of 5 represented the highest competency in extended inquiry use while a score of 1 represented the lowest. However, while Luft observed all
participants, Hogan and Berkowitz only observed four. Finally, most of the studies consisted of year long efforts involving summer workshops, academic year follow-ups, and classroom visitations. The only exception was Supovitz et al. (2000) who conducted a three-year longitudinal study following the summer workshop.

**Data Analysis**

Studies of professional development of teachers’ inquiry beliefs and practices used qualitative and quantitative methods of analysis. Quantitative methods used included analyses of variance in quasi-experimental designs (Radford & Ramsey, 1996), dependent t-tests (Luft, 2001), comparison of means (Hogan & Berkowitz, 2000), and hierarchical linear modeling (Supovitz et al., 2000). Luft (2001) used non-parametric analyses to identify trends between study participants regarding beliefs about teaching science. She further used qualitative methods of inductive and deductive analyses respectively to construct cases and conduct cross case analysis around teachers’ metaphors, definitions of inquiry, and experiences with extended inquiry instruction. Similarly, Westerlund et al. (2002) and Hogan and Berkowitz (2000) relied on inductive analysis that yielded the analytic categories and subcategories concerned with the different types of ecological inquiries (Hogan & Berkowitz, 2000), and similarities and differences between teachers’ perceptions of inquiry teaching and the program (Westerlund et al., 2002).

**Findings**

This section reviews the findings from the seven journal articles and documents discussed so far. These findings are presented in three subsections related to the influence of the professional development efforts on teachers’ beliefs, knowledge, and practice of
inquiry teaching. It is important to point out that the reviewed professional development efforts positively impacted participant teachers’ beliefs, knowledge and practice.

Beliefs

Findings from five of these studies indicated statistically significant increases in teachers’ preparation to teach inquiry (Supovitz et al., 2000), self-efficacy for science teaching, and attitudes toward science (Posnanski, 2002; Westerlund et al., 2002; Supovitz et al., 2000; Radford & Ramsey, 1996). These studies further reported that the majority of teachers who participated in their program highlighted the importance of students designing and conducting independent scientific inquiry and felt more comfortable teaching students that way. Similarly, Hogan and Berkowitz (2000) reported that teachers in their study had fewer concerns about using inquiry-based ecology in the schoolyard after participating in their programs. On another note, Luft (2001) reported that science teachers participating in the Inquiry Based Demonstration Classroom exhibited non-significant changes in their beliefs about science teaching, even though some participants’ exhibited subtle change. The researcher reports that these subtle changes occurred more often in induction teachers as compared to experienced teachers. Luft (2001) also reports that the Inquiry Based Demonstration Classroom resulted in participants modifying their views about their role in the classroom and about inquiry instruction, valuing their experiences with implementing an extended inquiry cycle and the insight they gained into student learning, and valuing the support and assistance they gained during the various follow-ups.
**Knowledge**

Teachers who participated in the reviewed studies exhibited significant increases in their content knowledge (Bell et al., 2003; Westerlund et al., 2002; Hogan & Berkowitz, 2000; Radford & Ramsey, 1996) and/or knowledge of inquiry (Bell et al., 2003; Posnanski, 2002; Radford & Ramsey, 1996). For example, Bell (2003) reported that teachers’ knowledge of environmental concepts and essential features of inquiry increased as a result of participation in their program. Specifically, teachers’ knowledge increased with respect to the evidence, explanations, evaluations of explanations, and designing and conducting investigations aspects of inquiry. As a result of this increase in content knowledge, teachers reported increased confidence in their ability to teach students using inquiry-based science (Radford & Ramsey, 1996). Similarly, Hogan and Berkowitz (2000) reported that teachers’ knowledge about ecology and research in ecology increased significantly as a result of their participation in the program, while Posnanski (2002) reported increases in teachers’ understanding of the various components of inquiry-based and problem-solving strategies.

**Practice**

Five of the reviewed studies reported program influences on participants’ classroom use of inquiry instruction. For example, Bell et al. (2003) found a significant increase in the percentage of teachers using inquiry practices (compared to pre-test), while Supovitz et al. (2000) found significant increases in teachers’ uses of these practices. Similarly, Luft (2001) reported that most of the teachers involved in the inservice program utilized extended inquiry practices in their classrooms. However, experienced teachers were slightly more likely to use extended inquiry cycles more often
than the induction teachers, even though the induction teachers experienced more shifts in beliefs. Furthermore, Hogan and Berkowitz (2000) reported that, as a result of participation in their program, elementary teachers taught science outside more often and based their activities on questions about the schoolyard. These researchers also state that the teachers’ styles of teaching underwent change. For example, more teachers were observed to use styles consistent with ecological inquiry more frequently. In order of sophistication, these styles include natural history observations, teacher-guided activities, and student directed investigations. Most changes occurred in the direction of natural history observations when initial content knowledge proficiency was low. As proficiency in knowledge increased, shifts occurred toward the remaining more desirable styles of inquiry. As a result of these observations, the authors conclude that teacher change in the use of inquiry-oriented practices happens in stages (Hogan & Berkowitz, 2000). Finally, Westerlund et al. (2002) reported that the four observed teachers transferred some of the experiences they learned in the research laboratories into their classrooms. These transfers consisted of specific techniques and authentic inquiries-based on researched topics.

**Implications**

The reviewed studies provide implications pertaining to professional development program characteristics and areas for future research. Several researchers recommend that professional development efforts involve collaborations between scientists, science educators, and teams of teachers (Posnanski, 2002; Hogan & Berkowitz, 2000; Supovitz et al., 2000; Radford & Ramsey, 1996) while emphasizing content knowledge (Bell et al., 2003; Hogan & Berkowitz, 2000), scientific investigations and research (Westerlund et
al., 2002; Radford & Ramsey, 1996), as well as a mix of inquiry-oriented pedagogical strategies related to the content (Westerlund et al., 2002; Hogan & Berkowitz, 2000; Radford & Ramsey, 1996). An additional recommendation centers on allowing participants to explore their beliefs about inquiry and insights gained from practice through a process of reflection (Posnanski, 2002; Luft, 2001; Hogan & Berkowitz, 2000).

These researchers also make suggestions for future research. They call for studies that explain connections between professional development efforts, teacher background, and environmental factors (Posnanski, 2002). These studies should be longitudinal and should attend to teachers’ beliefs and the relationship between their beliefs and their practice (Posnanski, 2002; Luft, 2001).

**Limitations**

Only one of the reviewed studies reports limitations associated with its design. These limitations related to small sample size and convenient sample (Luft, 2001). Even though the remaining studies do not report limitations, the majority of them rely on fixed-response survey research (Posnanski, 2002; Hogan & Berkowitz, 2000; Supovitz et al., 2000; Radford & Ramsey, 1996), protocol-based observations (Luft, 2001; Hogan & Berkowitz, 2000), and quantitative modes of analysis to report teachers’ beliefs, knowledge and inquiry practice (Posnanski, 2002; Luft 2001; Hogan & Berkowitz, 2000; Supovitz et al., 2000; Radford & Ramsey, 1996). Hence they rely on teachers’ self report of their practices. While these studies provide basic understanding of the factors that promote change in teachers’ beliefs, knowledge, and practice of inquiry, they constrain teachers’ responses and do little to reveal the subtleties involved in the change process. Furthermore, these studies provide little to no information about the specific contextual
influences that may contribute to science teachers’ decisions to completely adopt, selectively adopt or avoid the adoption of the different aspects of inquiry teaching. Finally, most of the studies fail to investigate the relationship between beliefs, knowledge, and actions, or the nature of teachers’ interaction with their students.

Summary

This body of research indicates that professional development efforts within the normative-reeducative perspective result in significant changes in teachers’ beliefs, knowledge, and inquiry-based classroom instruction. Teachers were shown to exhibit significant increases in attitudes, self-efficacy, and views about their roles as teachers. Furthermore, significant gains in content knowledge and knowledge of inquiry were reported, and these gains paralleled the implementation of inquiry based practices in the teachers’ classrooms.

As a result, three important program characteristics have been identified as necessary components for the initiation of change. These components include immersing participants in learning the content through inquiry, collaborations between scientists and science educators as they model inquiry-based practices, and teacher reflections on inquiry beliefs and practices.

The majority of the studies rely on pre and post survey research focusing on change in teachers’ attitudes and self-efficacy for teaching inquiry. Only one of the studies relies on observations and qualitative analyses to document the nature and occurrence of teachers’ classroom practices. The remaining studies rely on self-report data or use protocol-based observations to document these practices. These studies provide little to no information about the specific contextual influences that may
contribute to science teachers’ decisions to use inquiry-based practices or some of its salient aspects. Finally, most of the studies fail to investigate the relationship between beliefs, knowledge, and actions, or the nature of teachers’ interaction with their students. This becomes important because the literature has often shown that curriculum reforms, however, well-meaning, are shaped and altered by teachers’ beliefs and understanding of the local context (Bryan, 1998; Brickhouse & Bodner, 1992; Cronin-Jones, 1991). A research agenda for inquiry should recognize the integral relationship between beliefs and actions (Keys & Bryan, 2000).

Beliefs and Pedagogical Content Knowledge

This part of the chapter reviews research studies in the area of science teachers’ beliefs, PCK, and the relationship between these constructs and practice. The first section provides an overview of the various methodologies used to study beliefs and PCK. The second section targets research on science teachers’ beliefs. It is noteworthy to point out that multiple researchers have studied various aspects of teachers’ beliefs and a multitude of studies exist in the literature. However, the present work does not aim to present an exhaustive review of studies concerned with science teachers’ beliefs. Rather, it is only concerned with research surrounding science teachers’ beliefs about science and their beliefs about science teaching and learning. The third section reviews research studies concerned with PCK and each of its components. The section is based on Gess-Newsome and Lederman’s (1999) edited book that synthesizes the research targeting PCK. The second and third sections also review studies that relate each of the constructs to teachers’ practice.
Assessment of Beliefs and PCK

Most studies on PCK and the more recent studies on beliefs are qualitative in nature and require cognitive techniques such as interviews (Baxter & Lederman, 1999). Baxter and Lederman present an overview of the methods and techniques that can be used to study PCK. These researchers classify these methods into three categories: (a) convergent and inferential techniques; (b) concept mapping, card sorting, and pictorial representations; and (c) multi-method evaluations. These categories also subsume methods used to study beliefs.

Convergent and inferential techniques consist of fixed-response Likert-type self-report scales, multiple choice items and short answer formats. These methods have been commonly used to assess attitudes and beliefs (Abd-El-Khalick and BouJaoude, 1997; Gess-Newsome et al., 1993; Lederman et al., 1994). Only one research study is identified that uses such methods, namely multiple choice questions, to assess PCK (Kromrey & Renfrow, 1991). Critiques of convergent and inferential techniques target the assumption inherent to these techniques, namely that there exists a set of right answers.

The second group of methods consists of concept mapping, card sorting, and pictorial representations. The assumption underlying these methods is that they represent the organization of information as it is in long term memory (Baxter & Lederman, 1999). For concept-mapping, researchers typically ask participants to provide a set of terms about a topic and ask them to group the terms in a way that makes sense to them. The participants are also asked to describe the most important terms and the relationships that exist among them. In this tradition, researchers have used cards (Grossman, 1990) where the researchers select the terms, or pictorial representations (Gess-Newsome & Lederman,
1993) where participants have the freedom to select terms and depict the relationships among them as they see fit in a format of their choice. Critiques of these representations of knowledge included the ambiguity associated with what they represent and the transient nature of the knowledge they depict.

The third category of methods used to study beliefs and PCK consists of multi-method techniques. Research studies in this category employ a variety of methods to assess beliefs and PCK, including interviews (Conceptions of Teaching Science: Hewson & Hewson, 1989), video-stimulated recall, concept maps, and journals (Smith & Neale, 1991; Hashweh, 1987). In these studies, data collection is typically followed by triangulation of these multiple sources. Critiques of multi-method techniques target their time- and effort-intensive nature (Baxter & Lederman, 1999).

**Beliefs about Science**

Because reformers want students to reason about scientific ideas and to learn to evaluate arguments and evidence, it has been suggested that teachers need to believe that these activities are an integral part of the work of the disciplines (Kennedy, 1998). In fact, teachers who were the most effective in creating positive changes in student conceptions of the nature of science were found to emphasize inquiry-oriented questioning, active student participation, and problem-solving in their instruction (Lederman, 1986). Consequently, the need for teachers to understand the nature of the subject itself has been acknowledged.

At the most basic level, the nature of science (NOS) “refers to the values and assumptions inherent to the development of scientific knowledge” (Lederman, 1992, p.331). This implies an understanding of how knowledge is generated, tested, argued
about, and justified; and what is taken for granted, what makes something anomalous, what makes something important, how deviations from expectations are treated, and the epistemological variations that exist (Kennedy, 1998). Several researchers have attempted to assess teachers’ conceptions of the nature of science and its relationship to practice by the use of questionnaires (Abd-El- Khalick and BouJaoude, 1997; Gess-Newsome et al., 1993; Lederman et al., 1994) followed up by interviews (Abd-El-Khalick et al., 1998) and classroom observations (Lederman, 1995). Findings suggest that, irrespective of their academic background, science teachers possess limited knowledge of the history and philosophy of science (King, 1991; Gallagher, 1991) and hence hold inadequate or naïve conceptions of the nature of science (Abd-El- Khalick and BouJaoude, 1997).

Findings from this body of research also suggest that teachers hold various views when it comes to the nature of their discipline. For example, many teachers were found to hold positivist views, believing that the substantive content of science is fixed and unchangeable rather than tentative (Abd-El- Khalick and BouJaoude, 1997). Teachers who carry positivist views of their discipline teach their discipline as a body of knowledge only and emphasize vocabulary rather than a balanced presentation of human and rule-based knowledge generation and cautious evaluation of knowledge claims. These views support limited laboratory work and the presentation of science as the method of understanding the world (Gess-Newson, 1999). Additional views of the NOS were characterized in the literature. These included naïve, experimental-inductionist, experimental-falsificationist, technological, and science as a three-phase process (Aguirre, Haggerty & Lindner, 1990). Naïve views characterized science as a collection
of facts and explanations based on observed phenomena, while three-phase process recognized the role of theories; theories are developed by scientists, tested, and then accepted or rejected by the scientific community.

This body of research also attempted to relate teachers’ conceptions of the NOS to their classroom practice. The results are inconclusive as of yet, owing to “the strong influence of curriculum constraints, administrative policies, and teaching context on the translation of teachers’ conceptions into classroom practice” (Lederman, 1992, p.348; cf. Lederman & Zeidler, 1987). Several researchers suggest that teachers’ beliefs about the nature of science as an objective body of knowledge created by a rigid “scientific method” (Brickhouse, 1990; Duschl & Wright, 1989; Gallagher, 1991) impede their teaching of an accurate view of inquiry. For example, teachers who emphasized science as a body of knowledge spent more class time in developing terminology than on building relationships across concepts, and rarely engaged students in laboratory work (Gallagher, 1991). In fact, teachers with a more contemporary and accurate understanding of the nature of science tend to implement a more problem-based approach to science teaching (Brickhouse, 1990). Brickhouse (1990) suggested that experience and depth of content knowledge were likely predictors of the consistency of beliefs with practice (cf. Brickhouse & Bodner, 1992; Lederman, 1995). For example, novice teachers were found to be concerned with management factors as they attempted to develop an overall organizational plan for instruction (Brickhouse, 1990; Lederman, 1995). Other factors that impeded the translation of teachers’ conceptions of the NOS to practice include pressure to cover content (Duschl & Wright, 1989; Hodson, 1993), concerns for
student abilities and motivation (Brickhouse & Bodner, 1992; Duschl & Wright, 1989; Lederman, 1995), and institutional constraints (Brickhouse & Bodner, 1992).

Finally, successful techniques to improve teachers’ conceptions of the NOS include introducing the historical aspects of scientific knowledge or emphasizing explicit instruction on the nature of science. The latter technique is important in light of the 1960s and 1970s curricula that functioned under the assumption that students implicitly came to understand NOS by “doing science” (Abd-El-Khalick et al., 1997). Findings from such studies indicated that students did not develop the desired understandings of the NOS (Durkee, 1974; Tamir, 1972; Trent, 1965; Troxel, 1968; in Abd-El-Khalick et al., 1997). Combined with the implications from the research on teachers’ conceptions of the NOS, these findings resulted in several recent attempts to develop the desired understandings of the NOS in preservice teachers through explicit instruction (Abd-El-Khalick et al., 1997; Abd-El-Khalick et al., 1998). Findings indicate that even when preservice teachers demonstrated informed views on the NOS, their understandings did not explicitly translate into their teaching due to preoccupations with classroom management and the belief that NOS is less significant than other instructional outcomes (Abd-El-Khalick et al., 1998).

Beliefs about Science Teaching and Learning.

There is a large body of research indicating that teacher beliefs about science teaching and student learning influence classroom practice (Appleton & Asoko, 1996). Part of this body of research aims to identify teachers’ orientations to science teaching. Orientations refer to a teacher’s general way of viewing or conceptualizing science teaching. These beliefs serve as a “conceptual map” that guide instructional decisions
Several orientations to science teaching have been identified in the literature and related to goals or purposes of teaching and characteristics of instruction (Magnusson et al., 1999). Science teachers’ orientations could be didactic, process oriented, or they could emphasize academic rigor (Lantz & Kass, 1987), conceptual change (Roth, Anderson, & Smith, 1987), activities (Anderson & Smith, 1987), discovery, project-based science (Marx et al., 1994), inquiry (Tamir, 1983), or guided inquiry (Magnusson & Palincsar, 1995). Characteristics of instruction include teacher-, student-, project-, investigation-, and learning community-centered activities (Magnusson et al., 1999). Findings from this research indicate that teachers hold multiple orientations, including ones such as didactic, and discovery that have incompatible goals for teaching science (Smith & Neale, 1989).

Another significant portion of the research on teachers’ beliefs about science teaching and learning includes studies that have been conducted in the context of the implementation of a conceptual change approach (Posner, Strike, Hewson, & Gertzog, 1982). These studies focus either on the effects of in-service (Constable & Long, 1991; Porlan Ariza & Garcia Gomez, 1992; Hand & Treagust, 1994) or preservice programs (Hewson et al., 1999; Lemberger et al., 1999; Meyer et al., 1999; Stofflet, 1994; Hewson & Hewson 1989), or on the actual implementation in classroom practice (Tobin, 1993; Glasson & Lalik, 1993; Briscoe, 1991; Cronin-Jones, 1991; Johnston, 1991). Findings from research on inservice and preservice programs indicate that such programs result in change in the participants’ conceptions of teaching and learning science. Specifically, conceptual change strategies are adopted as they are found to be intelligible and fruitful (van Driel et al., 1998). For example, the three elementary teachers in Meyer et al.’s
(1999) study experienced development in their beliefs, especially in the area of student learning. These teachers accepted that their students held a range of important ideas on topics they were being taught and that “it was at least useful (and probably necessary) to elicit these ideas in the context of normal teaching” (p.344, cf. Appleton & Asoko, 1996). However the teachers in that study accepted this view for various purposes, namely monitoring student learning, as a way to make students pay attention, and helping students become owners of their learning.

As mentioned previously, research in this area has also addressed the correspondence between teachers’ beliefs of science teaching and learning that were acquired in these programs and their classroom practice. Findings from this body of research indicate that there is no general correspondence between inservice and preservice teachers’ conceptions of teaching and learning and their classroom behavior (Meyer et al., 1999; Mellado, 1998). Teachers’ existing belief structures (Cronin-Jones, 1991) or their commitment to the existing curriculum (Johnston, 1991) or their colleagues (Tobin, 1993) are among the factors that hinder the implementation of teachers’ beliefs. In that case, mismatches between teachers’ professed beliefs and classroom actions are observed (Briscoe, 1991; Johnston, 1991). Still, some case studies claim that changes toward constructivist ideas were observed in both teachers’ conceptions and their classroom practice. These changes seem to take place when sufficient time and professional support are available (Glasson & Lalik, 1993; Tobin, 1993; Appleton & Asoko, 1996).
Pedagogical Content Knowledge

The present study adopts a modification of Magnusson, Krajcik, and Borko’s (1999) model of PCK. These researchers suggest a model of PCK that comprises teachers’ orientations toward science teaching, knowledge of science curricula, knowledge of assessments in science, knowledge of instructional strategies, and knowledge of learners’ understandings in science. For the purposes of this study, PCK consists of four components: (a) knowledge of science curriculum; (b) knowledge of student understandings; (c) knowledge of instructional strategies; and (d) knowledge of assessment. In my opinion, Magnusson et al.’s orientations to science teaching component lies in the domain of teacher beliefs and was discussed earlier. This section begins by reviewing the findings from studies addressing the general construct of PCK in science teaching, followed by a review of recent research studies that address the different components of PCK. The section ends with a summary of the reviewed research and implications for future research.

Several studies that investigate teaching practices suggest that a thorough and coherent understanding of specific science topics, in combination with teaching experience, are precursors and positively contribute to PCK and its translation to practice. As mentioned previously, few studies exist in the literature on science education that target the construct of PCK and its relationship to practice. More often, studies investigate teaching practice as a function of familiarity with a specific domain, or analyze it along the lines of subject matter knowledge and pedagogical knowledge. Most of these studies indicate that “teachers, when teaching unfamiliar topics, have little knowledge of potential student problems and specific preconceptions, and have
difficulties selecting appropriate representations of subject matter” (van Driel et al., 1998, p.679). Furthermore, teachers have more misconceptions of these topics (Hashweh, 1987), they lecture or talk more often when teaching, and they mostly ask low cognitive level questions (Carlsen, 1993). Interestingly, Sanders, Borko, & Lockard (1993) noted that when experienced science teachers were teaching outside their area of certification, their PCK was limited and their teaching was based on their more differentiated knowledge of general pedagogy. These authors also stated that experienced teachers quickly learned new content as well as appropriate subject-specific instructional strategies while relying on their knowledge of general pedagogy. Sander et al. concluded that pedagogical knowledge provides a framework for teaching that is “filled in by content knowledge and pedagogical content knowledge … when teachers taught within and outside their science area” (Sanders et al., 1993, p. 733). Paralleling this conclusion, Smith and Neale (1989) found an inservice workshop focusing on conceptual change to be unsuccessful in developing PCK because participants were still constructing a “deeply principled conceptual knowledge of the content” (Smith & Neale, 1989, p. 17). Hence, these researchers perceived content knowledge as a precursor of PCK. Yet on another parallel, Gess-Newsome and Lederman (1993) found that the translation of preservice teachers’ subject matter structures into classroom practice was complicated by classroom complexity, which prevented the integration of subject matter and pedagogy (cf. Lederman, Gess-Newsome, & Latz, 1994). These researchers suggest that teaching experience might be a prerequisite to the development of PCK. Based on these findings, more research is needed to identify the influence of workshops that promote deep
understanding of the content and pedagogical practice on PCK, as well as the factors that promote its development and translation to practice.

More recently, studies that specifically aimed to characterize teachers’ PCK and its relationship to practice concluded that more experienced teachers’ PCK tended to be more developed than their novice counterparts, PCK could be developed through short-term workshops focusing on conceptual change, and that its development or adoption in practice may be inhibited by individual or contextual factors (Smith, 2000; van Driel et al., 1998; Adams & Krockover, 1997; Clermont, et al., 1993, 1994; Geddis, 1993). For example, Clermont, Krajcik, and Borko (1993, 1994) concluded that, compared with novice teachers, experienced teachers possess a more flexible and greater repertoire of representations and strategies when demonstrating a particular topic. Moreover, experienced teachers can relate their demonstrations more effectively to student learning. These researchers also concluded that PCK “can be enhanced through intensive, short-term, skills-oriented workshops” (Clermont et al., 1993, p.4). In that respect, Geddis (1993) concluded that PCK was key to the transformation of subject matter knowledge into “teachable content knowledge.” In his study, preservice teachers developed subject matter representations and instructional strategies as they discussed students’ misconceptions about electrical current. Also studying preservice teachers, Adams and Krockover (1997) found that PCK development appeared to be dominated by individual and contextual factors that facilitated or impeded the learning of instructional strategies. As a result of these factors, preservice teachers adopted conventional instructional strategies, stressing procedures rather than student understanding.
Similarly, in their review of the literature on PCK, van Driel et al. 1998 suggest this type of teachers’ knowledge is a specific type of craft knowledge that develops with experience. Scholars who formulated different conceptualizations of PCK agree that PCK develops through an integrative process that has its origin in classroom practice, which implies that prospective and beginning teachers usually have little or no PCK at their disposal (van Driel et al., 1998). The development of PCK entails the integration of various domains of knowledge such as knowledge of subject matter, pedagogy, student characteristics, and environmental contexts (Cochran, DeRuiter, and King, 1993), or subject matter and pedagogy (Marks, 1990). These claims about the sources of PCK are based on findings from research studies. As stated earlier, one group of researchers who studied novice and experienced teachers’ PCK of chemistry demonstrations reported that prospective or beginning teachers usually possess little or no PCK at their disposal, whereas experienced teachers have a greater representational and adaptational repertoire for teaching the content (Clermont et al., 1994). Other researchers suggest that PCK has its origins in teachers’ apprenticeship of observation, disciplinary education, and teacher education (Grossman, 1990). When studying the impact of a teacher education program on the knowledge of beginning English teachers, Grossman (1990) reported that the teachers’ PCK was rooted in their observations of classrooms, disciplinary education, and specific courses within teacher education. She suggests that classroom observations, both as a student and a student teacher, may often lead to tacit and conservative PCK, while disciplinary education may lead to personal preferences for specific purposes or topics. Grossman concludes that the impact of specific courses within teacher education is normally unknown.
Finally, few studies attempt to characterize PCK in specific topics. This constitutes part of the missing paradigm (Shulman, 1987). In an attempt to increase our knowledge of PCK for specific topics, van Driel et al. (1998) identified chemistry teachers’ PCK for teaching chemical equilibrium. He proposed the discussion of anomalous events as a way to promote conceptual change in students. The discussion could include the possibility of continuous changes taking place at the molecular level taking the concept of time into consideration, and the possibility of forward and backward reactions taking place observable one after the other. In a similar attempt, Smith (2000) identified the elements of her PCK as a science teacher educator that promote her progress and the progress of her preservice elementary teachers. These elements included knowledge of students’ experiences as science learners, their assumptions about scientists and their work, and their ideas about what learning to teach science ought to involve. More research is needed to elucidate teachers’ topic-specific PCK that aids in developing k-12, preservice, and inservice teachers’ understanding of content.

We now turn to a review of studies that target the components of PCK used in this study. These components are (a) knowledge of science curriculum; (b) knowledge of student understandings; (c) knowledge of instructional strategies; and (d) knowledge of assessment. The following sections describe each component and relevant research findings concerning it.

Knowledge of science curriculum

This component of PCK encompasses mandated goals and objectives, and specific curricular programs and materials. This component was originally considered to
be a separate knowledge domain in Shulman’s knowledge base for teaching, but Grossman (1990) and Magnusson et al. (1999) included it under PCK because it represents knowledge that distinguishes the content specialist from the pedagogue, which is at the heart of PCK.

Knowledge of mandated goals and objectives entails teachers’ knowledge of the goals and objectives for students in science, as well as the horizontal and vertical articulation of those guidelines across topics (Grossman, 1990). Knowledge of goals and objectives is derived from, among others, national and state level documents that delineate frameworks for guiding decision-making about science curriculum and instruction, as well as district standards (e.g. AAAS, 1989, Ohio Academic Content Standards, 2003; NSES, 1996).

Knowledge of specific curricular programs consists of knowledge of the programs and materials that are relevant to the teaching of specific scientific discipline and specific topics within the discipline (Magnusson et al., 1999). For example a chemistry teacher might be expected to be knowledgeable about curricula for teaching chemistry, including programs such as CHEM study and CBA (Chemical Bond Approach) which were developed in the 1960s, IAC (Interdisciplinary Approaches to Chemistry) which was developed in the 1970s, and CHEMCOM (Chemistry in the Community) which was developed in the 1980s. Teachers’ knowledge of such curricula would include knowledge of the general learning goals of the curriculum as well as the activities and materials to be used in meeting those goals (Magnusson et al., 1999).

Studies that involve surveys of the general state of science education have reported that most teachers surveyed were not knowledgeable about nationally funded
curriculum projects relevant to their teaching area (Weiss, 1978, 1987). Other studies that target science teachers’ adoption of specific curricular programs as a result of their participation in workshops indicate that even though these teachers are knowledgeable about those programs, they may not be in agreement with their learning goals and thus may modify or reject such programs and their materials (Cronin-Jones, 1991; Mitchener & Anderson, 1989).

Knowledge of instructional strategies

This component of PCK is composed of two categories, knowledge of subject specific strategies, and knowledge of topic-specific strategies (Magnusson et al., 1999). Teachers’ knowledge of subject-specific strategies consists of their ability to describe and demonstrate a strategy and its phases. Subject-specific strategies include the learning cycle, Generative Learning Model, conceptual change strategies, and Guided inquiry. All these models build on the learning cycle, which is a three phase instructional strategy consisting of exploration, term introduction, and concept application that uses discovery learning and conceptual change type of instruction (Karplus & Their, 1967). These strategies aim to elicit students’ prior knowledge (Osborne & Freyberg, 1985), present anomalous data to create cognitive conflict (Nussbaum & Novick, 1982), emphasize public communication and discussion of patterns and explanations (Magnusson & Palincsar, 1995), or scaffolding student debate about the adequacy of alternative explanations (Anderson & Smith, 1987). These strategies involve exposing and contradicting students’ existing conceptions in favor of more scientifically correct conceptions that are intelligible, plausible, and fruitful to the students (Posner, Strike, Hewson, & Gertzog, 1982). Teachers’ use of subject-specific strategies is influenced by
their beliefs, especially if there are differences between the latter and the premises of the strategies (Cronin-Jones, 1991; Olson, 1981).

Magnusson et al. (1999) surmise that science teachers’ knowledge of subject-specific instructional strategies is limited, based on the fact that there is a substantial body of literature aiming to help teachers become more knowledgeable about such strategies, and because earlier studies found that teachers perceived themselves as ill-prepared to teach inquiry-oriented instruction (Weiss, 1978; Stake & Easly, 1978). Furthermore, several research studies aimed to help participants adopt certain subject-specific strategies (Anderson & Smith, 1987; Smith & Neale, 1989; Hewson et al., 1999). These studies show that the ability to use subject specific strategies is dependent on knowledge of other domains such as knowledge of subject matter, knowledge of pedagogy, and an understanding of students (which is another component of PCK) (Anderson & Smith, 1987). Finally, several research studies show that teachers’ use of subject-specific strategies is influenced by their beliefs, especially if these beliefs differed from the premises of new approaches (Cronin-Jones, 1991; Mitchener & Anderson, 1989). The most salient aspect of teachers’ beliefs that influenced their use of reform-oriented instructional practices consisted of their views of their roles as a teacher.

Knowledge of topic-specific strategies is useful to help students understand specific science concepts (Magnusson et al., 1999). It consists of two categories, representations and activities. Topic-specific representations consist of ways to represent specific concepts or principles in order to facilitate students’ learning, as well as knowledge of the relative strengths and weaknesses of particular representations. Representations can be illustrations, examples, models, or analogies. Research has
described science teachers’ representations by inferring them from practice rather than from directly questioning the teachers about the representations that they use in their science teaching. For example, Dagher and Cossman (1992) described 10 analogies used by teachers to explain scientific concepts. While these researchers did not describe limitations associated with these representations, they indicated that a lot of them were conceptually and scientifically inaccurate. Finally, a lack of knowledge of topic specific instructional strategies may result in ineffective lessons as teachers lose momentum, struggle or fail to respond to student questions that require different representations (Sanders, Borko, & Lockard, 1993). These findings suggest that knowledge of topic-specific instructional strategies might be linked to knowledge of subject matter and warrants further research.

Knowledge of topic-specific activities consists of science teachers’ knowledge of the activities that can be used to help students comprehend specific concepts or relationships. They could be demonstrations, simulations, investigations, or experiments. Teachers who have taught a specific topic for a long period of time usually are more knowledgeable of activities that promote conceptual understanding than novice teachers (Clermont et al., 1994). For example, Clermont et al. (1994) reported that the experienced teachers in their study knew more variations of a demonstration for teaching specific chemistry concepts than did novice teachers. Furthermore, experienced teachers were able to detect misleading statements when shown someone conducting a typical demonstration for a specific chemistry concept, and they were more knowledgeable about the complexity of a demonstration and ways to simplify it to promote student understanding Clermont et al., 1994). Yet experience alone does not guarantee that a
teacher will know conceptually strong and powerful activities (Magnusson et al., 1994; Berg & Brouwer, 1991). Compared with teachers with similar years of experience and teaching the same curriculum, some experienced teachers in Berg and Brouwer’s (1991) study were not able to address students’ difficulty with the concepts of force and gravity because they lacked knowledge of conceptually powerful activities. Teachers’ knowledge of topic-specific strategies increases upon participation in long term or short-term enhancement programs (Krajcik et al., 1991; Clermont et al., 1993). However, it is important to point out that only few commonly taught concepts in chemistry and physics were targeted in these programs (Krajcik et al., 1991; Clermont et al., 1993). Finally, the increase in teachers’ knowledge of topic specific strategies was found to be dependent on the teachers’ subject matter knowledge in many cases (Hashweh, 1987; Sanders et al., 1993). For example, Smith and Neale (1991) found that even though teachers participating in their programs exhibited increases in their knowledge of topic specific strategies, there were differences among the teachers and these differences related to the teachers’ subject matter knowledge. These findings also appear in studies of teachers teaching outside their areas of expertise (Hashweh, 1987; Sanders et al., 1993).

Knowledge of learners’ understanding of science

This component of PCK includes teachers’ knowledge and beliefs about prerequisite knowledge that students need for learning specific content knowledge, their knowledge of variations in student learning styles and developmental levels within specific topic areas, and the topics or concepts that students find difficult to learn due to level of abstraction, alternative conceptions, or difficulties with problem solving (Magnusson et al., 1999). Teachers should be aware of students’ prior understandings of
the topic area that arise from reasonable, personal sense making of the natural world and that they can continue to change and evolve. When faulty or contrary to targeted scientific concepts, these understandings are labeled misconceptions and alternative conceptions (Driver & Easley, 1978; Wandersee, Mintzes, & Novak, 1994). Misconceptions are easier to learn by students because they are more sensible and coherent than targeted conceptions, and they are resistant to change (Wandersee, Mintzes, & Novak, 1994).

Few research studies about teachers’ pedagogical content knowledge of students’ understandings of science exist. Findings show that teachers can rate scientific topics based on their level of difficulty without any explanation as to why they rate certain topics as more difficult than others (Finley et al., 1982). It is not known whether these ratings reflected teachers’ knowledge and concerns about students’ alternative conceptions, problem solving, or other issues. More research is needed in this area. Other studies that directly assessed teachers’ knowledge of students’ understanding showed teachers to be knowledgeable of students’ difficulties, but lacking the knowledge to help students’ overcome these difficulties (Berg & Brouwer, 1991). Teachers studied could list all misconceptions students might have in the areas of force and gravity (Berg & Brouwer, 1991) and light (Smith & Neale, 1989). The teachers were also found to hold many of the same misconceptions their students held (Berg & Brouwer, 1991; Smith & Neale, 1989; Krajcik & Layman, 1989). Several researchers believe that teachers’ knowledge of students’ misconceptions increases with enhancement programs (Smith & Neale, 1991, 1989). However, this increase in knowledge does not necessarily go hand in hand with knowledge of ways to address these alternative conceptions. Instead of probing
students’ reasoning, a lot of teachers addressed these conceptions by providing students with more detailed explanations of the concepts at hand (Smith & Neale, 1989). These findings suggest that acquiring pedagogical content knowledge does not guarantee the ability to respond effectively during instruction. Furthermore, these findings may indicate the independence of the components of PCK, which implies that changes in one of the components may not be accompanied by changes in others. Further research is needed to elucidate the relationship among the components of PCK.

Knowledge of assessment in science

This component of PCK, which was originally proposed by Tamir (1988) consists of knowledge of dimensions of learning to assess and knowledge of methods of assessment (Magnusson et al., 1999). Science teachers should be aware of the dimensions of science learning that are important to assess, and according to current reform documents, the latter are consistent with the development of scientific literacy in students, as exemplified in the National Science Educational Standards (NRC, 1996). Furthermore, science teachers should be knowledgeable in the ways that might be used to assess the specific aspects of student learning that are important to a particular unit of study as well as the advantages and disadvantages associated with employing any specific assessment device or technique. There are a number of methods that could be used to assess students’ understanding in science, which include performance-based assessments, journal entries, models, and portfolios.

Research examining science teachers’ use of assessment indicates that teachers at all levels mostly use teacher-constructed or curriculum-embedded objective tests that evaluate students’ conceptual understanding dimension of scientific literacy (Doran et al.,
1994). What is not known is whether teachers use these forms of assessment because they lack the knowledge of other methods or because they are not knowledgeable about other dimensions of scientific literacy.

Summary

So far, the reviewed studies indicate that a thorough and coherent understanding of specific science topics, in combination with teaching experience, are precursors and positively contribute to PCK. Moreover, general pedagogical knowledge may be considered a supporting framework for the development of PCK. Finally, PCK could be developed through short-term workshops focusing on conceptual change, and has its origins in teachers’ experiences as students and student teachers, disciplinary education, and teacher education courses.

The development of PCK and its adoption in practice may be inhibited by individual or contextual factors. While the findings of the reviewed studies pointed to the necessary factors needed for the development of PCK (e.g. deep content knowledge, teaching experience, and general pedagogical knowledge) and its translation to practice, few studies, if any, investigate the influence of programs that combine these factors on the development of PCK. More specifically, more research is needed on the influence of such programs on teachers’ content knowledge as it relates to their alternative conceptions of the topic, their knowledge of students’ alternative conceptions, their knowledge of instructional strategies, and the nature of their instruction. While research on PCK suggests that the translation of PCK to practice is mediated by individual and contextual factors, more studies are needed that identify these factors and investigate ways to magnify or diminish their influence.
Finally, while research on the different components of PCK indicates that teachers’ knowledge of these dimensions can be enhanced, more research is needed to study the influence of these components of teachers’ knowledge on their practice, as well as the interaction or relationship between the different components.

Conclusion

Because the present study is concerned with the influence of a professional development program on science teachers’ beliefs, PCK, and practice, the first part of this chapter reviewed research on professional development programs designed to effect change in teachers’ knowledge, beliefs, and practices. Furthermore, since the focus of the study is on teachers’ beliefs about science, science teaching, and PCK, the second part of the chapter reviewed past research on these constructs.

Research findings indicate that professional development efforts within the normative-reeducative perspective result in significant changes in teachers’ beliefs, knowledge, and inquiry-based classroom instruction. Teachers were shown to exhibit significant increases in attitudes, self-efficacy, and views about their roles as teachers. Furthermore, significant gains in content knowledge and knowledge of inquiry were reported, and these gains paralleled the implementation of inquiry based practices in the teachers’ classrooms. Recommendations from these studies include programs that immerse participants in learning the content through inquiry, are a result of collaborations between scientists and science educators, model inquiry-based practices, and promote teacher reflections on inquiry beliefs and practices. Further research is needed that investigates the influence of such programs on teachers’ beliefs and PCK.
Because the majority of these studies are quantitative in nature and rely on teachers’ self-report of their practice, they provide little to no information about the specific contextual influences that may contribute to science teachers’ decisions to use inquiry-based practices or some of its salient aspects. Furthermore, most of the studies fail to investigate the relationship between beliefs, knowledge, and actions, or the nature of teachers’ interaction with their students. This becomes important because the literature has often shown that curriculum reforms, however, well-meaning, are shaped and altered by teachers’ beliefs (whether about science or science teaching) and understanding of the local context (Bryan, 1998; Brickhouse & Bodner, 1992; Cronin-Jones, 1991). A research agenda for inquiry should recognize the integral relationship between beliefs and actions (Keys & Bryan, 2000).

Finally, while research on PCK and its components indicates that teachers’ knowledge of these dimensions can be enhanced, more research is needed to study the influence of PCK and its components on teachers’ practice, as well as the interaction or relationship between the different components of PCK. In studying the relationship between teachers’ PCK and practice, special attention needs to be given to the factors (individual, beliefs or contextual) that mediate this relationship and ways to magnify or diminish their influence.
CHAPTER 3: METHODOLOGY

The purpose of this study was to investigate how a professional development effort, which immerses teachers in learning science content by inquiry and models sound pedagogical practices, promotes change in teachers’ inquiry thoughts and actions. More specifically, the study first aimed to describe middle school science teachers’ beliefs and PCK for teaching middle school physical science. Second it examined how the Physics by Inquiry course influenced their beliefs and PCK. And third, it investigated how the teachers’ beliefs and PCK influenced their practice.

Design

The study followed a qualitative case study research design (Bogdan & Biklen, 1998). Case studies allow for a detailed picture of the particular (Cronbach 1975), which often provides for more general conclusions to be drawn with respect to the phenomenon under investigation (Merriam, 1998). Two types of case studies, intrinsic and instrumental, are identified in the literature and differentiated by their purpose (Stake, 1995). Intrinsic case studies are concerned with better understanding a particular case, allowing it to reveal its story. Instrumental case studies are concerned with providing insight into an issue or refinement of theory. In the latter instance, “The case is often looked at in depth, its contexts scrutinized, its ordinary activities detailed, but because this helps us pursue the external interest” (Stake, 1994; p. 237). As Yin (1984) suggests, “Case studies…are generalizable to theoretical propositions and not to populations or universes…and the investigator’s goals is to expand and generalize theories” (p.21).

Case studies as a research design have a distinct advantage in “how” and “why” studies (Yin, 1984) because they allow understanding of some special people, particular
problem, or unique situation in great depth and detail. Cases are “bounded systems” (Smith, 1978) with integrated and working parts (Stake, 1994). They represent the study of the particular: a case unique in nature, history, setting, informants, or other contexts and cases (Stake, 1994). A case study design, by definition, is characterized by the nature of the unit of analysis, rather than by the methods of inquiry or particular strategies of data collection used (Stake, 1994; Grossman, 1990). Each case becomes a distinct unit of analysis within which the researcher identifies patterns and themes that might be useful in cross-case analysis (Grossman, 1990). The methods of case study research are consistent with qualitative, naturalistic, ethnographic, and phenomenological approaches (Stake, 1994). Caseworkers spend substantial time on site, in contact with case activities and operations, attempting to see natural happenings, and reflecting on and revising meanings of what is going on (Stake, 1994). Finally, as Grossman (1990) stated, “case study research can draw on a wide variety of data collection strategies; the common thread of case study research is the identification, conceptualization, and elaboration of an individual case, while setting the particular case within a larger theoretical and naturalistic context” (p.150).

Finally, cases are associated with issues of generalizability or transferability and time involved (Bogdan & Biklen, 1998). Transferability becomes an issue in the selection of subject or setting, “typical” vs. “unusual” cases. Qualitative researchers believe that transferability is not answered by case selection, but has to be explored as part of the study. Case study researchers cannot escape generalizations. However, they expect their readers to understand their generalizations and to arrive at some generalizations of their own. Hence the role of the researcher becomes to describe the case in sufficient detail so
that readers can vicariously experience its happenings, and draw their own conclusions (Stake 1995; 1994).

The design of this study encompasses two instrumental case studies of the beliefs, PCK, and practice of middle school science teachers who participated in the *Physics by Inquiry* program. The study used a case study methodology because its purpose was to contribute to a theoretical framework about teacher change. Shulman (1986, 1992) articulated a variety of ways in which case studies can contribute to our knowledge about teaching. Furthermore, the use of case studies to investigate teacher knowledge and beliefs represents an attempt to gather in-depth data on the content, character, and organization of a teacher’s thoughts for the purposes of contributing to a broader conceptualization of teacher cognition and its use in practice (Grossman & Wilson, 1987). This study sought to describe practicing middle school science teachers’ beliefs, PCK, and their use in practice. It also attempted to identify the influences of the teachers’ background and a common professional development program, *Physics by Inquiry*, on their beliefs, PCK, and practice. Specifically, the study targeted teachers’ beliefs and the components of PCK, which consisted of conceptions of science, science teaching, and learner understandings in science, assessment in science, science curricula, and instructional strategies. Several data collection strategies were used to gather this information, including in-depth interviews, observations of participants’ classroom teaching, and collection of artifacts. Data collection also included observations of the professional development program. Collectively, classroom observations, classroom artifacts, and the different types of interviews provided the opportunity to look for both explicit and implicit manifestation of beliefs, PCK, and the change process.
Case Selection

Cases in this study consisted of two female middle school science teachers enrolled in the Physics-by-Inquiry course. Heather was a 25 year old with 3 years of teaching experience and Jody was a 50 year old with 23 years of teaching experience, 13 of which were in teaching physical science. Heather taught at an area suburban school while Jody taught at the local urban district. Case selection within this study was convenient and criterion-based (Patton 1990). Since the purpose of the study was to investigate the influence of Physics by Inquiry on teachers’ PCK, cases were volunteers from the convenient population of teachers participating in the professional development program. On the first day of the program, volunteers were solicited after the study was explained. Criterion-based sampling further narrowed the convenient sample. From volunteers, only teachers teaching physical science in a middle school during the year following the Physics by Inquiry course were selected.

The main advantage of the criterion method of sampling is that it provides information rich cases for in-depth study based on selection criteria (LeCompte & Preissle, 1993). In that respect, selected cases served to maximize what we can learn about PCK and its sources through in-depth study leading to in-depth understandings and the generation of conclusions. Furthermore, the convenient nature of the case selection allowed me easy access to informants who were hospitable to the inquiry (Stake, 1995). A disadvantage to these sampling methods, in addition to the small sample size, is their bias, which makes the cases atypical and less amenable to generalization. The sample was biased in terms of age and teaching experience, as well as teaching setting. Furthermore, it might be argued that only a special “kind” of teacher chooses to
participate in professional development activities, a kind whose beliefs and PCK are already differentiated. Such biases might provide threats to the study’s validity. However, since my purposes are not to generalize to teachers in general, but to generalize to theory, the atypicality of the teachers becomes theoretically advantageous (Grossman, 1990), providing clearer insight into how, if anything, professional development can contribute to changes in teachers’ cognition and the process of teaching. These biases were explored in the case study, especially in interviews.

Finally, given the voluntary nature of the sample and its small size, I was unable to control for teaching context. The setting of the two cases consisted of an urban and a suburban school respectively. The case study approach allowed me to interpret individual teacher’s data with reference to the particular context in which she taught. The difference in teaching context proved to be an important variable to consider in the interpretation of the data for this study. Further case and setting descriptions will be provided in chapter 4.

Context

This study took place in two different contexts. The first context consisted of the *Physics-by-Inquiry* course. The second context consisted of the study participants’ classrooms and schools, and will be described in chapter 4.

*Physics-by-Inquiry*

*Physics by Inquiry* (PBI) and its accompanying curriculum materials were originally coined by Lillian McDermott and the Physics Education Group at the University of Washington-Seattle. The curriculum materials (McDermott et al., 1996) consisted of a set of laboratory-based modules that provide a step-by-step introduction to physics and the physical sciences to pre-college teachers. Through in-depth study of
simple physical systems and their interactions, students gain direct experience with the processes of science. Starting from their observations, students develop basic physical concepts, use and interpret different forms of scientific representations, and construct explanatory models with predictive capability. All the modules have been explicitly designed to develop scientific reasoning skills and to provide practice in relating scientific concepts, representations, and models to real world phenomena (http://www.phys.washington.edu/groups/peg/pbi.html).

PBI at the Midwestern University was offered only to practicing teachers. It was a four-week long summer course offered yearly to in-service grade 5-12 teachers by the Physics Department of the College of Arts and Sciences at a large Midwestern University. During the course, students participated in guided-inquiry activities that emphasized discovering rather than memorizing and questioning rather than telling. Dialogues between instructors and individual students or groups further characterized the course.

PBI was chosen for this study for several reasons, all of which relate to the parallel that existed between the course elements, recommendations for teacher professional development, and components of PCK. One of the course’s main goals was to help students think of physics as an active process of inquiry in which they can participate, rather than an established body of knowledge. Furthermore, consistent with current reforms in science education, PBI aimed to prepare pre-service and in-service 5-12 teachers to teach science as a process of inquiry and establish a sound foundation for the building of scientific literacy. Other goals consisted of strengthening subject matter background in topics typically covered in pre-college physics and physical science using
a hands-on, inquiry-oriented method of instruction; emphasizing the development of fundamental concepts and reasoning skills through laboratory experience; meeting the needs of teachers with varying levels of preparation in science and mathematics; and helping teachers anticipate student difficulties and alternative conceptions. All these goals are consistent with the recommendations of science and teacher education professional organizations (discussed in Chapter 1) which emphasized that science departments (partnered with teacher education programs) assume greater responsibility for offering college-level courses that provide teachers with strong exposure to appropriate content and that model the kinds of pedagogical approaches appropriate for teaching the content. In that sense, PBI allowed the participating science teachers to experience, as learners, the instructional approaches they were being prepared to use. Furthermore, PBI was an example of a partnership between the Physics Department and the College of Education at the Midwestern University. A senior physicist, several senior science educators, and previous science teachers carried out course design and instruction. The physicist and science teachers team-taught the course while the science educators conducted discussions on issues associated with science assessment and the integration of technology into the science curriculum.

PBI was also chosen for this study because it incorporated several effective professional development practices (Supovitz & Turner, 2000). As mentioned in Chapter 1, Supovitz and Turner (2000) identified six critical components of effective science professional development. Effective professional development efforts should (a) model inquiry teaching, (b) be intensive, (c) sustained, (d) be based on teachers’ experiences with students, (e) deepen content knowledge, and (f) be linked to other aspects of school
change. In that respect, PBI modeled inquiry science teaching, was intensive (approximately 114 contact hours) and was sustained (three follow up sessions throughout the school year and classroom observations by instructors). PBI was also designed to deepen its participants’ physics content knowledge while connecting learning to inquiry implementation in schools.

Finally, PBI was chosen because it incorporated several components of PCK and had the potential of developing this type of teacher knowledge. Components of PCK consisted of conceptions of science teaching, conceptions of the science curriculum, and conceptions of students’ understandings of specific science topics, conceptions of assessment in science, conceptions of instructional strategies for teaching science, and conceptions of the nature of science. In that respect, PBI emphasized participants’ conceptions of science teaching and learning, students’ understandings, instructional strategies, assessment, and the nature of science. These elements included teaching as facilitation rather than transmission, learning as a social process of knowledge construction, learner’s alternative conceptions as central to learning, and guided inquiry as an instructional strategy to be used in the science classroom. Furthermore, PBI emphasized and modeled questioning strategies to facilitate and monitor student-learning, strategies aimed at eliciting and addressing learners’ alternative conceptions, and assessments used to evaluate learning. A last element of PCK emphasized in PBI consisted of modeling the nature of science. Teachers and students were actively engaged in the social generation, testing and acceptance of scientific models and explanations. However, it is noteworthy to point out that this was an implicit aspect of the course, as opposed to any explicit discussion of the nature of science (Abd-El-Khalick et al., 1998).
As stated previously, participants gain direct experience with the processes of science through in-depth study of simple physical systems and their interactions (McDermott et al., 1996).

*Physics By Inquiry - 2002*

PBI course participants consisted of 19 in-service, 5-12 teachers. The lead instructor advertised the course using flyers sent to district and county educational offices who forwarded them to school principals. The course was advertised to the local school districts first and then advertised to outlying districts. While course participants were selected on first-come first-serve basis, the local urban school district was given priority. Participants placed a deposit of $75 that was returned to them at the end of the course.

Three instructors team-taught the course. The lead instructor Bill was a senior physics professor at the Physics Department at the University. Kay (pseudonym) was an Interdisciplinary (Physics and Curriculum and Instruction) doctoral student at the University who previously taught the course at the same university and at other universities in the area. Kay used to be a high school physics teacher. Dean (pseudonym) was a curriculum leader at one of the outlying districts, and had been a physics teacher for many years.

Bill introduced the philosophy behind the course, cooperative learning, and the syllabus. Bill, Kay, and Dean facilitated course instruction and conducted checkpoints, making sure that all participants participated and understood the concept at hand. Instructors facilitated the discussion through questioning and elaboration of answers and the requirement of evidence. In addition to the three instructors, invited guest speakers from the College of Education at the same university engaged the teachers in a discussion.
of the integration of technology into scientific inquiry units, as well as the role of assessment in learning science by inquiry. Towards the end of the course, in-service teachers who had previously taken the course were invited to share activities, experiences, and insights they gained from their practice of teaching science by inquiry.

PBI at the Midwestern University was established by the lead instructor and had been taught yearly, every summer, for several years prior to the study. It consisted of 4 weeks of all day classes during the summer of 2002 and three one-day follow-up sessions the following school year. The course discussions at the follow-up sessions centered on issues associated with the implementation of physics by inquiry lessons in the participant teachers’ classrooms. The instructors observed at least one classroom session of the participants’ inquiry teaching followed by feedback. The teachers received 12 credits for participation in the summer classes and an additional credit at the end of the next school year. They further received $200 in cash and $200 worth of equipment that could be used for inquiry instruction. During the summer, classes started at 9:00 AM and ended at 3:30 PM, and included a half-hour lunch break.

Scientific topics addressed during the PBI course were measurements of matter, pure substances, astronomy by sight, motion with constant speed, motion with changing speeds, and electric circuits (McDermott et al., 1996). The teachers completed a pre-test at the beginning of each module for the purpose of eliciting their prior knowledge and alternative conceptions. Furthermore, the teachers completed a post-test at the end of each module and completed homework assigned from the text, reflective pieces, individual and group lesson plans, and pre- and post- instruction concept maps. At the end of the academic year following participation in Physics by Inquiry, teachers were
expected to complete a “mini” portfolio to demonstrate changes they made in their classrooms, with their peers, and in the ways they interacted with their students.

Data Collection

Several methods were used to generate data for the study. Data collection for the case studies included in-depth interviews, classroom observations, and collection of artifacts. Data collection also included observations of the PBI course. Five in-depth conversational interviews were used to examine participants’ beliefs and PCK and were conducted at locations convenient to the participants. The interviews were designed to elicit information on the beliefs and PCK of the practicing teachers and various influences affecting them. As per Grossman’s (1990) discussion, since knowledge and beliefs are considered intangible and elusive objects of study, the interviews represented different approaches to eliciting this data. While some of the interviews asked participants directly about their beliefs and knowledge about science, the teaching and learning of science, assessment, and students’ understandings in science, others relied on stimulated recall or more indirect approaches where teachers’ rationales for classroom decisions served as indicators of their underlying knowledge and beliefs.

Data collection for this study was conducted in two stages, consistent with the two contexts of the study. The first stage took place during PBI and was supplemented by an interview with the lead instructor that provided a context for the course. The second stage took place during the following academic year, in the study participants’ classrooms.

Stage One

Stage one of data collection occurred during the four-week summer PBI course. It consisted of daily non-participant observations (Patton, 1990) of PBI, two interviews
with each of the participants, and the collection of course and participant artifacts. An additional interview with the lead instructor was used to provide a context for the course.

The researcher observed the sessions of PBI on a daily basis, throughout the four weeks. Daily observations had two foci. The first consisted of whole group lectures and discussions such as the first day of class when inquiry and cooperative learning were discussed, the session on assessment, and the session on technology integration. The second focus consisted of study participants’ interactions with the curriculum, each other, and course instructors. The researcher took on a peripheral membership role (Adler & Adler, 1994) where she was considered an insider, observing and interacting more closely with participants without participating in course activities. No observation protocol was used. Rather, the researcher was looking for manifestations of the components of PCK in the various course discussions. Examples of such manifestations included the discussion of alternative conceptions and instructor or participant use of questioning and topic-specific strategies. Other examples included participant statements relating to science teaching and learning, and the nature of science. Finally, the researcher sought instances where study participants related their experiences in the course to their classroom teaching experiences. The researcher used field notes generated from PBI observations to inform interview questions used in stage two of the data collection. For example, participants were asked to describe their views of inquiry, the role of alternative conceptions, and their views of teaching and learning in the Post-PBI interview (described below) based on specific instances selected from field notes. These observations permitted the researcher to understand the course and the teachers’ PCK to an extent not entirely possible using only the insights of others obtained through the
interviews. They further provided a check on what was reported in the interviews. Limitations of these observations included the possibilities of the observer affecting the situation and the selective perception of the observer distorting the data. The observer attempted to record, as accurately as possible the events, activities, and dialog in the classroom in order to provide a “written videotape” (Hewson et al., 1999) of the class. However, because participants were in different groups, this written description is an incomplete record by nature, because it was physically impossible to record everything that happened in the course. The researcher made choices as to which group to attend at any particular time, leading her to miss some interactions altogether.

Two interviews were conducted with each of the participants. The first interview was designed to collect data on the teachers’ Conceptions of Teaching Science (COT: Grossman, 1990), including their beliefs and knowledge about the purpose for teaching middle-school science. The interview also inquired into the number and type of undergraduate science and education courses and the influence each had on their conceptions of teaching, conceptions of teaching science, and classroom practice. This interview was used to collect data on teachers’ beliefs about science teaching and learning, beliefs about science, and several aspects of their PCK such as knowledge of learners’ understanding of science. Sample questions included: Can you tell me about your background in science? Tell me about your courses, undergraduate and graduate, favorite and least favorite. Tell me about what you see as the reasons for studying science in middle and high school. What are your goals for your students? What do you think makes science difficult for students? (Appendix A). This interview was conducted towards the beginning of PBI and provided the researcher with a baseline idea of
participants PCK prior to the course. COT was used in this study because it provided insight into participants’ beliefs and PCK, namely their conceptions of science, science teaching, and student learning, as well as their conceptions of their classroom practice prior to PBI. Furthermore, COT was used because it provided insight into the influence of participants’ background on their PCK and teaching. A limitation of this interview relates to its nature. As Grossman (1990) stated, “In some cases, the questions asked of the teachers may have prompted them to reflect on topics they had not previously considered; for example asking teachers about their goals for students may have prompted them to construct these goals extemporaneously. In this sense, interviews may have provoked the construction of new knowledge, in addition to eliciting already existing knowledge.” I addressed this issue during data analysis by looking across different data sources for evidence of teachers’ knowledge and beliefs.

The second interview investigated participants’ conceptions of teaching science in the context of physics by using the standardized open-ended Conceptions of Teaching Science protocol adapted for physics (CTS: Hewson & Hewson, 1989). CTS consists of a standardized task protocol developed by Peter and Marion Hewson at the University of Wisconsin-Madison:

1. In your view, is there science teaching happening here?
2. If you cannot tell, what else would you need to know in order to be able to tell?
   Please give reasons for your answer.
3. If you answered “yes” or “no,” what tells you that this is the case? Please give reasons for your answer.
The protocol is used to investigate teachers’ conceptions of teaching science by presenting them with ten instances about biology, chemistry, and physics respectively. In this study, the protocol was used in conjunction with the instances about physics only (Appendix B). This interview allowed respondents to consider the components of an appropriate conception of teaching science that, for analysis purposes were combined into six general categories: nature of science, learning, learner characteristics, rationale for instruction, preferred instructional technique, and conceptions of teaching science (Hewson & Hewson, 1989). CTS was conducted towards the end of the Physics by Inquiry course. Even though CTS and COT targeted some of the same components of PCK (e.g. conceptions of teaching science, science learning, science, and preferred instructional technique as it related to their practice), CTS was used because it provided an indirect way of externalizing participants’ tacit PCK (Anderson, 1987) and beliefs, which might not have been apparent during the COT interview. Furthermore, it served to counteract COT’s limitation; questions asked elicit already existing knowledge and beliefs, minimizing the extemporaneous construction of knowledge. Finally CTS was also used in an effort to investigate whether participants’ PCK was evolving. A limitation of CTS includes the possibility that ascribing teachers to a specific conception of teaching might “[wash] out the interesting nuances between [them]” (Hewson & Hewson, 1989, p. 207). However, in contrast to COT, it provided an environment in which a variety of views could be expressed without being biased by the structure of the task (Hewson et al., 1999).

Finally, additional limitations to the use of CTS and COT include interviewer effects that may bias or alter what participants say. For example, by unconsciously
smiling or nodding when certain answers are provided, the interviewer may influence responses. There is also the risk that participants, for reasons unknown, may not say what they really think. This may be because they want to say things they think the researcher wants to hear, or because they are uncomfortable discussing their true feelings.

Other data collection strategies at this stage included the collection of course and participant artifacts whenever they became available. Course artifacts included the syllabus, handouts on inquiry, assessment, and alternative conceptions, pre- and post-tests, and a copy of the curriculum materials. These artifacts were collected for the purpose of informing the researcher about the goals and foci of the course, as well as specific physics and pedagogical concepts emphasized within it. This was important because curriculum materials such as textbooks and handouts are inherently pedagogical. Content texts are not devoid of pedagogy because they are intended to explain or “teach” something to someone (Segall, 2003). These materials have the potential to further elucidate components of PCK emphasized in the course. Participants’ artifacts included lesson plans, four course reflections, and test grades. Copies of course reflections and lesson plans were collected when the participants submitted them to the instructors. Course reflections were collected for their potential to inform the researcher about participants’ views about what they learned most from the course, difficulties they experienced, and ways in which it might influence their practice. Lesson Plans were collected for the purpose of informing the researcher about participants’ intentions to use guided inquiry and other aspects of their PCK in their practice. Finally, test grades were requested from course instructors at the end of PBI and aimed to inform the researcher of
the participants’ progress towards meeting PBI’s goal of depth of physical science content knowledge.

Procedure

In order to access PBI, the researcher approached Kay, one of the instructors, who was a fellow graduate student. Kay introduced me to Bill, the lead instructor, who granted me access to the course. On the first day of class, I went to the laboratory where the course was to be conducted. When all the students arrived and the instructors left the room, I explained my research study to students and solicited their participation. I then distributed letters of informed consent, requesting that volunteers sign and date them. After ten minutes, I collected the informed consents. Four students agreed to participate. Of the four, two were ninth grade physical science teachers, one was an eighth grade physical science teacher, and one was a tenth grade chemistry teacher. Two of the teachers taught in the local urban district, while the other two taught at neighboring suburban districts. After I arranged to meet with the study participants at lunch, I called in the instructors who then proceeded with the course. At lunch, I described my study in more details and introduced the participants to each other explaining to them that I was going to request that they be placed in the same group during PBI. Unfortunately, the instructors were not able to place all the participants in the same group. One of the participants was placed in another group to maintain diversity.

Now that my participants were selected, I began my observations of PBI, generating field notes focused on general course discussions and study participants’ actions and interactions with the curriculum, each other, and the instructors. I observed the sessions of PBI on a daily basis, throughout the four weeks. I was at the course site
from 9:00 AM till 3:30 PM during the first week. For the remaining weeks, I was absent from 11:20-1:30PM when I taught a two-hour course at the College of Education. During that time, I collected course handouts and tests, and participant reflections and lesson plans.

The next step was the interviews. I arranged to meet with participants individually throughout the first week, either directly before or directly after PBI hours, at the site of the course. The first interview began with questions regarding the personal backgrounds and professional status of each participant. These initial questions were followed by the COT protocol. I conducted the second interview, individually, in the third and beginning of the fourth week of class. I began the interview with a description and explanation of the CTS protocol. I then proceeded with the interview by presenting each interviewee with each of the instances about physics, using the task protocol. All field notes were typed. I audiotape recorded all interviews, which were transcribed by a third party.

Stage Two

This stage of data collection took place during the academic school year following the PBI course, at the participants’ respective classrooms. Data collection at this stage consisted of observations of study participants’ classrooms, three interviews with each participant, and the collection of artifacts such as handouts, tests, grade books, and curriculum materials.

The researcher took on a peripheral membership role (Adler & Adler, 1994) where she was considered an insider, observing and interacting more closely with participants without participating in class activities. Observations took place at least twice a week and at the most four times a week for a period of six months. Field notes were
generated. No observation protocol was used. Rather, the researcher was looking for manifestations of teachers beliefs and the components of PCK in their practice. Similar to observations in PBI, classroom observations had two foci. The first focus consisted of whole group lectures and discussions where participants engaged their students in homework and test reviews, or more direct forms of instruction. The second focus consisted of participants’ interactions with their students, the content and type of questions used, the type of instructional strategies used, specific activities, models, and representations, references to and discussions of prior knowledge, and the identification of students’ alternative conceptions and the way in which they were addressed. These foci reflected participants’ beliefs and PCK in terms of their conceptions of science teaching, science learning, instructional strategies, curriculum, and assessment. The researcher used the field notes generated from these classroom observations to construct narrative summaries of the teachers’ practice. Field notes were also used to inform interview questions used in stimulated recall and Post-PBI interviews. In that respect, specific instances of classroom practice were selected and questions were generated in an attempt to investigate the teachers’ rationales for instruction and the influence of the course on their practice. Classroom observations permitted the researcher to understand the teachers’ beliefs and PCK to an extent not entirely possible using only the insights they provided in the interviews. They further provided a check on what was reported in the interviews. Limitations of these observations included the possibilities of the observer affecting the situation (teachers teaching the way they believed the researcher expected them to teach) and the selective perception of the observer distorting the data. The observer attempted to record, as accurately as possible the events, activities, and dialog in
the classroom in order to provide a “written videotape” (Hewson et al., 1999) of the class. However, this written description is an incomplete record by nature, because it is physically impossible to record everything that happened in the course. The researcher focused on events that centered on the teacher and her instruction, choosing to pay less attention to other aspects in the classroom.

Three interviews were conducted at this stage. The first interview, Post-PBI (P-PBI), was conducted after the completion of the PBI course in the early months of the academic year. P-PBI was constructed by the researcher for the purpose of investigating the influence of participants’ experiences in PBI on their views of inquiry, practice, assessment and other components of pedagogical content knowledge. Combined with the fourth PBI course reflection collected in stage one, P-PBI served to evaluate PBI’s influence on participants’ beliefs, PCK and practice. It provided insights into the origins of each of the participants’ conceptions, PCK and its components, and the origins of their practices. Sample questions include: What was the most important thing you learned in the Physics by Inquiry course? Did it change your views about inquiry? How do you use that in your practice? Is your teaching this year different from your teaching last year? Are your goals for student learning different this year?

The second interview consisted of the Teachers’ Pedagogical Philosophy Instrument (TPPI; Richardson & Simmons, 1994). TPPI consists of a standardized 50-item interview instrument that explores eight different attributes related to teacher actions and teacher philosophies. The extended interview TPPI was used to clarify participants’ pedagogical philosophy or reasoning behind their practices, and the values, contexts and beliefs informing that philosophy (Appendix C). Similar to COT and CTS, this
instrument targeted specific components of the participants’ beliefs and PCK including their conceptions of science, science teaching, student learning, assessment, and curriculum. This overlap in function and difference in format was used as a means to ensure consistency of participants’ views as well as to investigate the sustained influence of PBI as a professional development activity. It was also used in an effort to investigate whether participants’ beliefs and PCK were evolving.

The third interview took place following instruction of two units by each of the participants. It involved sessions of stimulated recall (Bloom, 1954) targeting specific researcher selected instances of teaching and the rationales the teachers provided for their actions, thus permitting the researcher to go beyond the external behavior to explore the internal states of observed participants. The drawback of this interview included its subjectivity to recall error, or self-serving responses (Patton, 1990). In that respect, participants’ responses may have been invented on the sport in an effort to match perceived expectations. The interview was based on a format used by Pamela Grossman (1990) in addition to questions about specific classroom events selected from observation field notes. Sample questions include: Tell me about your unit on electricity (waves)? How did you introduce it? Can you tell me about some of the lessons/discussion/activities? Tell me what you thought the students got out of the unit? Why do you have students correct each other’s papers? In the unit on energy, why do you think the students equated oxygen with energy?

Similar to COT, a limitation of TPPI and SR relates to their nature. As Grossman (1990) stated, “In some cases, the questions asked of the teachers may have prompted them to reflect on topics they had not previously considered; for example asking teachers
about their goals for students may have prompted them to construct these goals extemporaneously. In this sense, interviews may have provoked the construction of new knowledge, in addition to eliciting already existing knowledge.” I addressed this issue during data analysis by looking across different data sources for evidence of teachers’ knowledge. Additional limitations to all three interviews included interviewer effects that may bias or alter what participants say. For example, by unconsciously smiling or nodding when certain answers are provided, the interviewer may influence responses. There is also the risk that participants, for some reason or other, may not say what they really think. This may be because they want to say things they think the researcher wants to hear, or because they are uncomfortable discussing their true feelings.

Other data collection strategies at this stage included the collection of participants’ handouts and tests whenever they became available, as well as curriculum materials in the form of the textbook. Handouts and tests were collected for the purpose of informing the researcher about the goals and foci of each participant’s practice, as well as specific physics concepts they taught. Furthermore, together with the textbook, they are inherently pedagogical (Segall, 2003) and have the potential to further elucidate participants’ PCK; its components and the consistency between them.

Procedure.

During the summer course, I asked study participants if I needed any special permission, in addition to theirs, before I could enter their classrooms and conduct my observations. As there were none, I simply maintained contact with participants by email over the summer and the beginning of the school year. During that time, I narrowed my pool of participants to three based on my decision to observe physical science classrooms
only. I started visiting the three classrooms in September on a daily basis. The teachers introduced me to their students and explained the purpose of my visits. I visited Heather’s classroom every morning from 7:53-8:37 AM except on Wednesdays, early release day, when class ended at 8:30 AM. I visited Jody’s classroom every other day from 10:50 AM to 12:40 PM. After visiting the third participants’ classroom for two weeks, he elected to withdraw from the study due to work overload and family obligations. During classroom observations, I generated field notes that focused on the manifestation of teachers’ beliefs and PCK and their overall practice and interactions with students. I conducted these classroom observations at least twice a week and at the most four times a week for a period of six months. During those six months I collected classroom artifacts such as handouts and tests, and requested a copy of the textbook. The next step was to conduct the interviews. I conducted three interviews (Post-PBI, TPPI, and stimulated recall interviews) with each of the teachers. Heather’s interviews were conducted during her planning period. Jody’s interviews were conducted during her early lunch hour. All field notes were typed. I audiotape recorded all interviews, which were transcribed by a third party.

Role Negotiation and Ethical Considerations

During PBI observations and interviews, I gradually established rapport with participants by listening to their concerns about the course, following up on the major events in their lives, and reciprocating by sharing details of my life with them. As a result of our conversations, one of the participants applied and was accepted into a doctoral program in education at the same university.
Similarly, during stage 2 of data collection, I became involved in the teachers’ professional and personal lives. In addition to being pregnant, Heather was directing the school play and was busy with rehearsals and costumes. As we progressed through the year, Heather would request my help with some classroom logistics such as selling materials during the electric car project.

My relationship with Jody was somewhat different. I realized her trust in me grew as the study progressed and she started confiding me about some of the problems she faced in the school. I always listened carefully, exhibiting sympathy.

Finally, I portrayed myself as a learner. I emphasized that my observations and questions were not evaluative in nature. Rather, my goal was to gain insight into the knowledge, beliefs, and practice of effective teachers and their use of inquiry as an instructional strategy. In that respect, I aimed to learn from their expertise to hopefully inform preservice and inservice teacher education.

With regards to ethical considerations, participants signed letters of informed consent that explicitly presented the purpose and scope of the study and guaranteed their right to privacy, protection from harm, and termination of participation (Fontana & Frey, 1994). In that respect, one of the participants opted to terminate his participation due to personal reasons. I did not pressure him to remain part of the study. We parted amicably and had a friendly encounter at the first PBI follow-up session. I further excluded from analysis any data that reflected negatively on either participant. Finally, I only entered locales (physical or personal) that participants allowed me access to (Erikson, 1967).
Data Analysis

As mentioned before, interviews were transcribed by a third party. Electronic and paper copies were generated. Audiotapes were stored in a locked cabinet at the researcher’s home. Field notes were typed and printed. Electronic and paper copies of interviews and field notes were used in the process of data analysis. The researcher read the paper copies several times to familiarize her more deeply with the data. Electronic copies were used in the process of data analysis in conjunction with word processing software to manage data.

All data sources were analyzed for evidence of the influence of background and PBI on participants’ beliefs, PCK and their relationship to practice. Several iterative stages of analysis were conducted (Huberman & Miles, 1994). To develop the individual cases, analytic narratives of each teacher’s practice were constructed using field notes, classroom artifacts, and stimulated recall interviews. The analytic narratives of practice served as a data reduction strategy as well as a stimulus for further analysis of the data (Miles & Huberman, 1994; Huberman & Miles, 1994).

Initially, interview transcripts, field notes, and artifacts were deductively analyzed using external codes based on the components and subcomponents of PCK and categories generated by Hewson and Hewson (1989) for the analysis of CTS. External codes included nature of science, learning, learner characteristics, requirements for learning, areas of student difficulty, and dimensions of science learning to assess, methods of assessment, curriculum, rationale for instruction, preferred instructional technique, topic specific strategies, goals for teaching science, and conceptions of teaching science. Data sources including interviews, field notes and artifacts fit these codes (Table 1). Additional
codes were used to examine the influence of the PBI versus other factors on teachers’ beliefs, PCK and practice. These codes included apprenticeship of observation, previous experiences with science, previous teaching experiences, and PBI. Codes were compared across data sources in search for contradictions in an initial process of triangulation. Emergent themes relating to the epistemology of science and constructivism as a learning theory became apparent. Case belief profiles of emerging understandings were constructed by the researcher and shared and discussed with advisors. Case belief profiles served as a data reduction strategy as well as a stimulus for further analysis of the data (Miles & Huberman, 1994; Huberman & Miles, 1994). In order to remain true to the nature of case studies, I analyzed all the data for each individual at one time. Once all data sources were summarized and coded for a particular teacher, I wrote the first draft of the case study for each teacher, based on the case belief profile and the analytic narrative of practice, and included many original quotes. The first draft of the case study also served as a data reduction technique. The purpose of the case studies was to provide an in-depth portrait of each teacher, including as much relevant data as possible, and to interpret the cases with reference to the study’s research questions. Keeping in mind issues of generalizability in case study research, I included many of the teachers’ own words to allow the reader a chance to make generalizations or alternative interpretations based on the actual data.

In a second round of data analysis, draft case studies were subjected to deductive analysis consistent with emergent themes and based on Tsai’s (2002) framework and Prawat’s (1992) description of “naïve constructivism.” Tsai used his framework to characterize teachers’ beliefs of science, science teaching and science learning. The
framework included three categories that could be applied to teachers’ beliefs and three of the components of PCK: views of science, science teaching, student understanding in science, instructional strategies, and assessment. These categories were “traditional,” “process,” and “constructivist.”

Table 1

External Codes: Stage One of Data Analysis

<table>
<thead>
<tr>
<th>Code</th>
<th>Category</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>NOS</td>
<td>Nature of Science</td>
<td>COT, CTS, TPPI, FN, ART</td>
</tr>
<tr>
<td>LNG</td>
<td>Learning</td>
<td>COT, CTS, TPPI, P-PBI, FN</td>
</tr>
<tr>
<td>LNR</td>
<td>Learner characteristics</td>
<td>CTS, TPPI</td>
</tr>
<tr>
<td>REQ</td>
<td>Requirements for learning</td>
<td>TPPI, CTS, P-PBI, FN</td>
</tr>
<tr>
<td>DIFF</td>
<td>Areas of student difficulty</td>
<td>COT, CTS, TPPI, SR, FN</td>
</tr>
<tr>
<td>DIM</td>
<td>Dimensions of learning to assess</td>
<td>TPPI, SR, CTS, P-PBI, FN</td>
</tr>
<tr>
<td>ASS</td>
<td>Methods of assessment</td>
<td>CTS, TPPI, SR, P-PBI, FN, ART</td>
</tr>
<tr>
<td>CURR</td>
<td>Curriculum</td>
<td>COT, TPPI, P-PBI, ART</td>
</tr>
<tr>
<td>RAT</td>
<td>Rationale for instruction</td>
<td>CTS, TPPI, SR, P-PBI</td>
</tr>
<tr>
<td>INS</td>
<td>Preferred instructional technique</td>
<td>CTS, TPPI, P-PBI, FN, SR, ART</td>
</tr>
<tr>
<td>TOP</td>
<td>Topic specific strategies</td>
<td>FN</td>
</tr>
<tr>
<td>GOAL</td>
<td>Goals for teaching</td>
<td>COT, TPPI, SR, P-PBI</td>
</tr>
<tr>
<td>COT</td>
<td>Conceptions of teaching science</td>
<td>COT, CTS, TPPI, P-PBI, SR</td>
</tr>
</tbody>
</table>

According to Tsai (2002), the “traditional” category perceives teaching science as transferring knowledge from teacher to students, learning science as acquiring or
reproducing knowledge from credible sources, and scientific knowledge as correct answers or established truths. The “process” category perceives teaching science and learning science as an activity focusing the processes of science or problem-solving procedures, and scientific knowledge is viewed as facts being discovered through “the” scientific method or by following codified procedures. The “constructivist” category views teaching science as helping students construct knowledge, learning science as constructing personal understanding and science as a way of knowing. An additional category consisted of Prawat’s (1992) description of “naïve constructivism.” Naïve constructivism refers to a faith on the part of teachers in the ability of students to structure their own learning. In this case, the teacher’s role is indirect, s/he watches over the environment ensuring that it affords enough opportunity for students to be involved in interesting and engaging educational activity. A second set of case studies was generated.

Within-case analysis was conducted by an examination of case belief profiles and the creation of data displays in the form of matrices with text (Miles & Huberman, 1994) (Table 2 & Table 3). Case belief profiles and data displays were searched for contradictions and compared with analytic narratives of practice in a search for inconsistencies. Final cases were constructed. Within case analysis was followed by cross-case analysis (where participant actions and responses to same items within interviews were grouped) and constant comparison (where participant actions and responses across different portions of interviews were compared). Emergent themes about the change process were sought. Once themes were established, data sources were searched for discrepant information that might run counter to these themes.
<table>
<thead>
<tr>
<th>Category</th>
<th>Belief/Knowledge</th>
<th>Practice</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nature of Science</td>
<td>Constructivist: central role of theories</td>
<td>Consistent</td>
<td>Science experiences; content courses; PBI</td>
</tr>
<tr>
<td>Learning</td>
<td>Constructivist: Prior Knowledge</td>
<td>Consistent</td>
<td>PBI-conceptual change</td>
</tr>
<tr>
<td>Requirements for learning</td>
<td>Active participation; ability; effort; motivation, relevance</td>
<td>Consistent</td>
<td>Teaching experiences; PBI</td>
</tr>
<tr>
<td>Difficulty</td>
<td>Abstract concepts; Misconceptions</td>
<td>Consistent</td>
<td>Teaching exp; PBI</td>
</tr>
<tr>
<td>Dimensions of learning</td>
<td>Conceptual understanding; application</td>
<td>Formative</td>
<td>PBI</td>
</tr>
<tr>
<td>Methods of Assessment</td>
<td>Traditional &amp; alternative methods</td>
<td>Traditional</td>
<td>Teaching experiences; PBI</td>
</tr>
<tr>
<td>Curriculum</td>
<td>Fixed Entity; dictated by State; concerns for coverage</td>
<td>Own</td>
<td>PBI; purposes for teaching</td>
</tr>
<tr>
<td>INS</td>
<td>Multiple including Guided Inquiry</td>
<td>Consistent</td>
<td>PBI; Teaching exp. Beliefs/students</td>
</tr>
<tr>
<td>Goals for teaching</td>
<td>Guided Inquiry, Decision-making citizens; relevance</td>
<td>Consistent</td>
<td>PBI; Teaching Experience</td>
</tr>
<tr>
<td>COT</td>
<td>Constructivist:</td>
<td>Consistent</td>
<td>PBI</td>
</tr>
<tr>
<td>Context</td>
<td>Support &amp; autonomy</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 3
Data Display: Jody

<table>
<thead>
<tr>
<th>Category</th>
<th>Belief/Knowledge</th>
<th>Practice</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nature of Science</td>
<td>Positivist: discovery, additive, prescriptive; Process: a method</td>
<td>Consistent</td>
<td>Science experiences; content courses; PBI</td>
</tr>
<tr>
<td>Learning</td>
<td>Constructivist: Prior Knowledge</td>
<td>Traditional</td>
<td>Nature of Science; Content Courses</td>
</tr>
<tr>
<td></td>
<td>Traditional: additive learning</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Requirements for learning</td>
<td>Active participation; hands-on; motivation, prior knowledge</td>
<td>Consistent</td>
<td>Teaching experiences; PBI</td>
</tr>
<tr>
<td>Difficulty</td>
<td>ability; language; misconceptions</td>
<td>Traditional</td>
<td>Teaching exp; PBI</td>
</tr>
<tr>
<td>Dimensions of learning</td>
<td>Conceptual understanding &amp; application</td>
<td>Inconsistent</td>
<td>PBI</td>
</tr>
<tr>
<td>Assessment</td>
<td>Traditional &amp; alternative methods</td>
<td>Traditional</td>
<td>Teaching exp; PBI</td>
</tr>
<tr>
<td>Curriculum</td>
<td>Fixed Entity; dictated by State;</td>
<td>Consistent</td>
<td>Coverage concerns</td>
</tr>
<tr>
<td>Instructional Strategies</td>
<td>Multiple including Guided Inquiry</td>
<td>Traditional</td>
<td>Curriculum; control; Beliefs/students</td>
</tr>
<tr>
<td>Goals for teaching</td>
<td>Process (problem solving);</td>
<td>Consistent</td>
<td>Science experiences; purpose for teaching</td>
</tr>
<tr>
<td>Cot</td>
<td>Naively Constructivist</td>
<td>Consistent</td>
<td>PBI</td>
</tr>
<tr>
<td>Context</td>
<td>Lack of Support &amp; autonomy</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Trustworthiness

Trustworthiness in this study was established through the criteria of credibility, dependability, and transferability (Guba, 1981). Transferability (or generalizability) was discussed in the design and data analysis sections of this chapter. Data for this study were credible, dependable and defensible enough to draw plausible conclusions due to the use of the processes of triangulation (Denzin, 1978). The same data collector, the researcher, collected data throughout the study, and performed all data analyses. Data collector bias was minimized through the use of the same semi-structured interview guides and standardized interview guides throughout the study. However, different researchers have diverse views of what is real, what can be known, and how to provide credible accounts of social facts (Guba, 1990). Moreover, analysis of qualitative data is subjective, imprecise, and easily affected by researcher bias (Chris, 1995). Even though the synthesis of cases and findings represented the researcher's understanding of what the data meant (Gay, 1996), she took care not to let her preconceived ideas improperly influence the interpretation of the data. The researcher did this by engaging in a systematic search for negative or discrepant data, as well as using direct examples and quotes to support any conclusions that were put forth.

Denzin (1978) identified four types of triangulation: data, investigator, theory, and methodological triangulation. First, data triangulation involves the use of a variety of data sources in a study. Second, investigator triangulation involves the use of several different researchers or evaluators. Third theory triangulation involves the use of multiple perspectives to interpret a single set of data. Fourth, methodological triangulation involves the use of multiple methods to study a single problem.
In the present study, data was triangulated through the examination of teachers’ beliefs and PCK at different instances, using extended systematic and repeated observations (Denzin, 1994) as well as different interview protocols that yielded redundant information. The three interviews, COT, CTS, and TPPI, which were similar in focus, were administered at three different times and in different circumstances. The first two interviews were conducted during PBI, at the beginning and end of the course respectively. The third interview was conducted during the following school year, when the teacher was teaching in her classroom. Furthermore, investigator and theory validity were conducted when the researcher shared case reports with advisors who, in most cases, concurred with proposed interpretations. When discrepancies in interpretation occurred, the researcher reexamined the data looking for instances that lend support or undercut additional interpretations. Finally, methodological triangulation was conducted to increase confidence in the researcher’s interpretations. This practice was apparent in the multi-method design of the study which involved thick descriptions in field notes, information-rich interview responses, stimulated recall interviews, and relevant supporting documents such as textbooks, tests, and classroom handouts.

Summary

This study aimed to explicate the influence of PBI on science teachers’ beliefs and PCK and the relationship between these aspects of the teachers’ cognition and practice. In order to address these questions, the study followed a qualitative case study design where the unit of analysis was teacher change. Participants for this study were selected based on the criteria of teaching area and grade level from volunteers in a convenient population. The study took place in two different contexts, Physics by Inquiry
course and the participants’ classrooms. Data collection included extended observations, a standardized interview, semi-structured interviews, and the collection of artifacts. All data sources were analyzed for evidence of the influence of the Physics by Inquiry course on the beliefs and PCK of practicing teachers and its use in practice. Conclusions were drawn through the processes of analytic induction and deductive analysis (Patton, 1990). Thematic strands were identified in field notes, interview responses, and artifacts. Cases were constructed through an iterative process of theme generation, triangulation, and within case analysis. Final cases were subjected to cross case analysis resulting in emergent themes that were examined against data in search for discrepancies. The following chapter presents the findings of this study and includes the cases of Heather and Jody.
CHAPTER 4: FINDINGS

The purpose of this study was to investigate how a professional development effort, which immerses teachers in learning science content by inquiry and models sound pedagogical practices, promotes change in teachers’ inquiry thoughts and actions. More specifically, the study first aimed to describe middle school science teachers’ beliefs and PCK for teaching middle school physical science. Second it examined how the *Physics by Inquiry* (PBI) course influenced their beliefs and PCK. And third, it investigated how the teachers’ beliefs and PCK influenced their practice. For all questions, teachers’ beliefs that were of interest consisted of beliefs about science and science teaching. Teachers’ PCK was described as their knowledge of learners’ understandings in science, assessment, curriculum, and instructional strategies. It is noteworthy to point out that elements of teachers’ knowledge of learners’ understandings in science and assessment were used to infer their beliefs about science learning of learning.

Findings from this study indicate that this type of professional development effort results in changes in teachers’ inquiry thoughts and actions, but to different degrees. The degree to which each of the teachers changed was contingent upon several factors. The factors that mediated or impeded change included teachers’ existing belief structures, concerns for control and coverage, and local contextual factors.

PBI influenced the teachers’ PCK similarly, but to different degrees. Both teachers exhibited changes in their knowledge of instructional strategies, learners’ understanding of science, and assessment. For example, the teachers used language consistent with inquiry constructivist practices such as the role of prior knowledge and alternative conceptions in promoting or inhibiting student learning. However, they
differed in their knowledge of how to deal with these requirements for learning or areas of student difficulty. While Heather expressed knowledge consistent with constructivist views of student learning, Jody’s knowledge was more consistent with a traditional perspective. Finally, the teachers differed in terms of the extent to which their PCK guided their practice. Heather’s previously existing knowledge and the changes that occurred as a result of PBI guided and translated into her practice in most cases. By contrast, the new additions to Jody’s PCK were not accompanied with concomitant changes in practice. For example, both teachers emphasized their understanding of questioning as a form of assessment, but only Heather used questions to monitor student learning.

Not surprisingly, the teachers’ existing belief structures differed markedly. For example, Heather held beliefs consistent with constructivist views of science and science teaching and learning. On the other hand, Jody held beliefs consistent with positivist/traditional and process views of science and science teaching and learning. The most salient aspects of the teachers’ beliefs, those that played a role in their acquisition of PCK and their implementation of inquiry practice, consisted of their views about science, purposes for teaching, perceptions of their role as a teacher, and views of how students learn. Some of these beliefs were impacted by PBI. For example, both teachers changed their perceptions of their role as a teacher from a traditional perspective to a constructivist perspective that emphasizes facilitation. However, Jody’s practice did not reflect this new role. Rather, her practice reflected a naively constructivist view of her role as a teacher where she arranged the environment to allow students to practice the process of science.
Other factors that mediated the translation of teachers’ PCK to practice consisted of contextual factors. Such factors included the availability of administrative support, resources, and the level of autonomy each teacher enjoyed. For example, Heather enjoyed complete autonomy in her classroom. She independently developed curricular materials consistent with inquiry practices after her participation in PBI. These materials served as her curriculum the year of the study. By contrast, Jody had to use curriculum materials mandated by the district, and she had to keep to a schedule so that all students within that district were learning the same topics at the same time.

The following sections present two case studies, Heather and Jody, and pay particular attention to their background, teaching context, and beliefs about science, beliefs about science teaching, science learning, and PCK in terms of their conceptions of science, science teaching, science learning, curriculum, instruction, and assessment. The case studies will allow the investigation of the interaction between the various aspects of the participants’ teaching related to their context, background, beliefs, and knowledge.

Heather

Heather was an eighth grade science teacher at a suburban school in the area. She had been teaching physical science at the same school for the past four years. Heather held an undergraduate degree in Biological Sciences and Education. She taught on one of two teams for eighth grade. At the time of the study, Heather started a Master of Teaching and Learning degree in a distance education program. The following sections describe Heather’s background, teaching context, beliefs, PCK and the relationship between her beliefs, PCK and practice. The final section summarizes the key aspects of Heather’s case, drawing connections between its different elements.
Background

This element of Heather’s case refers to her intellectual and professional biography, namely her previous experiences in science and the reasons leading to her choice of a career teaching Physical Sciences. Together, these aspects have the potential to provide insights into Heather’s practice and knowledge base for teaching.

Heather did not always want to be a teacher, let alone a science teacher. Her biggest passion was the theatre and she dreamed of a career on the stage. However, at the urging of her parents, Heather let go of that dream in favor of a career that “paid the rent.”

Enter Science. As Heather mulled over choosing a major in College, she reflected on her years of schooling and came to the realization that her favorite subject was science. Heather loved science because she constantly excelled at and it helped satisfy her natural curiosity. This sense of satisfaction with science was fueled by her apprenticeship in the discipline. Throughout middle and high school, Heather prepared, presented, and competed with scientific projects at various science fairs. Heather’s projects competed at the district, state, and national level. Her favorite and most influential project involved hydroponics. In that and other projects, Heather collaborated with a classmate and the teacher to decide on a research question to pursue, collect data, and draw conclusions. After each competition, Heather re-examined her conclusions based on comments or suggestions made by science fair jurors and attendees. Heather believed that these projects afforded her a somewhat authentic apprenticeship in the practice of science, and resulted in a burgeoning love for inquiry and investigation.
Due to her love for science and her experiences practicing it, Heather entered a midsized public university in the Midwest as a Botany major. Unfortunately, Heather’s experiences with science at the university were quite different from her school days. Courses like Botany, Dendrology, and Plant Taxonomy focused on the memorization of scientific facts rather than investigations, and Heather did not enjoy them:

It was all absorbing what was given in a lecture and bringing down every detail you could, even when we went out into the fields around the lab and we walked around and we looked at trees and plants. They would say here is the X species and expect you to know it. We were just all being a sponge and absorbing it and spitting it right back. (COT)

Heather quickly realized she needed to change course; she was not enjoying Botany and was at a loss for what career to pursue. In weighing her options, Heather reconsidered her love for theatre and performing, and given her successful school science experience, decided to pursue a teaching degree, thus combining her strengths. She stated, “Teaching to me seemed kind of like a perfect fit of being that entertaining and the drama and theatre. I also really like science so they just kind of came together as a natural fit” (COT). For that reason she registered for an education course that confirmed her belief that teaching integrated science and performing. Heather took no additional Botany courses:

After taking plant taxonomy and dendrology…I thought I really like this theatre aspect and performing so maybe I’ll take an education course and see how that goes. I took an education class and thought that is acting and science at the same time so I stopped having botany classes. (COT)
While pursuing her Biology and Education degree, Heather took several science courses for majors and non-majors. Her favorite courses included a trip to the Amazons, organic chemistry, and genetics because they submerged her in authentic experiences and interactions with the content while emphasizing relevance to life experiences. She commented, “In organic chemistry there was so many connections that the instructor made to real life things that all of a sudden you could see why in the world this was happening…you were seeing the big picture” (COT). Interestingly, Heather faced some difficulties with Physics in her senior year. Despite her past successes in science and her diligence in completing assignments, Heather found physics to be very challenging:

Science has always been something that if I studied enough I could get it.

You did homework for hours and hours just to get a zero and you are like oh my gosh I got a zero. It was a little bit of a set back and I thought do I really want to take more physics? (COT)

Heather attributed these difficulties to her inability to understand the foreign professor’s use of the English language. As a result of that experience, Heather took the bare minimum physics courses; first year Physics and its co-requisite laboratory course as part of her degree and then settled for a couple of summer courses while she was teaching.

Given her experiences with Physics in college, it is interesting that Heather only ever taught Physics and Physical Sciences. Even though Heather felt least confident as a physics learner, she believed she was best equipped to teach physics and other physical sciences because she had several years of experience teaching such courses:

I honestly think now after going through teaching physical science and chemistry I feel that if I was given a choice of anything to teach I would pick
those two because I’ve experienced teaching them. My strengths as a student may be a little bit different because the only physics class besides a few summer classes and this one and my class last year I would feel least confident taking a physics class even though I feel most confident in teaching it. (COT)

In fact, Heather’s sense of self-efficacy for learning Physics eluded her until she participated in Physics-by-Inquiry (PBI) at the time of the study. PBI greatly contributed to her sense of self-efficacy for teaching physical science concepts because it helped deepen her understanding of concepts in physics. She stated: “A lot of the electricity stuff that we did I thought I understood pretty well because I would kind of come in and just kind of learned it enough for here but actually to really understand it in all its depth, probably not. I probably didn’t know until we really went though a lot of that in depth” (P-PBI). Her statements were corroborated by her results on each of the posttests administered in PBI. Heather received a grade of 96, 91, and 100% respectively.

After graduation, Heather was offered and accepted a position teaching eighth grade physical science at a suburban school, very similar to the high school she attended. Heather accepted the position believing she would enjoy teaching physics and chemistry more than the biology she taught during student teaching. At the time of the study, Heather was in her fourth year at the same school, teaching Physical Sciences, even though she was certified in Biological Sciences. With the consent of her school district and school, she did not pursue certification in Physical Sciences. Even though Heather enjoyed teaching, she did not see herself being a teacher for the next thirty years. She
envisioned herself becoming the next Bill Nye the Science Guy, preparing TV shows that teach science and entertain children.

**Context**

Heather taught an eighth grade physical science class in a suburban school district that was ranked an Ohio Department of Education District of Excellence for two consecutive years, including the year of the study. Heather’s home building was the district Junior High that housed approximately 600 students in 7th and 8th grades. One of the Junior High’s foci the year of the study consisted of incorporating Inquiry Learning into daily instruction. The district and the school adopted the Ohio Academic Content Standards as instructional guides. The district aimed to prepare students for vocations or for further formal education in college and professional schools. Finally, the school prepared students to take the ninth grade proficiency test and the upcoming Ohio Graduation Test.

Heather’s school was not divided into departments. Instead of a department head, the school had a science curriculum leader who happened to be Dean, one of the PBI instructors. According to Heather, Dean provided her with all the support and materials she needed to incorporate inquiry. He had recommended that she apply for PBI. Within the school, teachers operated in teams, and Heather was a member of one of two teams for eighth grade.

A typical school day started at 7:25 AM and ended at 2:45 PM; a total of eight bells. Heather’s planning period took place during second bell. Her classroom was a model eighth grade science classroom. There were science posters on the walls, rockets hanging from the ceiling, beakers, test tubes and other glassware showing through cabinet
windows. The teacher’s desk was located at the front of the room facing 7 student group
tables and an eighth equipment bins table. In addition to the teacher’s computer, there
were 6 student computers, a printer, a television set, and a videocassette recorder. The
room was very well lit, warm in the winter, and lacking air-conditioning in the summer.
There were 25 students in the class. All were white and middle class.

Beliefs

Heather held constructivist views of science and a guided inquiry orientation
toward science teaching that were reflected in her practice. Her views of science were
reinforced as a result of her participation in PBI. Interestingly, Heather’s beliefs about
science teaching underwent some change. More specifically her goals for teaching
science and her views of her role as a teacher evolved to include emphasizing evidence
and facilitation respectively. The following sections describe her beliefs about science
and science teaching, and examine the relationship between these beliefs and practice.

Beliefs about Science and Physics

Heather’s definition of science pointed to a constructivist stance, which was
evident in her practice. She believed that science consisted of a body of knowledge and a
way of knowing that explained the world and its interactions, which was consistent with
the constructivist view that recognized science as one way of understanding the world.
When asked to define science, Heather referred to the study of living and nonliving
things and their interactions. She stated, “Typically speaking, science is made up of study
of life, biology, or study of matter which would be chemistry. Then the interactions of
matter would be physics” (COT). Heather believed science played a part in all aspects of
life because a lot of its topics dealt with concepts people experienced on a daily basis.
Examples of such topics included rocks and minerals, heat, electricity, and physical and chemical changes. For example, when I asked Heather whether science was going on in the instance where the teacher was passing crystals around to students, she stated that science was going on because the instance dealt with crystals which is a scientific topic: “Science going on because using crystals…science going on because of subject matter” (CTS). In another instance, Heather believed science was going on because the subject matter dealt with, current, was scientific: “There is science going on because they need to know a little about current and they need to know about what happens with the light bulb and current. So, I guess it goes back to the subject again” (CTS). Similarly, in instances where the scientific topics of insulation and physical/chemical changes were introduced, Heather stated that science was taking place because of the material: “Insulation versus ice water is science….There’s science: cooking and heating. Physical versus chemical changes but not as much as any of these other demonstrations” (CTS).

Additional evidence for Heather’s constructivist views of science consisted of her belief in the central role of theories. She ascertained, “Everything has some sort of relation to scientific theories” (COT). Heather subscribed to a view of science dominated by a three-phase process of theory invention, testing, and acceptance. This belief was evident in her emphasis on the dynamic nature of science and the importance of theories when discussing the knowledge an expert in science would hold:

For someone to be knowledgeable or know science I would say that they would have to have a pretty good understanding of how science is a changing process. Just to say that somebody knows the current areas or the history wouldn’t necessarily have all the pieces of the puzzle but have an appreciation for how
science has changed or how theories have changed or have we used to think. Spontaneous generation was the way it was and now we think it’s different. I don’t know that to really say that someone is knowledgeable or to know science means that they know all the things or all the pieces of the puzzle, for example, they know every law or every formula or every definition or every famous invention. I would think it is more understanding of how science is a dynamic changing subject and that science is involved in every aspect of everything we do (COT).

The emphasis on theories represented a more integrated model of science, one with a wealth of connections and relationships between and within the different disciplines in science, and which helps us understand the world and the relationships within it:

In my opinion an expert would have to be someone who would have to know a lot more if not all but a lot more of the details in between and be able to perform some more of those connections as if it were like a web or if it were Newton’s Law or how it can web out into other things. If you were talking with an expert in physics or genetics or molecular biology or whatever it is that you could almost give them a topic and they could find a way to link it to something else. So someone who is an expert would have a lot more of those avenues or webs to link it whereas somebody who is knowledgeable about science but just not an expert in that field would be able to explain how that subject has changed or explained a few concepts but their connections would be a lot fewer. (COT)

Finally, Heather believed the process of theory invention, testing, and acceptance was a result of social construction and analysis of derived patterns. She believed science
was a way of knowing, invented through scientists’ agreed conventions and paradigms. This belief was evident in her assumption that, together with her students, she was conducting science in her classroom because they were collaboratively constructing their understanding of scientific concepts, relying on evidence, discussion, persuasion, and consensus. Heather’s expectations for each group were to work collaboratively, discussing activities, questions and answers, evidence that support the different answers, and reaching consensus on reported answers. For example, in a session where students were collaboratively working using textbooks to investigate energy conversions, Heather asked a group why they concluded that their books had energy. Students answered that the table vibrated when the books hit it, and the books rebounded. At that point, Heather asked them what would happen if they closed their eyes as they released the book. One of the students observed that she could hear the book going through the air, “a swoosh sound.” Other students chimed in confirming the observation. Heather asked what that meant, and students agreed that the book’s energy was also converted into sound energy (1/21).

Heather’s conceptions of physics are intertwined with her conceptions of teaching physics and were reminiscent with her physical science school curriculum. She defined physics as the study of interactions between the different components of matter. In reply to a question about the different areas that make up physics as a discipline, she used motion, forces, and general properties of matter, electricity, light and sound, which were the same areas she used to describe her conceptions of the middle school physics curriculum. Even though she mentioned astronomy, Heather was reluctant to include it in her list because she did not teach that in the eighth grade
physical science course. For example, Heather explained, “Those are the things that come to my mind because those are what I teach as an aspect of physical science” (COT). When asked how the different areas she listed were related within the field of physics, she replied that energy would be the underlying theme in all aspects of physics. In addition to knowledge of laws, theories, and facts within the discipline, Heather believed that an expert in science would have an understanding that science is an integrated dynamic process that is relevant to our everyday lives.

In short, Heather held constructivist views of science; an integrated, dynamic body of knowledge and way of knowing that represented one way of understanding the world. Furthermore, Heather believed the process of theory invention, testing, and acceptance was central to science, and involved the social construction of knowledge.

Beliefs about Science Teaching

This component of Heather’s PCK refers to her knowledge and beliefs about the purposes and goals for teaching science at a particular grade level and the resulting orientations or views toward science teaching. Heather held a guided inquiry orientation to teaching science that was driven by her purpose for teaching and was a result of her earlier experiences with science and PBI. The following sections describe Heather’s goals and purposes for science teaching and her resulting views about teaching and learning.

Goals for science teaching.

Heather had several goals for teaching science all of which related to her general purpose for teaching. Her purpose for teaching consisted of preparing successful responsible citizens. She believed it was important for her students to be
able to use knowledge learned in the classroom to properly function in society, make
decisions based on evidence, and live by values such as honesty and a thirst for
knowledge:

I would really say that teaching and education in general should be built on
educating a whole person and not just focusing on a subject area. I’m not just
a science teacher but I have a duty and responsibility to make sure these
students become responsible members of society. When they don’t then that’s
basically everybody who came in line had a part to play in that I guess. I
don’t know, I would say that to help students become life long learners is part
of it and to become successful people. (TPPI)

Thus, in relation to her purpose of preparing functional members of society,
Heather’s conceptions of the necessity for teaching science in the middle school
centered on providing students with the necessary foundations and competencies for
future careers. In that respect, she believed science in the middle school should
emphasize scientific content and processes that lay a foundation for future learning
and careers, whether the latter be science related or not:

A lot of kids are like why do we have to know this and there are so many
practical applications even if someone isn’t going to be a scientist. Let’s say
they are going to be an author…it’s so important to know what to do when
you come across an acid spill or your son gets into ammonia. What type of
knowledge will you have of that? We can teach you all of the little pieces in
your life and problems you’ll have in your house but if you have an
understanding of some science then that may help you out. (COT)
To lay a foundation for future learning, Heather believed middle school science should emphasize conceptual understanding of scientific concepts as opposed to an emphasis on formulas. As students gain deep conceptual understanding of concepts, they are better prepared to approach the same concepts mathematically in high school. She proclaimed, “I guess I’m going to relate it a lot to math as in you can’t get to higher level math thinking and theories and problems until you understand the basics. For someone to wait until high school to ever talk about science then you mess up part of that knowledge of science” (COT). Heather further calls for the need to start building this foundation even before the middle school to be sure to afford students an understanding of science:

If you are in Kindergarten classroom and you grow some plants in a cup and you say oh look this one turned to light and oh this one didn’t do very well because it is in the dark. Even though maybe you haven’t talked about why a plant grows to the light or we haven’t talked about the plant physiology of why that is happening, there is still, you start to understand that there is a process of why do things happen. Well could we try it again? I guess it’s more the understanding of the scientific method…if you don’t allow for students of all ages to experience science then you are not really going to know what science is. (COT)

In addition to her belief that science should be a required topic in the middle school, Heather held personal goals for teaching science. Heather’s personal goals were three-pronged and also stemmed from her general purpose for teaching. First and foremost, Heather aimed to prepare functional members of society who were able
to make decisions based on evidence. For that reason, Heather expected her students to use evidence to support their work at all times. She declared, “one of my personal goals that I think is important from the time the students come into my classroom in August until they leave in May is that they can support anything they say with evidence” (COT). The emphasis on evidence was apparent in her practice as will be described in the section on assessment and instructional strategies and was a result of her experience in PBI QUOTE. Second, she believed in relating the big picture in science to students’ lives to help them realize the fruitfulness of knowledge gained in the science classroom and hopefully generate excitement and enthusiasm for the discipline:

A lot of people’s experience with science is that they don’t like it because it’s been boring or it’s been dumb or they don’t see the need of why they use it. I hope that at some point of coming into my classroom in August from the time they leave that they have a little bit of excitement about some aspect of science and even though it may be a little tiny aspect, that they have some sort of enthusiasm and excitement. (COT)

Finally, Heather emphasized the role of social collaboration in the generation of knowledge, in an effort to prepare students for their roles in society. This emphasis was rooted in her middle and high school science experiences where she collaborated on projects, and was reinforced in PBI where cooperative learning was explicitly emphasized. As mentioned before, Heather’s expectations for each group were to work collaboratively, discussing activities, questions and answers, and reaching consensus on reported answers. For example, in a session where students were
designing an experiment to test for conductors, Heather informed students that they had to answer questions in their big blue book as a group and reach consensus on how to test for conductors (1/30). She further made sure students realized they were accountable for their learning individually and as a group. For example, at each checkpoint, Heather asked questions of each member of the group. In general, all students within a group had the same answer written down and when asked would report it. If upon probing, a group member was not able to explain the answer or support it with evidence, Heather asked the group to work with that student emphasizing the need for all members to reach an understanding of the topic.

*Views of science teaching.*

Heather’s goals for science teaching were consistent a guided inquiry orientation towards science teaching. She expected her students to constitute a community of learners whose members share responsibility for understanding the physical world. As members of that community, Heather also aimed to develop in her students an understanding of the processes of science, including process skills such as making observations and evidence-based inferences.

Heather believed that science teaching was occurring only when accompanied by student learning. She declared, “For teaching to take place learning has to take place. So, I guess technically, if nothing is being learned then there is no teaching happening.” She described teaching as the process of increasing students’ understanding of concepts or processes. She stated, “I think science teaching is the process of increasing student knowledge … or more importantly, understanding about an aspect of science. It can be a specific idea or a general concept or topic” (CTS). She further described her role as a
teacher as someone who engages students in the learning activity by asking them guiding questions. For example, when commenting on an instance in the Interview about Instances where a teacher passed out crystals and asked students to describe what they saw, Heather stated, “Science teaching [is going on] because the students are asked to give information about the crystals the teacher gave them. Describing is part of teaching because it’s more engaging than telling the students about the crystals, having students be involved, participating” (CTS)

In short, Heather guided inquiry orientations toward science teaching were consistent with constructivist views of teaching. She believed that teaching involved deepening or increasing students’ understanding of concepts and processes through facilitation or guidance.

_Pedagogical Content Knowledge_

Heather’s PCK was coherent and consistent with constructivist views except in the case of assessment. Her constructivist PCK is due in part to her participation in PBI. The specific aspects of Heather’s PCK that are attributed to PBI consist of her understanding of the role of prior knowledge, alternative conceptions, questioning as a method of assessment, and inquiry. Heather’s constructivist PCK was reflected in her practice and was mediated by her purposes for teaching, beliefs about her students, and teaching context, except in the case of assessment. This section will describe Heather’s PCK and how it relates to her practice. Specifically, Heather’s knowledge of student understanding in science, assessment, curriculum and instructional strategies will be discussed.
Knowledge of Students’ Understanding of Science

Heather held constructivist beliefs about students’ understandings of science that were reflected in her practice. She believed that her students’ understandings of science were mediated by their abilities, motivation, and the effort they invested in their learning. She also believed that they learned through active participation in relevant activities that activate their prior knowledge and address the areas where they face difficulty. This aspect of Heather’s PCK refers to her knowledge of the requirements for learning and of areas of student difficulty. Requirements for learning include pre-requisite prior knowledge while areas of difficulty include abstract concepts, problem-solving, and alternative conceptions. The following sections describe Heather’s knowledge of students’ understanding of science.

Requirements for learning.

Heather believed student engagement and prior knowledge played an important role in students’ learning in science because they served two purposes, active participation and relevance, which were related to her goals for teaching science and constructivist beliefs about learning. She defined prior knowledge as student understandings of scientific concepts that result from life experiences or previous formal instruction. As such, Heather believed prior knowledge played an important role in providing context for new learning, relating new ideas to what students already knew, or to daily experiences. For that reason, Heather started each new lesson with oral or written questions aimed at activating students’ prior knowledge. For example, prior to the activity intended to investigate conductors and insulators, Heather asked students to complete the following pre-lab questions, using concepts from the static electricity
laboratory, in an effort to activate prior formal learning and engage students in the task (1/30):

1. What is a conductor?
2. What is an insulator?
3. Are ALL metals conductors?

Heather’s practice reflected her emphasis on students’ prior knowledge to promote engagement and relevance when she strove to relate concepts learned to applications students might encounter in their everyday experiences. For example, when introducing the concept of insulation, Heather stated, “It is something you have in the attic and it is pink and foamy” (1/21), in an effort to relate the concept to something the students were familiar with. The students realized she was talking about insulation and Heather proceeded to ask them what they used it for. Similarly, when discussing transfer of heat through conduction, she used the examples of an oven ring and a toaster (3/4). When discussing waves, Heather related a scenario where people were required to build their homes at a certain distance from the shore to prevent waves from changing the shore’s shape (3/12).

Heather’s emphasis on the interconnectedness and relevance of learning experiences was consistent with her goals for teaching science, beliefs about the integrated nature of science, and perceptions of how she learns best. Heather’s goals for teaching science included promoting an understanding that science is part of and can explain students’ lives. Furthermore, as mentioned in her background, Heather stated that her favorite courses, where she learned best, were the ones where instructors made connections to real life experiences resulting in her understanding of the “big picture”
(COT). Finally, Heather’s emphasis on student engagement and active participation is consistent with her constructivist beliefs:

I guess I believe my students learn best when they are actively engaged in things. They are a part of the learning process so not just I’m telling you that this is important so you need to learn it but they actually see the value in and want to learn as well.

*Knowledge of areas of student difficulty.*

Heather identified areas of student difficulty related to students’ developmental levels and prior knowledge. She listed abstract concepts or concepts that lacked connections to student experiences, problem solving, unfamiliar terms, and alternative conceptions as sources of student difficulty.

Developmentally, Heather believed most of her middle school students experienced difficulties in learning abstract concepts. As a result, Heather believed her role as a teacher lay in helping students visualize abstract concepts by focusing on concrete representations or relating concepts to common or lived experiences rather than simply lecturing about them. For example, in the case of acceleration, Heather was aware of this difficulty as a result of her previous experiences with teaching the concept. She created a lesson plan to address difficulties with acceleration using concepts learned in the PBI course, in fulfillment of the individual lesson plan requirement. She then taught the lesson plan to her eighth grade students and realized how providing students with concrete experiences with the ticker tape and graph generation made understanding the abstract concept more accessible:
Acceleration is a really hard concept to visualize and see and they know at a light you are speeding up or slowing down and they can talk about that but to actually do a lab where they measure acceleration was difficult. When we use the ticker tape we connected it to and they made the graph. It was much easier for them to visualize and see that that was speeding up or that was slowing down and what that would look like. (P-PBI)

In addition to difficulties with abstract concepts, Heather identified several area related to prior knowledge, namely problem solving, unfamiliar terms, and alternative conceptions as sources of student difficulty. Heather believed her students were challenged by her requirement for evidence and its necessity for problem solving, especially because they were not required to use that skill in prior classes. She realized her goal of relying on evidence was going to prove difficult at the start of the year, when students were reluctant to rely on their problem-solving skills and the evidence available to them to reach conclusions. However, Heather was confident her students were capable of learning the process and taking control of their learning. She stated, “For the most part our kids are good and if you say to do something then they will do it” (TPPI). With Heather’s insistence, perseverance and patience, students learned to rely on themselves and stopped looking to Heather for correct answers, a triumph Heather was keen to maintain:

I think I’ve worked so hard to try to get to this point; get them to discover things on their own and if I now take them back and hold their hands and say, oh no you didn’t get that right and here is why, then I think everything we have been working to until this point is just completely thrown out the window. Then they
start to rely on me more again. At the beginning of the year they wanted to know if everything was right. Is this right? Is this right? Is this right? Instead of saying yes or no I would say, I don’t know what do you think? What does your group think? What did you data say? What did you do? If now they are going through it and I stop them and say that’s not right then they start to rely on me too much again. Then they go back to I don’t know how to do this? Is this right? We don’t know how to do this? I feel confident by stopping them at certain check points and asking them questions I’m keeping track of some of the groups that don’t have the; maybe they have some misconceptions there. I think that in the end they are going to say, OH!! I get it now. Rather than, Mrs. Heather told us it was wrong so it’s got to be wrong. (P-PBI)

Furthermore, Heather believed her students faced difficulties in science due to a preponderance of unfamiliar scientific terms or terms students rarely used in everyday life such as mass, volume, grams, and liters. Heather believed such difficulties would be lessened if terms were related to something students were familiar with or if they could experience them. However, she believed students would still have a hard time relating such terms’ meanings in their own words due to their unfamiliarity with them:

And I would say that writing things, like our operational definitions that we’ve done, that they would have a really hard time describing in words. A lot of times they can describe in spoken words better than they can in written words or they can do it better than they can describe it. And maybe to predict what would happen if, when we were doing the density, if you added a mass but you kept the volume the same. They would maybe have a hard time predicting that without.
Because mass, I think, and volume are terms that we use in the science classroom but aren’t everyday. Like a liter and a gram aren’t every day. So they don’t feel as comfortable with that but they understand something being more dense versus less dense. Like if you take a sponge and you squeeze it but to apply the terms mass and volume to that situation I think is difficult just because I don’t think they’ve done it very much (COT)

Finally, Heather listed alternative conceptions as an area of student difficulty. However, even though she recognized and addressed students’ alternative conceptions in her practice, she was very vague in her discussion of alternative conceptions during interviews aimed at eliciting this part of her knowledge. She admitted her ignorance of her students’ alternative conceptions and attributed that to a lack of pre-testing. She stated: “I haven’t been pre-testing so I guess I don’t really know what all the alternative conceptions are” (P-PBI). Heather was able to pinpoint alternative conceptions in the CTS interview. For example, she realized that the instance describing a students’ statement that the cup was preventing the cold to get to his hand was erroneous. She further recognized some of her students’ alternative conceptions in a stimulated recall interview. An example of the alternative conceptions consisted of students’ beliefs that batteries produce a constant current:

For instance, one of the groups just this morning said, because the batteries are the same the current is the same and that makes me think did you really just do that because you should have kind of led yourself to the point that if the current through the light bulbs are different, then the current through the batteries are different. (SR)
Heather mostly used cognitive strategies like creating dissonance to dispel alternative conceptions and guide the students to an understanding that was scientifically acceptable. For example, Heather recognized that a group of students believed that the current in a closed circuit was used up in the bulb, and hence was more in the part of the circuit preceding the bulb than in the part after the bulb (2/5). Heather asked the student to consider adding a second bulb to the circuit, and to describe the current that would enter that bulb. The student responded that the current would be less because the first bulb used some of it up. Heather asked one of the students how he would describe that qualitatively. The student said that the second bulb would shine less brightly than the first one. Heather asked the student to add a second bulb to his circuit and describe what happened. The student realized that the bulbs were shining with equal brightness and concluded that the same current was going through them both. Heather then asked the student if some of the current was used up when it entered the second bulb and the student said no.

Heather’s awareness of students’ alternative conceptions, the use of pre-tests to elicit them, and cognitive strategies to dispel them was consistent with her experiences in the PBI course where these strategies were modeled. The course emphasized participants’ alternative conceptions in the unit on electricity in two different sessions. In one of the sessions, a course instructor described the different alternative conceptions students might have about the study of electricity, how teachers can identify these misconceptions and ways to dispel them. The alternative conception identified in Heather’s practice was one of the conceptions discussed in PBI.
In short, Heather’s emphasis on prior knowledge reflected her goals for teaching science, beliefs about science, and constructivist beliefs of teaching and learning. She believed in the importance of prior knowledge for the purpose of providing connections and relevance in student learning. Even though she believed alternative conceptions constituted an important part of prior knowledge, she did not actively seek to externalize them, a practice consistent with constructivist views. However, if alternative conceptions became apparent at checkpoints, she used strategies consistent with conceptual change pedagogies to dispel them. Despite her belief that students were challenged by problem solving strategies, Heather’s perseverance and confidence in her students’ abilities resulted in their reliance on evidence to make interpretations and reach conclusions.

Knowledge of Assessment in Science

Heather’s beliefs about assessment in science were inconsistent with her practice, except in her use of questioning as a formative assessment strategy. She attributes her use (or lack of it) of assessment methods to her experiences in PBI. The knowledge of assessment in science component of Heather’s PCK refers to her knowledge of the dimensions of science learning to assess and methods of assessment. Methods of assessment consist of specific instruments, procedures, approaches, or activities used during specific units, as well as advantages and disadvantages associated with the use of a particular assessment device or technique. The following sections describe Heather’s knowledge of both these aspects and their use in practice.

Knowledge of dimensions of science learning to assess.

Heather believed it was important to assess dimensions for science learning related to explanations and application of concepts (conceptual understanding) through
connections between concepts and across disciplines, as well as the ability to support learning with evidence by focusing on student reasoning. These dimensions for science learning were consistent with a constructivist view of learning and paralleled dimensions of scientific literacy.

Heather equated learning or knowing a concept with being able to explain and use it. She stated, “I guess the big thing would be when I could explain it without using information that someone else told me. I could put it in my own words; make my own connections or come up with my own explanation for it” (TPPI). Knowing a concept implied the ability to apply it to new situations and rely on connections among different disciplines to solve new problems:

I would say when you can apply it to other situations or if you are looking at something you can bring in that knowledge from another subject. I guess if they can apply it to another situation that they haven’t seen before. If we would for instance work on the lever and they can complete the task that I’ve given them and then I give them a new task and they can apply that then I would say they understand it and if they can apply it in a correct manner and explain why. (TPPI)

She also consistently emphasized students’ ability to use evidence to support their learning and believed it was important to assess that dimension. Heather strove to assess this dimension of student learning throughout her practice. For example, during a session on Gravity (11/13), Heather was reviewing students’ response to a laboratory activity. One of the questions addressed the difference in gravity between the Earth and the Moon. Students’ unanimous response was that the Earth had less gravity than the Moon. Heather asked a student for his evidence for that claim and he responded that he just knew.
Heather emphasized the need for specific evidence to support conclusions. At that point a student volunteered that he had read in a book that the moon’s gravity was a sixth of the earth’s. Another student pointed out that whenever she saw news reports of the landing on the moon, or movies with people on the moon, everybody looked like they were jumping from or floating from place to place. Heather asked her what that implied about gravity and the student responded that since that is not how we walk on earth, it implies the moon has less gravity.

*Knowledge of methods of assessment.*

Heather believed that her repertoire of methods of assessment was inadequate when it came to assessing the dimensions of science learning she deemed important. She mostly relied on written tests (concept checks), but believed they were not the best way to assess students’ learning in her classroom where she emphasized authentic learning. The problem was that Heather believed she lacked the knowledge and skills necessary for assessing student learning through inquiry in a way that translated into enough grades for the grade book. She commented, “I feel like a lot of times I have to just walk around and put down points because a lot of the stuff that they are doing I think they are doing okay. They are doing the effort and those kinds of things. That’s only the hardest thing is. You know on a weekly basis am I putting enough grades in the grade book kind of thing” (SR). The only method she could think of to formally assess student learning through inquiry consisted of extended response/essay questions. However, due to her reluctance to grade “160 pages of long extended response essays,” Heather continued to rely on her more traditional, teacher-constructed forms of assessment that consisted of closed ended multiple-choice and fill in the blank items on concept checks and laboratory write-ups:
I think that a lot of my assessment is tell me the word, fill in the blanks. They are not really, I don’t know. That’s also a choice that I make because I can’t grade a hundred and sixty pages that are long extended response question too. There is a trade off. There are a lot of things that I think that I am missing but at the same time personally I just couldn’t do it. (Post-PBI)

An examination of Heather practice painted a similar picture. Heather’s reliance on the traditional forms of assessment resulted in an emphasis on students’ ability to recall and select scientifically accurate facts rather than an assessment of conceptual understanding and applications of concepts. Throughout the year, Heather used whole class reviews of tests, laboratory notebooks, and worksheets to make sure students had the right answers, the correct units, and knew the formulas needed to check find the right answer. For example, when reviewing the unit on Work and Power Heather consistently emphasized the units of both power and work by asking student what they were, what the formulas and units for speed, power, and weight were respectively (11/20). Furthermore, as students corrected homework related to the same unit, Heather requested answers for questions from different students and highlighted how they could attain the same answers using formulas.

The exception to Heather’s traditional use of assessment consisted of the use of questioning as a means of formative assessment. At checkpoints, Heather relied on questioning to evaluate students’ concept development progress and monitor learning. For example, during a session on testing conductors (1/30), Heather asked the students how they knew that the metal object was an insulator or a conductor. Students said that if the bulb lit then the object was a conductor, if the bulb did not light, then the object was
an insulator. A group of students told Heather that the light was brighter at times with some conductors. Heather asked them what they thought that meant. One of the students said that some metals were more conductors than others. Heather proceeded to tell them that maybe they could divide the conductor column into more of or less of a conductor.

Heather attributed her recent use of formative questions to PBI where this practice was extensively modeled. Her statements and her practice indicated that she spent more time monitoring group learning through discussions and questions at checkpoints, which enabled her to accurately assess individual students’ learning and concept development:

I’m spending a lot more of my time walking around and talking to them during class as they go through it. I find that it’s been a great thing… By checking how they are doing at different steps, what they’ve written and making them stop and asking them questions. I feel like when I get the end results pretty much everybody has the same idea rather than there are some kids that are just, completely have different ideas and they have to go back and redo everything.

(Post-PBI)

However, Heather believed the course insufficiently addressed issues related to assessing student learning through inquiry. She stated, “[Inquiry] was the main thing I came away with I think. I don’t think that there was, I was kind of hoping there would be more of other aspects of it. Okay, once you’ve implemented inquiry then how do you assess it?” (P-PBI).

In short, Heather’s constructivist views of learning were evident in her choice of dimensions of science learning to assess consistent with scientific literacy. These dimensions consisted of explanations and application of concepts (conceptual
understanding) through connections between concepts and across disciplines, as well as the ability to support learning with evidence by focusing on student reasoning. However, except for the use of formative questions at checkpoints, Heather used traditional methods of assessment that were inconsistent with her choice of dimensions of learning to assess, focusing on students ability to accurately recall scientific knowledge. Heather attributed the inconsistency between her beliefs and practice to a lack of knowledge about how to assess learning though inquiry, an issue insufficiently addressed in PBI.

Knowledge of Science Curricula

Heather’s knowledge and use of science curricula were shaped by the State of Ohio’s requirements for the standardized tests. However, she selected topics for teaching from these requirements based on her purposes and goals for teaching. Heather further enjoyed autonomy in her choice of curricular program and developed her own curricular materials based on State requirements, her stated purposes and goals, and PBI. This category of Heather’s PCK refers to her knowledge of national, state, and local goals and objectives for science teaching. It also includes knowledge of specific curricular programs, their general learning goals, and activities and materials used in each. The following sections describe Heather’s knowledge of science curricula.

Knowledge of national, state, and local goals.

In making instructional decisions, Heather relied on national, state and district goals and objectives, as well as statewide examinations. She described these goals and objectives as the content, concepts, and topics she covered daily in her classroom:
I guess being kind of tied to a curriculum I feel like that these are the content standard that are important. If I haven’t covered them and I don’t have to beat them into kids. I can change things a little bit but I feel like by the end of the school year we have mastered those things that our state and district have said your students should know then I feel like those are the most important. It’s the physical science concepts that we’re covering everyday. I don’t know that one is more important than the other. (TPPI)

As Heather made curricular choices that guided her instructional decisions, she was faced with the necessity to cover topics in order to prepare her students for tests, and selected these topics based on her personal goals. So, even though Heather based her instructional decisions on state and district goals and objectives, she faced time limitations that forced her to select out certain topics. Heather stated, “Because there is only 180 days... there are certain points like when we get to our semester I want to make sure that they can take an exam. Sometimes I kind of work my way backwards. This is where I want to be, I work backwards to kind of set that up” (TPPI). For that reason, she based a lot of what she taught on what her students needed to pass the statewide examinations or what she deemed important to meet her goals of preparing successful citizens.

With respect to statewide examinations, Heather was concerned about the Ohio graduation Test (OGT) and the ninth grade proficiency test. These tests were a major determinant in how Heather chose what she was going to teach, making sure she covered concepts students were expected to know for these tests:
[I decide based on] our curriculum that we have and the expectations and the material we have to get through and the state standards of what our kids should be prepared for. That kind of goes back to proficiency testing. If I know that this year I’m supposed to cover these things so when the kids take the test in tenth grade they are expected to know it. I make sure that we get that done.

As stated above, Heather also selected specific topics based on essentials that were necessary to meet her personal goals for teaching (successful citizens). In that respect, she emphasized topics essential to generating an understanding of the big picture required by students to become functional members of society. Adhering to this goal sometimes resulted in what Heather conceived a watered down curriculum:

Then from [district curriculum] I look at the big picture. There are some things that are still in there that I just really don’t think that in the big picture it’s worth some of our time that we have to do to get there. I don’t know. In deciding what to teach I look at what should an intelligent person who has study this material understand. To go through all the little minute details some kids will get it right away and some kids won’t. That’s where you spend a lot of your extra time. I don’t want to say I’ve dumbed down the standards but I look at what is the minimum and that’s where I focus the majority of my time.

Knowledge of specific curricular programs.

Heather did not describe many Physical Science or Physics curricular programs. She was only aware of the Active Physics series because she participated in a workshop about it when her school district was considering adopting the series. Even though Heather mentioned Active Physics, she did not describe any learning goals, activities, or
materials related to it because she no longer had recourse to use it since her district
decided against adopting the series.

Because Heather was not happy with the district’s textbook selection, she
designed her own instructional materials in the form of a laboratory book she called \textit{Blue
Book}. The book was a result of reflections on activities she used in her classroom over
the previous three years, and adaptations of activities from PBI:

Really what I did was took a couple of years and kept a hold of all of the stuff that
I had done and put it in a binder and wrote notes about okay this should change,
this is good or this should stay. Also, from the physics by inquiry class when it
was over, I brought in a lot of our activities together and put them in a book so I
had a chance this summer to not only go through those activities but to actually
adapt them for school. Those couple of weeks or maybe even a month and a half
after the class I pretty much rewrote a lot of our labs and put it together in that lab
book that we have.

The \textit{Blue Book} was used in all eighth grade Physical Science classrooms and was
based on national, state and district standards. Heather included topics and activities she
deemed important for students in eighth grade as they prepared for statewide tests and
necessary for effective citizenship. These topics are listed in (Appendix D). Several of the
topics are the same as those covered in PBI (e.g. motion, electricity, and properties of
matter). Most of the activities in the book relied on Guided Inquiry as an instructional
strategy, an influence she attributed to the Physics by Inquiry Course and an effort to
abide by the National Science Education Standards’ (NSES) (1996) emphasis on inquiry.
In short, Heather’s conceptions of curriculum were guided by goals of coverage and her personal goals for teaching. She selected topics to teach from the district standards based on what she needed to cover for the statewide examination while focusing on the big picture. As a result of her dissatisfaction with available curriculum programs, Heather adapted PBI activities and activities she used in previous years to develop and use a book that incorporated her selected topics and the NSES emphasis on inquiry.

Knowledge of Instructional Strategies

Heather’s choice of which subject specific strategies to use in her instruction was driven by her goals and purposes for teaching and expanded on by PBI. She also based her decisions on her knowledge of students and their abilities. The knowledge of instructional strategies aspect of Heather’s PCK concerns her knowledge of subject specific and topic specific strategies. Subject specific strategies are broadly applicable instructional strategies specific to science teaching as opposed to other subjects. Topic specific strategies have a narrower scope, apply to teaching particular topics, and can be representations or activities.

Heather was knowledgeable about and used several instructional strategies in her practice, namely guided inquiry, hands-on activities, and more didactic strategies like retrieving information from texts or movies. Per her admission, guided inquiry was a new addition to her instructional strategy repertoire and was a result of the Physics-by-Inquiry course. Heather used guided inquiry in the units on motion, properties of matter, and electricity. She used a combination of hands-on activities and didactic strategies in the unit on waves and Newton’s laws.
Even though at the time of the study a lot of Heather’s practice relied on guided inquiry, it was not always the case. Prior to taking the PBI course, Heather’s teaching consisted mostly of hands-on activities, which she equated to inquiry teaching. She claimed, “I guess my definition before going into the course was more hands on. Saying that hands-on and inquiry is the same thing” (Post-PBI). Heather used hands-on activities in conjunction with more didactic strategies such as defining the concept at the beginning of a session, giving students directions for an activity, explaining what their results should look like, and spending the remainder of class time monitoring behavior:

I think probably last year would be more introduce what the concept was at the beginning of the class, maybe like five or ten minutes, go through the directions with the kids, go through what their end results would look like with the data table and everything and then let them go and not check in on them much comprehension wise but maybe more behavior wise. Make sure everybody is following the directions and then at the end either have them submit their work or check their final work. Last year was kind of like at the beginning and end check how they did, in the middle it was just keeping the peace. (Post-PBI)

Despite Heather’s continued use of used hands-on activities the year of the study, she believed her practice was significantly different because she no longer introduced activities by discussing the method to do them or the results students should expect. Rather, she held open discussions with students at the onset of activities in an effort to activate their prior knowledge and emphasized the use of evidence to support work throughout:
There is a difference between hands on and inquiry. I still find myself wanting to go over the lesson before we do the lab. Kind of what we did today was a shorten schedule to kind of play around with but what we miss today really maybe is that it doesn’t set up the lab we are doing tomorrow it’s inquiry.

From that I really have to challenge myself because when we did simple machines. I didn’t let them read the textbook about simple machines. We just started talking about pulleys one day and the relationship of the pull down and the forces and things like that. That made it made it more inquiry and less hands on. (Post-PBI)

Combined with her emphasis on the use of evidence, Heather’s consistent use of questioning to guide students’ thought processes reinforced the belief that her practice incorporated inquiry even when her students performed hands-on or information retrieval activities. She felt that her interactions with her students reflected her inquiry philosophy. She declared:

I think my interactions with the students are very much inquiry based; I don’t usually tell them. Even when we are talking in a small group I try to give them questions to maybe lead them to figure out why their answer is not right. Sometimes I let them have not right answer. A couple of groups this morning still had not good answers from the first day but when they get to the next section they are going to say, wait a second. They will know that what they had at the beginning is not right. (SR)

Whenever Heather used guided inquiry in her practice, she attributed it to the PBI course. She stated, “[Physics by Inquiry] was like a great springboard for [using
inquiry] and it was also a lot of my thinking about inquiry was, it changed because I actually had to do it” (P-PBI). Heather defined inquiry as the collaborative discovery or exploration of scientific concepts through questioning for the purpose of promoting conceptual understanding:

I would define inquiry as discovering or exploring. Identify a concept and understand it. Well I think providing experiences and sometimes a controlled environment, for instance, what we are doing now for electricity I wouldn’t just say, hey guys use as many batteries as you want, use as many bulbs as you want. You have to give them some limits but letting them kind of put the meaning together and not really guiding them with statements but more guiding them with questions. I guess working in groups. I don’t think it’s really inquiry if they just did it all by themselves all of the time. (Post-PBI)

She explained that adopting the guided inquiry instructional strategy was not easy. It took a lot of time, patience, student training and trial and error. She stated, “It was really hard at the beginning and it was really slow. Some of the first couple of labs I thought we could get through in a day or two but it took us a week to get through it” (Post-PBI).

After a lot of training and guidance, students rose to Heather’s expectations. Heather trained them in the new method, gradually relinquishing the level of control until students were able to independently conduct the inquiry activities, and rely on evidence to support their answers. For example, Heather started the year emphasizing every aspect of each activity, requesting answers for each question from every student to insure they were on task and able to answer questions and support their answers. Five months into the year, Heather was confident in her students’ ability; her hard work and headaches paid off:
I think they pretty much know what to expect and they know I’m going to ask questions I think really those first couple of labs that we did I had to be really stressed and asked them almost every single question so they realized that every question and everything on the lab is important. They didn’t just pick it up on their own. I had to really guide them and that first month was really bad. I was thinking at one point, oh my gosh what have I done? Every day I was nuts and I had the worst headache and everything was just kind of like, what am I doing? This is horrible. Now that it’s February, that’s kind of a long turn around but I feel like that even if I wasn’t here today and they had a sub, I feel like they could have done it without me. (SR)

As mentioned before, Heather did not ubiquitously adopt guided inquiry in her practice, despite all the time and effort she invested in the new strategy. Heather gave several reasons for this state of affairs, all of which related to perceived obstacles to the implementation of guided inquiry. These obstacles included student boredom/frustration, assessment, and resources. A first obstacle cited by Heather consisted of students’ boredom/frustration and was a result of her experiences in the PBI course. During the summer course, Heather realized how hard it was to work in groups and collaboratively construct knowledge and believed that the same problems she faced with adults would probably exist in her eighth grade classroom:

I realized that it really is frustrating to do it every day, especially my philosophy about group work changed. For the first time in my life it was really difficult some days to get your work done with a group. Now I can
sympathize a little bit better with kids who are like, I seriously can’t work with this person. I think going through it and feeling the whole excitement about the different things and also the frustrations. I think it made it a more realistic picture of how it was going to work in here. You know the results are pretty much different than eighth graders but not a lot. Things are still the same.

She further realized, after the first few inquiry units she implemented, that students could not be expected to do inquiry every day because they got tired and bored with the process. For that reason, she believed it was necessary to intersperse hands-on or information retrieval activities between guided inquiry activities. Heather declared:

We have to change things up a little bit because they start to get really worn down if we just do this all the time. Stopping for a little bit and giving them a break and doing some different types of things where they don’t have to, you know it’s not all check points and stuff like that.

A second obstacle consisted of resources. Resources consisted of support by fellow teachers and the administration, given the time and effort intensive nature of guided inquiry, as well as the large class size. She declared, “I would say really resources of time and people. I don’t feel like it’s physical. We have enough supplies and those kinds of things. It’s just the support” (TPPI).

A final obstacle to Heather’s implementation of guided inquiry was mentioned previously and consisted of her lack of knowledge of how to assess guided inquiry authentically, while still harvesting enough grades to report to the administration and
parents. She stated, “I just think the hardest thing still for me is to have enough grades in the grade book” (Post-PBI).

The only two reasons for Heather’s selective adoption of guided inquiry that were not related to obstacles to inquiry implementation consisted of her belief that certain hands-on activities or projects were successful in previous years. She attributed success to these activities if they fulfilled her goals for science teaching and were enjoyable to students. For example, the electric car project, which consisted of students following guidelines and conducting Internet research to build electric cars, met both those requirements. It was consistent with her goals for teaching, namely interconnectedness and collaboration, and students enjoyed it:

It’s like the electric car project that we did. The kids had to work together and they see that there is a benefit of so and so had a really great idea. Well maybe other people have an opinion and those kinds of things. I’d say like more projects or activities where they have to use a lot of different skills. It’s not just electricity but they have to do language arts things. Things were kind of integrated there at the electric car project. It was a good example of that although it was a crazy day. (TPPI)

Similar activities included the use of guiding questions as students watched Bill Nye movies on electricity and waves, completing worksheets after reading a text on waves, fun activities to generate waves, and building a rocket:

For instance, with our Newton’s Laws and things like that; let’s build a bottle rocket and I’ll give you all the directions and you are just doing it as an
application kind of thing…so I guess if I’m not doing inquiry I don’t really
know what I’m doing. (SR)

In short, Heather’s views of subject-specific instructional strategies were
consistent with her guided inquiry views of science teaching. However, examination
of her practice suggested she still used strategies inconsistent with her stated views.
Heather’s use of guided inquiry strategies was limited by obstacles such as inadequate
knowledge of assessment strategies, a need for instructional variation to avoid student
boredom/frustration, and support resources. Whenever she used “fun” instructional
strategies inconsistent with her orientation for teaching, Heather choices were rooted
in her personal goals for teaching science and emphasized the use of evidence.

Summary

Heather’s beliefs and PCK were consistent with constructivist views and were
rooted in an amalgam of personal history, the PBI course, and previous teaching
experiences. Analysis of her PCK indicated coherence among its components that
translated into her practice, except in the case of assessment. This translation was
mediated by Heather’s beliefs about science and science teaching, purposes for
teaching, previously held beliefs about her students and their abilities, and her
teaching context. This section summarizes Heather’s beliefs and PCK and discusses
the influence of PBI on these two constructs. It also draws connections between the
different elements of Heather’s case, namely her background, context for teaching,
beliefs, PCK, and practice.

Heather held constructivist views of science evident in her beliefs that science
was an integrated, dynamic body of knowledge and way of knowing that represented one
way of understanding the world. Central to her views was the social construction of knowledge through a process of theory invention, testing and acceptance. These views of science had origins in her early experiences with science, her experiences as a learner, and PBI. Heather’s views of science reflected her early experiences with the discipline and were reinforced by the Physics by Inquiry course. In both cases, Heather participated in scientific investigations in middle and high school where she collaborated with colleagues, and her teacher, to ask questions, collect data and derive conclusions based on evidence.

Consistent with her constructivist views of science, Heather held constructivist views of teaching science evidenced by her guided inquiry orientation towards science teaching and views of science teaching as facilitation. She believed her role as a teacher consisted of facilitating students’ social construction of knowledge. Heather’s goals for teaching science were based on her general purpose for teaching; preparing responsible citizens, functional members of society who make decisions based on evidence. Both her views on facilitation and her emphasis on evidence were a result of her participation in PBI. Prior to PBI, she believed her role was to explain targeted concepts and model science activities to students at the beginning of the class and then monitor their behavior as they conducted the activities. Similarly, Prior to PBI, Heather’s goals for teaching science emphasized relevance and were a result of her learning experiences in college. For example, her least favorite courses were ones where the emphasis lay on memorization of facts. Her favorites were ones that, like PBI, submerged her in relevant, inquiry-based applications of science.
Combined with her goals, Heather’s orientations to science teaching and previously held beliefs about students’ abilities served as conceptual maps that guided her classroom practice. Her adoption and continued use of guided inquiry as an instructional strategy despite difficulties was a result of contextual factors, her confidence in her students’ abilities and motivation for learning, and her belief that they will succeed if they exert the effort. Contextually, Heather was supported at the district and school levels as she developed and implemented her PCK for inquiry. Her district’s goals consisted of incorporating inquiry learning into daily instruction. Her curriculum leader, who was one of the PBI instructors, provided Heather with resources, materials, and a sounding board for her ideas when she needed it. A last contextual factor that influenced Heather’s use of inquiry consisted of her autonomy as a teacher. She developed her own curricular materials, which aligned with her goals and beliefs, and she was able to teach at a slower pace while her students became more comfortable and proficient with the new instructional approach.

Heather’s PCK reflected constructivist views also. She held constructivist views of learning that were evident in her choice of dimensions of science learning to assess. These dimensions consisted of explanation/application of concepts through connections between concepts and across disciplines, and the ability to support learning with evidence by focusing on student reasoning. Both dimensions were consistent with dimensions of scientific literacy and were a result of PBI. Central to Heather’s constructivist views of learning was her emphasis on student engagement and prior knowledge. She believed students’ role in the science classroom consisted of active engagement in the social construction of knowledge. Heather further emphasized the importance of alternative
conceptions in students’ learning. She described conceptual change strategies as ways to address these areas of difficulty. This emphasis on prior knowledge and alternative conceptions is a result of PBI.

Heather’s constructivist PCK translated into her practice in most cases. She believed her students conducted science in her classroom because they participated in communities of learners whose members shared a responsibility for understanding the physical world by relying on evidence. Together with her constructivist guided inquiry orientation towards science teaching, Heather’s concerns for coverage dictated how and what she taught. As a result, she selected topics to teach from the district standards based on what she needed to cover for the statewide examination while focusing on her goals of teaching “the big picture.” Despite her guided inquiry orientation to science teaching, Heather used a variety of instructional strategies to maintain student engagement. Her choice of strategies was rooted in her personal goals for teaching science and emphasized the use of evidence.

Additional aspects of Heather’s practice that reflected her constructivist views of teaching and learning consisted of her facilitation of students’ learning and her awareness of student difficulties. Because of her belief in the importance of students’ prior knowledge in promoting engagement and relevance in students’ learning, Heather strove to relate concepts learned to applications students might encounter in their everyday experiences. Her emphasis on the interconnectedness and relevance of learning experiences was consistent with her goals for teaching science, beliefs about the integrated nature of science, and perceptions of how she learns best. Furthermore, even though Heather did not actively seek to externalize students’ alternative conceptions, she
recognized them whenever they became apparent at checkpoints, and used conceptual change pedagogies consistent with her constructivist beliefs to dispel them. The only aspect of Heather’s practice that was inconsistent with her constructivist beliefs was her use of traditional methods of assessment that failed to assess the dimensions of learning she emphasized. Instead her traditional assessments focused on students’ ability to accurately recall scientific knowledge.

Finally, in addition to more deeply understanding the content, Heather’s use of guided inquiry, her awareness of misconceptions in physics and strategies to dispel them, and her use of questions at checkpoints were a result of her experiences in the Physics by Inquiry course where such practices were modeled and discussed. Furthermore, Heather attributed the inconsistency between her constructivist beliefs of learning and her use of traditional assessment to a lack of knowledge about how to assess learning through inquiry, an issue insufficiently addressed in PBI.

Jody

Jody is a 50-year-old ninth grade physical science teacher at an urban school neighboring the university. She was certified in comprehensive science from a midsized Midwestern University 30 years prior to the study. Jody has been teaching for 23 years, 13 of which were spent at her current school. At the time of the study, Jody was in her second year of teaching physical science to ninth graders. Prior to that, she taught physics and chemistry to eleventh and twelfth graders. The following sections describe Jody’s background, teaching context, beliefs, PCK, and the relationship between her beliefs, PCK and practice. The final section summarizes the key aspects of Jody’s case, drawing connections between its different elements.
**Background**

This element of Jody’s case refers to her intellectual and professional biography, namely her previous experiences in science and the reasons leading to her choice of a career teaching science. Together, these aspects have the potential to provide insights into Jody’s practice and knowledge base for teaching.

Jody began her undergraduate studies with the intent of graduating with a Medical Technology degree. She soon switched majors to a bachelor of General Studies with an emphasis in Environmental Studies because of her love of the outdoors and the fact that she found her chemistry courses hard and competitive:

The chemistry I started out with was the chemistry for majors so it was mostly pre-med. Originally, I thought of maybe getting into the medical technology. My love for the outdoors told me that I couldn’t sit in a lab all day. That’s why I switched from that. It was tough. I found that chemistry really rough because I was competing against some very highly intelligent people that wanted to get into med school. It was kind of interesting but I really struggled with that. (COT)

At the same time, Jody decided to get a degree in education and took an extra year to complete that. She thought of her teaching certificate as a backup. Throughout her undergraduate schooling, Chemistry courses were Jody’s least favorite. She attributed her difficulties with chemistry to a lack of prior knowledge needed to excel in the courses. She stated, “I don’t think I had enough background before I went in. That just made it really tough. There seemed to be more pressure with it” (COT). By contrast, Jody’s
favorite courses were Geology and Geography of Appalachia that incorporated a lot of field trips. Jody only took one Physics course for Non-Majors.

After graduation, Jody took a job as a naturalist for the State of Ohio natural park systems. Her responsibilities included teaching high school students about land management. Jody enjoyed her work, which paid well, but realized it would not be compatible with having a family:

What I did was teach high school kids just general land management. I worked on trails and cutting down trees and wildlife habitats. I did that for the state of Ohio and I thought well you know I can’t stay where I am forever. I could move to another camp. I knew the money was very good and if you are going to settle down and get married with kids it doesn’t work very well.

(COT)

Her experience teaching high school students helped Jody realize teaching might be a good career choice. Jody was offered a teaching position at a school that was part of her church where she taught science to grades one through eight for two years. She enjoyed that job because it afforded her a better understanding of the scope and sequence of science in grades one through eight, something she would not have otherwise thought of, and she enjoyed that age group of students who had a lot of enthusiasm for learning science. During that time Jody married and left the classroom for a while.

When she was ready to teach full-time, Jody applied for a position at the urban school where she was teaching at the time of the study. Her first assignment consisted of teaching chemistry to college preparatory students. Just like in college, Jody thought chemistry was difficult, especially because it involved a lot of math. She
relied on her colleagues in the science department for help in terms of lessons and content. As a result of her experiences with teaching chemistry, Jody realized the importance of a teacher’s knowledge of the content and felt that her lack of knowledge was detrimental to the students:

I mean teaching chemistry the first year was a little difficult. I had the college prep kids. There was a whole lot of math. I felt like I was learning along with the kids. That’s really not the best thing for the kids sometimes. I did learn a lot. I had to rely a lot on other teachers. How do you teach this? What do you know? What is the most important part? I had really good help. I had the science department at [school name] was one of the top science departments there. I had a very strong cohesive group and everyone helped everybody. They shared lessons and ideas. (COT)

Jody taught 11th and 12th grade chemistry and physics for 11 years. Her years of teaching the subjects resulted in her belief that her strengths lay in the area of physics and chemistry. To improve her content knowledge, Jody participated in many professional development programs, both during the school year and in the summer. Examples of such programs included a district wide training on the Active Physics series and the PBI course. Jody enjoyed PBI and believed it deepened her understanding of physical science concepts. Her scores on each of the posttests administered in PBI were 99, 93, and 100% respectively.

Context

Jody taught a ninth grade physical science course at an urban school district. The district make-up consisted of 70 percent African-American and was rated in Academic
Emergency by the Ohio Department of Education. Jody’s high school, also rated
Academic Emergency, had block scheduling in place. Classes started at 7:30 AM and
ended at 1:50 PM. Jody taught two blocks each day separated by her lunch break at 10:15
AM. Her planning period took place after the second block. The curriculum mandated by
the district for all ninth grade Physical Science classes consisted of *Active Physics* (see
below). All teachers in the district were expected to follow *Active Physics* and attend to
its chapter within the same time frame. Students in ninth grade were expected to take the
ninth grade proficiency test and prepared for the Ohio Graduation Test.

Jody’s classroom resembled a college science laboratory without most of the
equipment. The teacher’s desk and bench were at the front of the room facing five long
student benches with sinks at one end. Students listened to teacher instructions and
copied notes at these benches. When activities and group work were done, the students
and the teacher moved to the back of the room where there were five student group tables
surrounding the teacher’s desk. Computers were conspicuously absent. The room was
well lit; however air-conditioning was poor both in the summer and in the winter. When
it was warm, fans could be heard in the background. During any given class session, 6
resounding bells sounded signaling the start and end of classes in another part of the
building. There were 16 students in the class, 2 white, 1 Hispanic, and 13 African
Americans.

At the time of the study, the science department no longer existed, having made
way for two teams of ninth grade teachers. Jody worked closely with the math teacher on
her team to align their curricula, where applicable, in science and math. She stated, “They
are willing to pay us extra to figure out exactly where it overlaps so that we can totally
align our courses, so that when I’m graphing things, she is working on graphing skills” (COT). Teachers were expected to remain with a given group of students for two years. So for example, Jody was teaching ninth grade physical science the year prior to the study, and was supposed to move up with the students and teach tenth grade biology the year of the study. However, due to the need to have an additional team of teachers for ninth grade, and Jody’s reluctance to teach Biology, she was able to stay on in ninth grade and teach physical science.

**Active Physics**

*Active Physics* (publisher or project developer, 1999) is an activity-based physics curriculum developed by Arther Eisenkraft, Ph.D., in association with the American Association of Physics Teachers (AAPT) and the American Institute of Physics (AIP). The developers characterize *Active Physics* as a different species of physics courses. It addresses the same physical science concepts found in other books (e.g. mechanics, optics, electricity) but in a different sequence. In traditional books, forces are addressed in the fall, waves in the winter, and solenoids in the spring. In *Active Physics*, students are introduced to physics concepts on a need-to-know basis as they explore issues in Communication, Home, Medicine, Predictions, Sports, and Transportation.

Chapters within the book are independent of each other. Chapters are composed of nine activities, each divided into seven sections. Each chapter begins with a challenge that introduces students to a situation in need of a solution, followed by the activities. The first section of each activity consists of a “What Do You Think?” question intended to elicit students’ prior understanding and is part of the constructivist approach. The second section consists of “For You to Do” where students engage in activities as they respond
to questions. The third section consists of “Physics Talk” which summarizes the physics principle discussed and includes equations where appropriate. The fourth section consists of an “Inquiry Investigation” which is presented for students who wish to go further independently. The fifth section consists of “Reflecting On The Activity And The Challenge” that relates the activity to the initial challenge. The sixth section consists of the “Physics To Go” homework assignment where students are asked about the specifics of the activity. The chapter concludes with a “Physics At Work” profile where students are introduced to someone whose job is related to the chapter challenge.

**Beliefs**

Jody held positivist views of science and traditional and naively constructivist views of science teaching. While her views of science remained unchanged after her participation in PBI, Jody’s beliefs about science teaching underwent some change. More specifically her goals for teaching science and her views of her role as a teacher evolved to include teaching problem-solving and facilitation respectively. The following sections describe her beliefs about science and science teaching.

**Beliefs about Science and Physics**

Jody held positivist beliefs about science that were consistent with her traditional practice. These beliefs were rooted in earlier experiences with science as a naturalist. Her love of the outdoors nurtured a view of science as observation and discovery of nature. Jody defined science as a body of knowledge and ways of knowing that explained natural phenomena. She believed the main value of science lay in its explanatory power. She stated, “Science is really the study of a world and its interactions physically and chemically. I guess I see it as being a way of researching or a way of looking at
problems” (COT), and “A strong value for me is that science is such a neat way of explaining things” (TPPI). In addition to viewing science as explanatory, Jody believed it was a process of verifying patterns present in nature supports the positivist view whereby scientific knowledge is out there for scientists and, in turn, students to discover:

[Science] It’s always changing. History is changing and all the facts are changing. You don’t have to know all of it but you do have to see how patterns have been in the past and that you can see the same thing that went on. You can pretty well expect the same kind of pattern to repeat itself. That’s true in science. That’s all part of science too. It’s learning to use what you do know to help you.

(TPPI)

Consistent with her positivist views, Jody held a cumulative conception of science that was evident in her belief that science as a body of knowledge was not static; it changed due to increases in factual knowledge resulting from research advances in the field rather than paradigmatic shifts involving theory invention, testing, and acceptance. She believed scientific understandings in a lot of disciplines changed since her undergraduate days. Jody attributed these changes to advances in research resulting in new findings. For example, she said, “For me to teach biology now would be pointless because there is a lot of changes and I haven’t kept up in it…little things. I just know genomes and the whole genes, all that whole thing, in the past 25 years, that has changed dramatically” (COT). The belief that scientific knowledge changed because new knowledge was added contributed to Jody’s sense of self-efficacy for teaching specific scientific disciplines. Hence, she did not believe she had the necessary understanding to teach Biology because she had not taken any Biology courses in a long time, whereas she
felt comfortable teaching physical science because she participated in several Physics professional development efforts in recent years, which focused on the same curricular topics.

In addition to believing that science consisted of a cumulative body of knowledge, Jody believed it involved a way of knowing. Jody’s conception of science as a way of knowing translated into a single process of scientific discovery. She believed in the scientific method as a set procedure used by scientists to generate scientific knowledge, as opposed to one of many methods to identify the world. Jody’s emphasis on process was apparent when she attributed instances to “science” in the Interview about Instance if, and only if, there was evidence of the process of “how and why” things occur. For example, she commented, “[Science is not going on because] they are not playing with the process and figuring out how to balance it. They are just going through a report, reading it and that’s it” (CTS). To Jody, processes of science included physical manipulation of objects, or more “hands-on” activities as well as science process skills such as observation, collaboration, and more importantly, discovery of scientific patterns. So Jody believed that, for science to be taking place, scientists and student needed to be actively manipulating objects of science and looking for patterns as they question why and how things happen:

[Science is occurring] because they are actually working. I would assume they are working with the actual parts and trying to understand why one bulb is brighter than the other. They are actually doing things and trying to understand what it is that is happening. (CTS)
This belief that science is a process of physical manipulation held true throughout Jody’s classroom practice and was evident in her reliance on physical manipulations in all activities. For that reason, all observed sessions showed students involved in activities where they were using springs, telephone cords, slinkys, and chimes to create waves, time frequencies, and measure wavelengths.

Not only did Jody believe in the scientific method, she also viewed it as a general prescriptive, step-by-step experimental procedure that allowed for verification of scientific knowledge:

[What I value most about science is ] probably the problem solving aspect. There is so many ways to look at a problem and science is such a great way to look at the process. What am I looking for? You start thinking about what’s the variable. What’s the control? What am I really trying to find out? To me I see it being helpful in many areas. It’s simply following directions like putting a piece of furniture together. (TPPI)

The belief in a prescriptive step-by-step procedure that verified scientific knowledge was evident and reinforced in Jody’s teaching practice. Whenever Jody deviated from the Active Physics text which promoted guided inquiry, she emphasized the scientific method, teaching it to her students and going over the steps and what they do at each step to verify the relationship that we already know exists. An example from Jody’s teaching that illustrates this practice consisted of a session where she asked students to design an experiment to test which variables influence the pitch of a string. She instructed them to control variables, generate a data table and hypothesis, and conclusions. Jody then proceeded to tell students which variables to study and control for, namely tension and
length, and how to do the experiment following the steps of the scientific method listed on the board (2/27). Thus, by giving students detailed instructions and directions, Jody turned what could have been an inquiry activity into a “cookbook” type laboratory experiment.

Finally, Jody believed that an expert in science or physics was someone with an excellent knowledge of scientific facts, problem solving skills, and the ability to relate the different topics within science to each other. For example, she stated:

I would expect them to have more factual knowledge or that they would have that also and could recall facts easily and things like that. I would also expect them to have really good problem solving skills. If they are an expert then they can put everything together. They don’t just know the facts but they can put it all together. (COT)

Jody’s conceptions of physics as a discipline were not easily separated from her conceptions about teaching physics. In response to a question about the different areas that made up physics as a discipline, she described the areas she taught in 11th and 12th grade, namely kinematics, the study of motion and forces, waves, sound and light, electricity, and magnetism. Jody’s description of Physics as the set of topics she taught went unchallenged throughout the study, in all interviews and observations. She never mentioned, in interviews or in practice, scientific themes as described by the National Science Education Standards (NRC, 1996) or even how the different areas within physics could be relate to each other. She approached the different units of study as unrelated, distinct topics, which highlighted the conspicuous absence of any discussion of the big ideas and fundamental principles of Physics and how they related to other scientific
disciplines. The only comments Jody made about science and other disciplines science pointed to her belief that science was different from other subjects like math and English because of certain values inherent to science that were not present in other subjects. One example Jody mentions about such values consists of the potential of science to open students’ minds. She stated, “I think science opens their minds to other things.” Furthermore, Jody believed that relationships between science and math consisted of topics taught in both, while the relationship between science and English consisted of writing products produced in the science classroom that could be graded by the English teacher. These beliefs were reinforced by her practice and her relationship with the Math and English teacher at her school.

In short, Jody held positivist and process conceptions of scientific knowledge that translated into her practice and had roots in her love of nature and the outdoors. She believed that science consisted of a cumulative body of knowledge and a prescriptive scientific method used to discover it. Jody also believed that an expert in science was someone who had a firm and integrated grasp of the body of knowledge and scientific method. The following section will describe Jody’s conceptions of teaching science based on a discussion of her goals.

Beliefs about Science Teaching

This component of Jody’s beliefs refers to her conceptions of the purposes and goals for teaching science at a particular grade level and the resulting orientations or views toward science teaching. Jody held process and didactic orientations to teaching science, which were driven by her purpose for teaching and were a result of her earlier experiences with science. Jody also exhibited constructivist views of
science teaching that were a result of PBI. However, her practice reflected more naively constructivist views consistent with her didactic and process orientations. The following sections describe Jody’s goals and purposes for science teaching and her resulting views about teaching and learning.

Goals for teaching science.

Jody’s conceptions of the necessity for teaching and learning science evolved during her career and were consistent with her conception of science. At the beginning of her career, Jody believed that science was just another subject students needed to learn. Her conceptions evolved as a result of her teaching experience, and after taking the Physics by Inquiry course, Jody realized how her goals were changing. At the time of the study, she believed it was important for students to see how science was part of the world, especially those students who might not pursue science-oriented careers. In that respect, Jody’s goals consisted of nurturing an appreciation for science and its relevance in everyday life, teaching the process of the scientific method to explain things, and ensuring acquisition and mastery of concepts. The following paragraphs will describe Jody’s goals for science teaching and learning, how they related to her conceptions of science, and, where appropriate, how they were evident in her practice.

One of Jody’s goals for science teaching consisted of nurturing in students an appreciation for science and its relevance in everyday life. She believed students needed to study science to develop an appreciation for it and an understanding that it is part of their lives:

I know what I used to think, it’s just one of those things that you’ve got to learn. I guess I’m seeing, I know the kids see no purpose in it and that has always
bothered me. It’s like why are we doing this and who cares? I think it’s important to show them how much part of the world it is...It’s more than whether they know the facts or not, it isn’t as important as seeing the need for science in medicine and others. If they are really interested in science then you are going to go that way and you are going to learn the facts of things but just having an appreciation and understanding that it’s part of your life. (COT)

The need for developing an appreciation for science and its relevance to students’ everyday life probably stemmed from Jody’s belief that science was necessary for explaining the world and its process is useful to all students, even those who might not pursue science-oriented careers. Jody wanted her students to realize that even though they might not revisit specific content, waves for example, in the future, the process of learning about waves and discovering the existing patterns will be helpful to them when faced with other questions and problems in their professional lives. She believed it was essential to teach students the process of science because it would be more useful to them than any facts or information found in reference books, especially when that information becomes outdated after a while:

That’s why I like science because it’s problem solving and math too. If you know how to logically think something through then that will work with other things too. I can’t get that past the kids because they see no value in what we are doing now. You may never use this exact thing in your job in the future but you will be able to think and work it through. That’s what it is you need to be able to do.

That’s what I hope for them. (COT)
Jody’s evolving conceptions were also apparent in her discussion of her learning
goals for her students. Prior to the study, Jody’s goals for her students focused on
coverage of standards. However these goals gradually morphed into the belief that it was
important for students to be able to solve problems scientifically and to develop a
scientific habit of thinking. These beliefs were consistent with her conceptions of science
as a cumulative body of knowledge and a way of knowing. She declared, “I’m seeing
more and more the goals should be that they are willing to try and solve problems, that
they start seeing any problem more scientifically. To see that there is a method to solve
their problems if they reason it through and think it through. I guess what I want them to
understand is how to think” (COT). Jody believed that learning how to think was
necessary for her students beyond her classroom and she emphasized the importance of
learning the process over learning the facts because the latter are not static, they change
cumulatively:

I think the real learning that is valuable is that it’s not just book knowledge. It’s
not the knowledge because you can look up facts and things but it’s more how to
use what you know. That’s why I like science because it’s problem solving and
math too. If you know how to logically think something through then that will
work with other things too. I can’t get that past the kids because they see no value
in what we are doing now. You may never use this exact thing in your job in the
future but you will be able to think and work it through. That’s what it is you need
to be able to do. That’s what I hope for them. (TPPI)

Finally, Jody aimed for mastery of concepts because she believed that her
students needed to have a basic foundation that would be useful in future learning and for
Jody stated: “Well you’d like to move on when they’ve pretty well mastered a concept” (TPPI). Jody’s definition of mastery consisted of evidence of correct use of scientific terminology. Jody’s practice further supported this view through her concern with making sure her students had the right answers, definitions, and way to solve problems.

In short, Jody’s goals consisted of preparing students for all careers, not just science-oriented ones, by nurturing an appreciation for science and its relevance in everyday life, teaching the process of the scientific method to explain things, and ensuring acquisition and mastery of concepts. A combination of these goals indicated Jody’s general purpose for teaching, namely representing science as an academic discipline.

*Views of science teaching.*

Jody’s goals for teaching science were consistent with process and didactic orientations. Her conception of teaching consisted of presentation and explanation of relevant information. She believed that teaching involved the transmission of knowledge from the teacher to the student and she believed that the process of knowledge transmission was integral to teaching. She stated, “I know I enjoy passing knowledge on. That’s part of what we are doing.” When referring to teaching as presentation of information, Jody claimed, “Teaching is just giving information to the kids so that they are able to use it.” She further associated teaching with explanation. For example, when presented with the instance where students are asked by their teacher to observe different crystals, she stated, “At this point she is not really teaching anything. She is not
explaining anything or doing any more than that. It is still to me at least a good way to begin” (CTS).

In contrast to her traditional views of teaching, Jody described a teacher’s role as facilitation. She believed her role, as a teacher, was to guide students through questions and set up appropriate physical environments conducive to discovery. For example, in the CTS, Jody’s emphasis on guiding students was mostly apparent when she consistently categorized instances as teaching episodes if the assumption that the teacher was guiding students towards a certain understanding could be made.

In her own words, Jody described her role as a teacher to be a resource person. She claimed, “I guess my philosophy is just being a resource person. I give lots of information and I try to stimulate them to ask questions. I provide experiences for them to actually try things” (TPPI). Furthermore, Jody maintained that she tried to set up the environment and provide the necessary materials for students to discover science by doing activities, reading from textbooks, or copying notes:

I very seldom lectured much. I would put notes on the board and go over notes. I was hardly ever really lecturing them. We did a lot of activities. I guess teaching to me is more facilitating. It’s setting up environment where they can learn. You’ve given them what they need whether it’s the textbook and so they can look up things you are not talking about. It’s just learning by doing. (COT)

[…]unless they are actually doing it and working with the beam balance and trying to think things and trying to figure out the measurements I don’t think it’s really teaching. Just reading about something isn’t really teaching. (CTS)
Upon examination, Jody’s practice reflected her conception of teaching as presenting information and part of her conception of teaching as facilitation. Jody’s emphasis on presentation was apparent in all sessions where she wrote vocabulary words and their definitions on the blackboard expecting student to learn that information because they copied it into their. Presentation is also evident in Jody’s practice whenever she attempts to make learning relevant to students’ lives by telling them about real life examples of specific phenomena and concepts addressed. For example, when initially discussing waves, Jody mentioned Tsunamis as an example, something none of the students had experience with, and proceeded to describe it. Finally, presentation and transmission were also apparent when Jody discussed the “Physics to Go” questions at the end of each activity, which the students had previously responded to, by going through each of the questions and dictating “correct” answers. Jody’s presentation views were probably a result of her experiences learning science by watching or listening to explanations of phenomena. For example, in response to the instance involving a television documentary, Jody stated, “I know I’ve learned a lot from watching programs like that. Some of those are definitely teaching. They are explaining how something is working.”

Conversely, the only aspect of Jody’s conception of science teaching as facilitation that was apparent in her practice was her emphasis on her role as a resource person who sets up the environment and provides students with materials to manipulate. This emphasis was evident in all the observed sessions where Jody had the materials needed for a specific activity set up, exactly how they were supposed to be used in the activity, before students entered the classroom. A pertinent example consists of the
physical set up for the activity where students were expected to deduce the relationship between frequency and wavelength. Jody lined the lab benches with tape, marked to indicate measurement units required for the activity, and provided a string for wave generation and a stopwatch for timing.

To sum up, Jody held both traditional and naively constructivist conceptions of teaching. Her traditional conceptions were a result of her learning experiences in science and were apparent in her beliefs about teaching as the transmission of knowledge and her practice of presenting students with term definitions and correct answers. Jody’s naively constructivist views were apparent in her beliefs about the role of a teacher as someone who watches over the environment, ensuring that it affords enough opportunities for students to be involved in interesting and engaging educational activities.

Pedagogical Content Knowledge

Jody’s PCK was consistent with traditional and process views, with evidence of beginning shifts to constructivist views in certain areas. The changes in Jody’s PCK consist of an understanding of the nature of inquiry and the importance of prior knowledge and alternative conceptions in students learning. These changes are a result of her participation in PBI. Despite these changes in her views about the requirements for learning and areas of student difficulty, Jody’s PCK is characterized as traditional because she did not acquire knowledge of how to deal with these issues in a constructivist manner. Finally, Jody’s practice was consistent with her traditional and process views. The translation of her PCK into practice was mediated by her purposes for teaching, beliefs about her students, concerns for coverage and control, and teaching context. This section will describe Jody’s PCK and how it relates to her practice. Specifically, Jody’s
knowledge of student understanding in science, assessment, curriculum and instructional strategies will be discussed.

*Knowledge of Learners’ Understandings of Science*

Jody held traditional and process beliefs about students’ understandings of science that were reflected in her practice. She believed that her students’ understandings of science were mediated by their abilities and motivation for learning. This aspect of Jody’s PCK refers to her knowledge of the requirements for learning and of areas of student difficulty. Requirements for learning include pre-requisite prior knowledge while areas of difficulty include abstract concepts, problem-solving, and alternative conceptions. The following sections describe Jody’s knowledge of students’ understanding of science.

*Requirements for learning.*

Jody believed student learning could only occur in the presence of a set of necessary conditions. To learn, students should be willing to use prior knowledge to collaboratively engage in the manipulation of objects. Hence Jody viewed prior knowledge, learning by doing and motivation for learning as requirements for learning.

Jody believed students’ prior knowledge played an essential role in new learning. She defined prior knowledge as background knowledge about a topic that is a result of instruction in previous grades. Jody believed that a lack of prior knowledge is problematic for learning. She claimed, “Sometimes a roadblock is a piece of knowledge; you have to know this in order to do this [activity] right now” (COT). She emphasized that point because she believed students forget what they learn in previous grades and hence do not remember the necessary prior knowledge:
Most of it is set up to try to make them think the problem through. It is not as specific as to what to do and unfortunately sometimes [Active Physics] is too assuming if the kids know certain things, which my kids do not know. They probably should but I don’t know where their background is coming from. I know I need to go back sometimes and give them definitions of words that you think they would already know. I think it’s assumed with this book that there are certain terms that you should know already.

Because of her belief that a lack of prior knowledge negatively influences learning, Jody provided students with necessary information before they performed an activity to enhance their learning. She believed this was a necessary step to avoid wasting time re-learning what should have already been learned. She stated, “Rather than wasting time and trying to discover what those things are sometimes I just give them the vocabulary and try to get them to where they should be before the activity.” This practice was apparent in her teaching whenever she gave students vocabulary words and their definitions to make sure they all had the necessary background. For example, at the beginning of each unit, Jody wrote definitions for terms and concepts that were important for its understanding. She consistently instructed students to copy definitions from the board: “You will find on the board the vocabulary words you will need for today’s activity. I want you to copy them down so that you all have the same background because I know that some of you might have forgotten them and need refreshment” (1/31). This view of the role of prior knowledge in students’ understandings and how she addresses it is consistent with her presentation/transmission views of teaching.
Jody’s second requirement for student learning consisted of learning by doing in groups. She believed students learned only if they were observing phenomena and manipulating objects. She stated, “They learn best by doing the stuff…what I’m trying to get them to see is that the answer is right there. You have to work on it and look at it to try and figure it out. That’s what I think” (TPPI). She believed that students learned by doing, in a group, and following structured guidelines probably because that was one way by which she learned:

I know that I learn best by somehow actively being involved. I think my labs and things to me have always been helpful. It’s taking things apart and putting things together. I’m the one at our house that if there is directions to follow and you have to put something together then I’m the one to do it. It’s like a cookbook thing that I like and I have no problem doing that. To some people that is difficult. I know I learn best by something that is tangible and I can touch. I know that’s probably the best way that I learn. (TPPI)

Jody’s practice consistently reflected her conceptions of learning by collaborative manipulation since her students performed activities based on the Active Physics textbook by manipulating necessary and relevant materials.

In addition to believing that students needed to be “doing” or manipulating objects by working in groups for learning to occur, Jody maintained that active engagement was a necessary condition. Jody’s conceptions of active engagement implied students’ motivation for learning, doing the activity at hand or their curiosity about it. She believed that students would not learn if they were not attending and paying attention. She stated, “Move on to something else because maybe they are just not getting it and
you could spend three more days or two more weeks and they still wouldn’t get it just because sometimes they turn certain things off” (TPPI). Furthermore, students needed to be curious about the learning situation, desiring to learn, asking questions and wanting to know more about it for learning to occur:

Number one is curiosity. A real good learner wants to know more. They are not satisfied with just this is it and okay. I have one good student like that in my morning class. What he’s doing now is saying there is more to it even though it’s the same knowledge he’s never seen that there is more ways to use what he’s learned. You know he wants to know. He wants to do things.

Jody did not believe her students were willing or motivated to learn. She stated, “A lot of them have great capabilities they just haven’t been motivated in regular education” (TPPI). Jody attributes her students’ lack of motivation for learning to competing priorities and responsibilities they were too young to assume:

They are expecting their own children to be in charge. We have one student right now and he’s totally in charge of everything like earning money for food. It’s his grandmother and I don’t know what happened to his mother but he’s taking care of all the younger kids. He’s expected to look out for them and fight their fights. He does very little in school. They are made to be adults before they are actually adults. There is just this huge difference and it seems to be getting worse every year. You get more younger parents who are thirteen and fourteen years old and they are parents. (TPPI)
The only way Jody knew how to increase her students’ motivation and desire for learning was by trying to make learning context more relevant to them, relating it to experiences they enjoy and know. She stated:

You can see it in the other things they like. It’s like learning a rap song. They want to know that and they will figure out all the words and they will write them out. They really get into it. They learn a lot that way but it’s just that I wish I could get them to use that in another sense. (TPPI)

For that reason, Jody strove to relate concepts dealt with in class to the students’ experiences in an effort to make learning relevant. For example, to introduce the concept of waves, Jody asked the students if they had ever heard of tsunamis and told them what she knew about them (1/29) and when discussing waves, Jody described the role of wave frequency in tuning pianos (3/13). Unfortunately, Jody’s choice of examples was not relevant to students’ lives.

Knowledge of areas of student difficulty.

Jody identified areas of student difficulty related to students’ knowledge, abilities, and background. She listed alternative conceptions, language, and problem solving as areas of student difficulty. The following paragraphs describe Jody’s beliefs and practice with respect to each of the areas.

Jody believed a main area of student difficulty, one that greatly influences learning, related to their alternative conceptions. She defined alternative conceptions as wrongful understandings that arise because students did not examine a certain phenomenon hard enough, accepted common sense interpretations, lacked the right vocabulary, or were badly taught in previous classes:
It’s basically when they say something that at first it looks like it could be the answer but they haven’t really looked enough about it that it is a misconception. They don’t know but they are asking and questioning it. I’m just saying that they learn from their misconceptions and finding out why that can’t be. (P-PBI)

If I was trying to work this with ninth graders they would have a lot of misconceptions. They probably haven’t really studied electricity that much and unfortunately a lot of what they do learn isn’t really taught right in the younger grades. That is a misconception that we deal with all the time in many areas. I think they think of electricity as more moving than you know. (CTS)

Jody believed that she could help students dispel alternative conceptions by listening to their questions and guiding or directing their thinking towards a scientifically acceptable understanding:

[Teaching is going on] Because the student is questioning and wanting to know. He is trying to understand and the teacher is helping through the process.

I’m presuming that the teacher is responding to the question. The kid is wanting to know something and wanting to understand something. They could be easily led into a better understanding of what’s going on. (CTS)

However, an examination of her practice painted a different picture. Heather attempted to dispel students’ alternative conceptions by providing them with opportunities to manipulate learning objects long enough or examine the phenomenon hard enough. She consistently relied on students to answer the *Active Physics* activity questions independent from her. She did not conduct any checkpoints as was modeled to her in the Physics by Inquiry Course, or question students to externalize their reasoning.
This view was also apparent when Jody was taking the Physics by Inquiry course. For example, when attempting to balance a unit x with a unit y that was 5 times its mass, Jody’s group hung 5 x units at 10cm from the fulcrum of the scale and 1 y unit at 50cm. At the time, Jody stated that she liked such experiments because they would always provide a visual confirmation to the students, even though they may not really understand what was going on, they are able to see it and try to figure it out (6/12).

A second area of student difficulty consisted of mismatches between students’ language and vocabulary and the language and vocabulary of science. Jody believed students’ language was a huge stumbling block in terms of their learning. She attributed a lot of students’ misunderstandings and resistance to learning to the difference between her language, the language of science, and her students’ language. For example, students had difficulty understanding the word tension, and when they understood it, they were resistant to using it:

Their language is quite different. It’s English but it’s not. Trying to word something to where they will understand it has been really difficult. We were talking about tension and they had a hard time understanding tension but if I stay tighten or loosen, they understand that but they still can’t associate that with tension. They are actually doing it and feeling the tension and everything but it’s just this block that they have. Why use this word to say tighten or loosen. (SR)

Finally, Jody also believed that problem solving was an area where students experienced difficulty. She believed this difficulty arose due to prior learning experiences, where students were used to receiving information from teachers,
memorizing it, and regurgitating it on a test. For that reason, Jody believed that 
students’ prior learning histories played an important role in her students’ resistance 
of new ways of learning by problem solving, and engendered attitudes of laziness and 
the expectation not to do the work:

I think it has to do partially the way they are taught in elementary schools.

Perhaps what’s going on there is more, this is what you need to know. They give everything to them. They give them all the vocabulary; they give them all the notes or whatever. It’s all prescribed for them. That’s what they expect now. Since this isn’t anything like that and they aren’t having test that way… They are actually fighting doing some of the work. They do have to think and it’s like they don’t like it. (SR)

Jody believed this unwillingness to do work and to think resulted in an inability to problem solve, ask questions, and think critically. For that reason, Jody realized she needed to give her students more structured guidelines in terms of how to think a problem through, where to begin, which questions to ask, and how to come up with an answer.

She stated:

I guess I’m saying that sometimes I’m finding with the students that I have, that I have to give more directions because they don’t seem to know how to start. They don’t quite know how to come up with questions.

The biggest problem is students not wanting to think at all. I’m just having a real difficult time to get them to stop and really think. What I’m discovering is that a lot of them don’t know how to think. They don’t know how to see something through and work towards an answer. (TPPI)
Jody’s practice reflected her belief that students found difficulty with problem solving or were reluctant to do it, and translated into telling them the right answer rather than allowing them the time to think about it, or even taking the time to understand their reasoning. Jody rarely allowed students enough time to respond to questions she posed which meant she almost always was ignorant of how or what her students thought. For example, during a session on Newton’s laws (1/29), she read statements from a sheet out loud and asked students which law they thought the statement fit. When students did not answer right away, Jody asked, “Does it fit Newton’s first law?” Students said yes. Jody then asked them what their evidence for the answer was, and after waiting for three seconds, she told them the evidence was that the penny dropped into the cup and remained at rest and that depicts Newton’s first law. Furthermore, if students gave faulty answers to questions, Jody consistently corrected it by stating the right answer and its explanation. For example, after explaining and demonstrating wavelength and frequency of a wave (1/31), Jody asked students to observe what happened to the wavelength of a wave as she increased the frequency. One of the students stated that the greater the frequency, the greater the wavelength. This was a faulty conclusion. However, rather than asking the student for his reasoning, Jody told the class the correct relationship: as frequency increases, the wavelength decreases. She also told them her reasoning by stating, “We started with half a wavelength for the whole distance, and when I went faster, I had a complete wavelength within the same distance.”

In short, Jody’s conceptions of student learning were consistent with traditional and process views of learning where students learned by doing the process of science and working collaboratively. Jody believed that a necessary condition for student learning
consisted of motivation or desire to learn and appropriate background knowledge. She identified several areas of difficulty for students in science. These consisted of alternative conceptions, language, and problem solving skills. Jody did not attempt to facilitate students’ learning by helping students overcome areas of difficulty. Rather, consistent with her traditional views of teaching, Jody supplied her students with needed prior knowledge and correct answers.

Knowledge of Assessment in Science

Jody’s beliefs about assessment in science were inconsistent with her practice. Her beliefs about dimensions of science teaching to assess are a result of PBI and her mandated curriculum. Her use of assessment methods and her classroom assessments are consistent with her concerns for coverage for the Ohio Graduation Test. The knowledge of assessment in science component of Jody’s PCK refers to her knowledge of the dimensions of science learning to assess and methods of assessment. Methods of assessment consist of specific instruments, procedures, approaches, or activities used during specific units, as well as advantages and disadvantages associated with the use of a particular assessment device or technique. The following sections describe Jody’s knowledge of both these aspects and their use in practice.

Knowledge of dimensions of science learning to assess.

Jody believed it was important to assess dimensions for science learning related to understanding and application of concepts (conceptual understanding) rather than memorization. She stated, “I’m not concerned about memory of every term but just the understanding.” These dimensions are consistent with a constructivist view of learning and the conceptual understanding aspect of scientific literacy.
Jody associated learning with applying what was learned. In essence she believed that students had learned if they could use the knowledge to solve new problems by remembering how they solved it before:

I think sometimes you learn a lot of things but you don’t think you have right away. When you are against that problem again and you remember how you did it before and that helps you to do the problems. It’s like solving new problems but you are using things you’ve used in the past so you must have learned in order to do that. It’s kind of like putting everything together that you’ve done and solving this new problem. That’s when you realize, oh yeah, I really did learn.

(TPPI)

Knowledge of methods of assessment.
Jody’s repertoire of methods of assessment included authentic assessments in the form of projects, traditional assessments in the form of written tests, and formative assessments such as questions at checkpoints.

As part of the Active Physics curriculum, Jody was expected to assess her students using projects at the end of each unit. These projects were intended to incorporate all concepts addressed in the unit and demonstrate students’ understanding of them through application or synthesis. Thus students were expected to build models, posters, or present research related to the concepts in the unit, and they were assigned grades based on set criteria such as providing rationales for statements or specific set-ups. For example, the assessment for the unit on waves consisted of students putting on a show with light and sounds. 30 points were awarded based on how many concepts or components the show had. 40 points were awarded for students’ ability to explain concepts. The remaining 30
points were awarded based on students (10 points) and the teacher’s (20 points) overall evaluation of the project.

Jody’s problem with the *Active Physics* assessments started with the instating of the Ohio Graduation Test (OGT) and her belief that projects were not preparing her students to take the test because they did the projects and still failed to understand the concepts. This belief was based on her observation that students did not know what they were talking about when they presented their projects, and they failed all written tests she made them take even if they had answered relevant questions in the book:

The last questions after they are done with the activity go along with that and they are the “physics to go questions.” Those are kind of assessment too because you can’t answer those unless you’ve understood the activity somewhat. By the time you get there you pretty well have to know. They do fine on this. This is the stuff that gets me. If I give them an actual test and I’ve done that several times. If I give them a quiz or a test they do horrible. They get their answers to the [Physics to Go] questions right, you know. I’m trying to figure out where this gap is at that they can’t cross over into actually answering questions like that on the quiz. (SR)

[Traditional quizzes] was more to see if they knew stuff in the way that I’ve taught in the past. I’m just like, can they now, a couple of days later, use what they learned and show it on paper in a quiz? And they can’t. (SR)

To try and bridge the gap, Jody believed she could use more formative forms of assessment in her teaching, like questions at checkpoints. She stated, “[…] now that I’ve taken the class I’m more aware of little things to change and I’m trying to keep points and I’m trying to find out where they are as they go.” (P-PBI). This realization was a
result of her experiences in the Physics by Inquiry Course where she was impressed with how course instructors conducted checkpoints throughout the course and were successful at identifying errors in her groups’ thinking. Jody believed such practices would benefit her teaching and her students, especially as she realized that her students were not internalizing their learning. However, during group work, Jody sat at her desk and maintained a record of individual and group behavior. When students directed questions at her, she either asked them to refer to the text or repeated the statement, question, or explanation she had provided previously. She did not try to promote student understanding, rather expected them to “guess what was in her head,” and later expected them to do well on tests. For example, when she asked the students what type of waves went through strings and chimes, she waited for some time as students gave her different responses. She then answered her question by stating, “What I am trying to get you to see is that all those sound waves are traveling in longitudinal waves. The materials can be experiencing transversal waves but sound waves always travel in longitudinal waves” (3/13). This emphasis on passing on her ideas rather than finding out her students’ is consistent with her positivist view of science where knowledge is held by an expert. Finally, the expectation that students do well with that information on traditional tests is inconsistent with her expressed concern with understanding and application as dimensions of student learning to assess.

In short, even though Jody held constructivist views of learning reflected in her belief that learning represented the understanding and application of concepts, her assessment practices were inconsistent with that view. Rather than relying on authentic forms of assessment and questions to monitor students’ progress, Jody used traditional
assessments to measure her students’ ability to memorize and regurgitate information she knew and had previously shared with them. Jody attributes her use of traditional tests and her concern for accuracy to the need to prepare students well for the OGT.

**Knowledge of Science Curricula**

Jody’s knowledge and use of science curricula were shaped by her concerns for coverage of the State of Ohio’s requirements for the standardized tests. Her curriculum was mandated by the district and was based on State and district standards. This category of Jody’s PCK refers to her knowledge of national, state, and local goals and objectives for science teaching. It also includes knowledge of specific curricular programs, their general learning goals, and activities and materials used in each. The following sections describe Jody’s knowledge of science curricula.

**Knowledge of national, state, and local goals.**

In making instructional decisions, Jody relied on state and district goals and objectives, as well as statewide examinations. Even though she believed that national, state, and district standards guided her instruction, she was mostly concerned with her students’ ability to pass the Ohio Graduation Test (OGT). For that reason, Jody’s was mostly concerned with goals of coverage, making sure her students were properly equipped to pass the OGT:

> We follow standards here a lot and I see that as being a good method. There is certain things they have to know and I kind of like that. It’s just with the new state test coming up for tenth graders I know that the state has way too many standards to really truly do. All that material has to be covered because it’s going to be on the test. The test is going to have more short answer, fill in the blank
and extended response type questions. It’s not just multiple-choice so this all fits in with that I think. It’s trying to get them to think that way that really helps.

In her day-to-day teaching, Jody faithfully followed the Active Physics textbook guides and activities. However, when unforeseen obstacles, like lack of equipment, prevented her from adhering to the Active Physics text Jody selected concepts and activities based on students’ interest (what they would like) and the minimum understandings they would need to pass the OGT. Jody also identified time as a limiting factor in her curricular enactment:

Sometimes when there is just too much there you have to try and figure out what is the basics that they need to know and understand from that. I think you are also looking to see what they might be more interested in.

Knowledge of specific curricular programs.

Jody used Active Physics curriculum program mandated for ninth grade physical science in her school district. She believed the program’s main goal consisted of learning physics by inquiry, centered on a problem or question. Each chapter consisted of eight or nine activities based on a common format. The format consisted of three stages: elicitation of prior knowledge with no emphasis on concept accuracy (What do you think?), guided concept development using manipulation of relevant materials, and concept elaboration with the Physics-to-Go questions. Each chapter ends with a challenge, the summative authentic assessment were students develop a product based on their understanding of the chapter concepts and their ability to apply them.

In short, Jody’s conceptions of curriculum were guided by a concern for coverage of state standards to prepare students for the Ohio Graduation Test. To achieve that goal,
she used the inquiry-based *Active Physics* curricular program mandated by her school district.

*Knowledge of Instructional Strategies*

Jody’s choice of which subject specific a strategy to use in her instruction was driven by her mandated curriculum and her orientations to science teaching. She also based her decisions on contextual factors, concerns for control, and knowledge of students and their abilities. Jody used didactic and hands on types of instructional strategies in her classroom. The knowledge of instructional strategies aspect of Jody’s PCK concerns her knowledge of subject specific and topic specific strategies. This aspect of pedagogical content knowledge concerns a teacher’s knowledge of subject specific and topic specific strategies. Subject specific strategies are broadly applicable instructional strategies specific to science teaching as opposed to other subjects. Topic specific strategies have a narrower scope, apply to teaching particular topics, and can be representations or activities.

Prior to the study, Jody believed that teaching involved factual lecturing where the teacher tells students what they are expected to memorize and students take notes. For example, she declared, “You give them all these notes and they are supposed to remember it.” Her experience with teaching and her school’s adoption of the *Active Physics* series led her to a decision not to lecture. She reflected, “The more I tried it [lecturing], the more it didn’t work for me.”

At the time of the study, Jody believed she was using guided inquiry as an instructional strategy because she adhered to *Active Physics*. She defined inquiry as curiosity to learn ways of understanding phenomena on your own. She stated, “I think
inquiry is just being curious about things and learning to come up with ways of understanding it on your own. You are investigating different things and trying different things. You learn by doing that” (P-PBI). The noteworthy aspect of Jody’s definition is her emphasis on independent learning which, as will be seen in this section, was reflected in her practice.

Jody attributed her understanding and use of guided inquiry to her experiences as an educator in national parks and professional development activities like the *Physics by Inquiry* course (6/11) where she came to realize the importance of questioning and listening to students’ responses and asking them to support their responses with evidence:

> I think that is partially because I taught outdoor education and being outside everything was doing and perhaps that beginning helped me a lot. I wasn’t aware of a lot of it at the time. I know that more, that the students can do something and working together and asking each other questions and things. True science and learning is going on then. (CTS)

Even though Jody believed that she was using guided inquiry as an instructional strategy throughout her practice, observations of her classroom indicated otherwise. Jody’s instruction was consistent with her didactic and activity-driven orientations to science teaching. She mostly relied on instructional strategies such as lecturing and hands on activities as observed in the units on predictions, Newton’s Laws, and Communication (Waves). Typically, Jody started activities with vocabulary words followed by modeling of the day’s activity. She then allowed students to perform activities independently and answer questions in their groups. During that time, Jody invariably monitored behavior. At the end of the activity, Jody reviewed the questions making sure students had the
correct answers. In this model, Jody’s role consisted of providing students with vocabulary definitions, demonstrating the activity to be performed, lecturing about data gathering procedures, results, and answers to questions, and monitoring or controlling student behavior.

Jody identified several barriers that impeded her successful implementation of guided inquiry. These barriers included lack of resources and student resistance (discussed previously). For many of the activities, Jody did not have enough materials, like slinkys and tuning forks, for all her students for two reasons. The first reason consisted of students’ constant mishandling despite explicit instructions for proper handling. The second reason consisted of a failure on the part of the department to place orders she made.

In short, Jody used instructional strategies consistent with a didactic and activity-driven orientation to science teaching and was driven by issues of management and control. She relied on lectures and demonstrations to ensure the accurate transmission of scientific knowledge, while expecting her students to independently perform mandated activities.

**Summary**

Jody held positivist views of science and traditional and naively constructivist views of science teaching. While her views of science remained unchanged after her participation in PBI, Jody’s beliefs about science teaching underwent some change. More specifically her goals for teaching science and her views of her role as a teacher evolved to include teaching problem-solving and facilitation respectively. Jody’s PCK was consistent with traditional and process views, with evidence of beginning shifts to
constructivist views in certain areas. The changes in Jody’s PCK consist of an understanding of the nature of inquiry and the importance of prior knowledge and alternative conceptions in students learning. These changes are a result of her participation in PBI. Despite these changes in her views about the requirements for learning and areas of student difficulty, Jody’s PCK is characterized as traditional because she did not acquire knowledge of how to deal with these issues in a constructivist manner. Finally, Jody’s practice was consistent with her traditional and process views. The translation of her PCK into practice was mediated by her beliefs about science, beliefs about her students, concerns for coverage and control, and teaching context. This section summarizes Jody’s beliefs and PCK and discusses the influence PBI on these two constructs. It also draws connections between the different elements of Jody’s case, namely her background, context for teaching, beliefs, PCK, and practice.

Jody held positivist and process conceptions of scientific knowledge. She believed science consisted of a cumulative body of facts and a prescriptive scientific method used to discover it. Jody also believed that an expert in science was someone who had a firm and integrated grasp of the body of knowledge and scientific method. These views of science had origins in her earlier experiences with science and were reinforced by PBI. Her positivist conceptions of science had roots in her love of nature and the outdoors, which fueled her belief that scientific patterns exist in nature for scientists (and students) to discover by using the scientific method. These views went unchallenged in PBI, she still believed the instructors were the “holders” of knowledge and, irrespective of her understanding were going to drive the pace and discussion with the group.
Consistent with her positivist and process views of science, and driven by her purposes for teaching science, Jody’s goals for science teaching included the development of knowledge of scientific processes, scientific content, and a love and appreciation of science. These goals resulted in didactic and activity driven orientations to science teaching. Jody’s traditional didactic conceptions were apparent in her beliefs about teaching as the transmission of knowledge. Her activity driven orientations and naively constructivist views were apparent in her beliefs about the role of a teacher as someone who watches over the environment, ensuring that it affords enough opportunities for students to engage in the processes of science. These beliefs about science teaching seem to be a result of her learning experiences in science. She believed she learned by listening to and understanding information (like viewing a documentary), as well as following step-by-step instructions.

By contrast, Jody held partially constructivist views of learning reflected in her emphasis on the understanding and application of concepts, as well as student engagement in the learning process. Consistent with these views, Jody’s PCK exhibits her knowledge of several areas of difficulty for students in science. These consisted of alternative conceptions, language, and problem solving skills. However, Jody’s understanding of the role of prior knowledge and alternative conceptions were consistent with her positivist views of science and traditional views of science teaching. She believed in providing students with information to compensate for lack of prior knowledge, and dispelling alternative conceptions by allowing them additional time to manipulate materials. Finally, Jody believed that a necessary condition for student learning consisted of motivation or desire to learn and appropriate background
knowledge. Jody’s knowledge of and use of constructivist terms such as prior knowledge and alternative conceptions seems to be a result of her experiences in PBI were these constructs were addressed.

An examination of Jody’s practice reflected her traditional, process and naively constructivist PCK, and was mediated by her beliefs about science and science teaching, her beliefs about students, and her concerns for coverage and control. In her classroom, students conducted science by independently performing activities designed to help them discover scientific patterns. Jody’s didactic and activity-driven orientations to science teaching, which were in conflict with her mandated curriculum, guided her instructional practices. She relied on lectures and demonstrations to ensure the accurate transmission of scientific knowledge. Jody listed several barriers to her use of inquiry-oriented strategies including her beliefs about her students; ability and contextual factors such as lack of equipment and administrative support.

Even though Jody held constructivist views of learning reflected in her belief that learning represented the understanding and application of concepts, her assessment practices were inconsistent with that view. Instead of relying on authentic forms of assessment and questions to monitor students’ progress, Jody used traditional assessments to measure her students’ ability to memorize and regurgitate knowledge she held and had previously shared with them. This practice was consistent with her traditional positivist view of scientific knowledge where experts (like teachers) held all the knowledge. Furthermore, Jody did not attempt to facilitate students’ learning by helping students overcome areas of difficulty. She did not attempt to elicit students’
alternative conceptions and provided students with vocabulary definitions as a way to circumvent the requirement of prior knowledge.

Other elements of Jody’s case that influenced her practice consisted of her concerns for coverage, control, and previously held beliefs about students. Jody’s concern for coverage was a result of the district and state’s emphasis on standardized tests and the requirement that she prepare her students to pass the test. Her emphasis on the transmission of scientific knowledge was exacerbated by her concern for imparting knowledge necessary for passing the Ohio Graduation test. Furthermore, while her students engaged in hands-on activity, Jody performed duties of control, monitoring student and group behavior. Finally, Jody’s previously held views of her students’ motivation and ability to learn greatly influenced her adoption of guided inquiry and contributed to her traditional views of teaching and resulted from a contrast between her culture and the culture of her students. Jody believed her students lacked the ability to problem solve and were not motivated to learn because of competing priorities like parenting and playing around.

Findings

The purpose of this study was to investigate how a professional development effort, which immerses teachers in learning science content by inquiry and models sound pedagogical practices, promotes change in teachers’ inquiry thoughts and actions. More specifically, the study first aimed to describe middle school science teachers’ beliefs and PCK for teaching middle school physical science. Second it examined how PBI influenced their beliefs and PCK. And third, it investigated how the teachers’ beliefs and PCK influenced their practice. For all questions, teachers’ beliefs that were of interest
consisted of beliefs about science and science teaching. Teachers’ PCK was described as their knowledge of learners’ understandings in science, assessment, curriculum, and instructional strategies. It is noteworthy to point out that elements of teachers’ knowledge of learners’ understandings in science and assessment were used to infer their beliefs about science learning.

So far, two case studies have been presented that pay particular attention to the change in teachers’ beliefs, PCK, and practice. The case studies have allowed the investigation of interactions between the various aspects of the teachers’ thoughts and teaching related to their background, context, PBI, beliefs and knowledge. The following sections summarize and compare the change experienced by each teacher by focusing on the elements that mediated changes in their thinking and the elements that mediated change in practice.

Change in Teacher Thinking

PBI influenced the teachers’ beliefs and PCK similarly, but to different degrees. Both teachers exhibited changes in their knowledge of instructional strategies, learners’ understanding of science, assessment, and beliefs about science teaching. The following sections describe these changes and compare them with the teachers’ practice.

Beliefs

Both teachers’ beliefs about science teaching underwent some change as a result of their participation in PBI. They entered the course with traditional views, believing their role as a teacher consisted of sharing their knowledge with students, demonstrating and explaining the laboratory activity, and monitoring student behavior. During the year following PBI, the teachers expressed beliefs consistent with a more constructivist view.
They stated that their role as a teacher consisted of facilitating student learning, guiding students through questions, and arranging the environment for optimal learning. These beliefs are consistent with practices modeled in PBI. However, while Heather believed teaching implied allowing students to socially construct knowledge with her guidance, Jody did not relinquish her belief that teaching consisted of transmitting knowledge to students.

Just as their views of science teaching changed, the teachers’ orientations to teaching science changed as a result of their participation in PBI. To appreciate the change that occurred in teachers’ orientations, it is worthwhile to revisit their general purposes for teaching and their purposes for teaching science. Heather’s purpose for teaching in general and teaching science in particular centered on the development of responsible, functional citizens. Jody’s purposes were to develop an appreciation for science and an understanding that it is part of life in all students, not just the ones headed for science careers. Prior to PBI, Heather and Jody’s goals for science teaching included making science relevant. After the course, their goals were expanded. Heather realized the importance of evidence in science and hence her goals included the need for her students to rely on evidence as they make conclusions and decisions throughout her course. This new goal tied in with her purpose for teaching. She related that members of society make decisions based on evidence. In a similar fashion, Jody’s goals for science teaching expanded as she realized the importance of having her students go through the process of science as a mechanism for problem solving in all areas of life. Heather and Jody also believed in the importance of social collaboration for science learning as a result of their participation in PBI. For that reason, both teachers’ goals emphasized
group work. Based on these goals and her views of science teaching, Heather held guided-inquiry orientations to science teaching. By contrast, Jody held didactic and activity-driven orientations to science teaching.

Finally, the teachers’ beliefs about science were not modified as a result of their participation in PBI. Heather and Jody’s beliefs were very divergent, yet were reinforced during the program. Heather held beliefs consistent with constructivist views of science that emphasized the role of theories in the social construction of knowledge. On the other hand, Jody held beliefs consistent with positivist/traditional and process views of science. She believed science consisted of a body of knowledge and that the scientific method was the way to generate this knowledge. Heather’s constructivist views of science were a result of her participation in investigations in the form of science projects for science fairs. Her experience developing those projects contributed to her view of science as a socially constructed enterprise involving the generation of theories or models. Similarly, Jody’s positivist views of science were rooted in her love of nature and her experience as a naturalist. She believed science was a great way to understand the world and its beauty and aimed to develop an appreciation of science in her students. Interestingly, both teachers’ beliefs were reinforced as a result of their participation in PBI. Heather’s three-phase process view of science (generation, testing, and acceptance of theories) was reinforced because it was modeled in PBI as participants generated models, tested them, and based on empirical evidence accepted and shared them with instructors. Similarly, Jody’s positivist views of science were reinforced because she perceived the activities in the course to be verification activities; instructors had a plan of action, a way of solving problems, and her role was to figure out what the instructors’ expectations were.
Pedagogical Content Knowledge

The teachers differed markedly in terms of their PCK. Heather’s PCK was consistent with constructivist views of instructional strategies and learners’ understandings in science. Together with constructivist views, her knowledge of curriculum and assessment included traditional elements. By contrast, Jody’s PCK was a mix of traditional and constructivist views of assessment, instructional strategies, curriculum, and students’ understandings in science.

Prior to PBI, Jody and Heather’s PCKs were similar with respect to their knowledge of learners’ understanding in science, methods of assessment, curricula, and instructional strategies. They indicated that to facilitate student understanding, new learning needed to be situated in relevant contexts. The teachers also cited abstract concepts as an area of student difficulty.

Furthermore, Heather and Jody indicated conceptual understanding and concept application as the most important dimensions of student learning to assess. They were also knowledgeable about authentic methods of assessment such as student projects, research papers, and posters. Similarly, both Jody and Heather cited Active Physics as a physical science curriculum consistent with the use of inquiry, and relied on the State of Ohio’s Academic Content Standards and the Ohio Graduation Test to guide their instruction. They both believed that the science curriculum was a fixed body they needed to deliver. Finally both teachers defined inquiry as hands-on activities.

PBI influenced the teachers’ PCK. Both teachers’ knowledge of learners’ understanding in science, inquiry as an instructional strategy, and assessment underwent some change as a result of their participation in PBI, but to different degrees. For
example, the teachers’ knowledge of learners’ understanding of science was modified towards more constructivist views. Their knowledge included the role of prior knowledge and alternative conceptions in promoting or inhibiting student learning, topic-specific alternative conceptions, and group work as a method to promote learning. However, they differed in their knowledge of how to deal with these requirements for learning or areas of student difficulty. While Heather expressed knowledge consistent with constructivist views of student learning, Jody’s knowledge was more consistent with a positivist/traditional perspective. Heather referred to conceptual change strategies as means to address these difficulties in student learning. By contrast, even though Jody recognized the importance of prior knowledge and alternative conceptions, she believed that students overcame such difficulties when the teacher provided them with the necessary prior knowledge, or allowed them enough time to observe or interact with the phenomenon in question.

Heather and Jody also became knowledgeable about constructivist subject- and topic-specific instructional strategies. They cited inquiry and guided inquiry as instructional strategies specific to teaching science. Heather and Jody’s beliefs about the meaning and role of inquiry in science teaching changed. Inquiry was more than involving students in hands-on activities. It involved both hands-on and minds-on processes, actively engaging students’ minds through the use of questions. Hence, both teachers expressed views of inquiry consistent with views espoused in PBI. Furthermore, Heather and Jody added questions as a method of assessment to their repertoire of methods of assessment. They became aware of the importance and role of questions in monitoring student learning, a practice modeled in PBI.
Finally, both teachers were teaching outside their area of certification. They had minimal preparation in physics and physical sciences but were most comfortable teaching these subjects. The teachers attributed this sense of self-efficacy with teaching physical science to their experience teaching the subject which resulted in them learning by teaching it. After their participation in PBI, Heather and Jody reported an increase in depth of knowledge with respect to the topics they learned in the course. Their scores on the course posttests reflected this increase. It is noteworthy to point out that while Heather’s curriculum included units similar to the content focus in PBI, Jody’s curriculum was structured differently and I did not observe her teach any of the concepts emphasized in PBI.

**Coherence**

The teachers differed markedly in terms of their beliefs, PCK and coherence among these constructs. Heather’s beliefs and PCK were coherent as was determined by her constructivist views of science, science teaching, and science learning, as well as her knowledge of authentic, inquiry-based methods of assessment, instructional strategies, and specific physical science curricula such as *Active Physics*. The only exception to this trend consisted of Heather’s beliefs about a fixed curriculum.

By contrast, Jody’s beliefs and PCK lacked coherence as was determined by her positivist views of science and traditional/constructivist views of science teaching and student learning. Furthermore, Jody’s knowledge of instructional strategies, science assessments, and specific curricula were consistent with constructivist perspectives. However, similar to Heather, her views of the curriculum were more traditional, viewing it as a fixed entity.
Changes in Teacher Action

Prior to PBI, Heather and Jody described their teaching practice as explaining new material, giving directions for activities, managing behavior, and collecting class work and homework. The nature of their instruction was consistent with didactic and activity driven orientations to science teaching. After participating in PBI, the teachers’ practice changed, to different degrees. The nature of Heather’s instruction became more consistent with guided inquiry orientations to science teaching, while Jody’s remained didactic and activity driven. The only aspect of Jody’s instruction that was different from previous years consisted of her adoption of group work, which she attributed to her experience in PBI.

The changes observed in the teachers’ beliefs and PCK were not always accompanied by concomitant changes in practice. Heather’s beliefs and PCK guided and translated into her practice in most cases. By contrast, the changes in Jody’s beliefs and PCK were not reflected in her practice. In Heather’s case, beliefs and PCK were coherent and reflected constructivist views that translated into practice. For example, she relied on guided inquiry instructional strategies where students collaboratively engaged in the construction of models. Heather also actively engaged her students’ prior knowledge and attempted to address their alternative conceptions through the use of conceptual change pedagogies. Finally, Heather consistently used questioning to facilitate students’ learning and emphasized their reliance on evidence to support conclusions.

Conversely, Jody’s beliefs and PCK lacked coherence exhibiting a combination of traditional and constructivist views. Only Jody’s traditional PCK translated into her practice. For example, despite her knowledge of inquiry strategies, Jody’s practice was
characterized by the use of hands-on activities where students discovered knowledge in groups independent of the teacher. Furthermore, even though she believed her role as a teacher consisted of facilitating student learning, Jody consistently transmitted knowledge she held to students by emphasizing definitions, real-life examples that were not familiar to students, and dictations of correct answers to textbook questions. The only aspect of Jody’s constructivist view of science teaching that translated into her practice was her emphasis on being a resource person and re-arranging the environment to facilitate learning and remove obstacles to learning. Jody made sure that the environment, in terms of materials and knowledge needed, was arranged to ensure student engagement in the activities. These practices reflected a naively constructivist view of science teaching rather than her expressed constructivist beliefs. Finally, Jody’s goals and purposes for teaching science did not guide or translate into her practice; rather, her practice reflected a constant concern for maintaining control of the students and covering the material in *Active Physics*. On a regular basis, Jody spent class time monitoring students’ behavior whenever they were working in groups. Her concern for covering *Active Physics* stemmed from the district stipulation that all ninth grade teachers follow the same pace and complete the text.

Interestingly, both teachers expressed constructivist views of student learning that did not match their use of assessment. Jody and Heather emphasized the central role of prior knowledge and alternative conceptions in students’ learning, and they believed in assessing the conceptual understanding and application dimensions of scientific literacy. However, both teachers used more traditional forms of assessment to assess students’ learning, a practice they attributed to an insufficient emphasis on inquiry assessment in
PBI. Finally, even though Heather and Jody believed that the science curriculum was a fixed body they needed to deliver, Heather’s views were undergoing some change as evident in her decision not to adopt the school science book and develop her own curricular materials. She developed and used the *Blue Book*, an inquiry based textbook, and relied on her experiences in PBI to do so. By contrast, Jody’s view of a fixed curriculum translated into her practice. She solely relied on *Active Physics* in her day-to-day teaching, adhering faithfully to its text.

*Coherence*

Heather’s practice was mostly coherent, exhibiting constructivist views consistent with her stated purposes for teaching. The only exception to this statement consisted of her assessment practices. Heather’s assessment was consistent with traditional views except in the case of formative assessment, exemplified by her reliance on questions at checkpoints.

Similarly, Jody’s practice was mostly coherent. She consistently relied on traditional and activity-driven practices in her daily instruction. The only exception to this statement consisted of her intermittent use of alternative assessment practices. Jody relied on authentic assessments at the end of each chapter in her textbook because that was the district expectation.

*Interaction between Beliefs, PCK, and Practice*

The teachers’ beliefs and PCK were not the only factors that influenced their practice. They did not solely rely on their beliefs and PCK as they made instructional decisions. Additional factors that influenced their practice consisted of purposes for
teaching, concerns for coverage, concerns for control, previously held beliefs about students’ abilities, and contextual issues.

Both teachers were influenced by concerns for covering the required curriculum. They cited the state and district standards as the reference that dictated their choice of topics to cover in class. This concern was driven by the district expectation that students pass the state standardized test. For example, Heather made instructional decisions based on her personal goal for teaching, namely preparing successful citizens who are able to make decisions based on evidence, as well as her concerns for covering content required for the Ohio Graduation Test (OGT). Similarly, the need to cover Active Physics content as well as content required for the OGT guided Jody’s instructional decision-making. However, Jody was also concerned about maintaining control of her classroom and her didactic practice reflected that concern.

Furthermore, translation of the teachers’ beliefs and PCK was mediated by their previously held beliefs about their students. Heather believed her students were capable of learning and problem solving, were headed for higher education, and would exert the effort needed to learn in a different way, namely through inquiry. This belief helped her persevere in her choice of instructional strategy whenever she faced difficulties. By contrast, Jody believed her students were incapable of problem solving and refused to think because of the existence of competing priorities. She believed her students lacked the necessary background to engage in this new way of thinking and were incapable of such forms of independent learning. For that reason, Jody believed she had to completely structure the learning environment and transmit discrete facts of knowledge to students who were not able to construct knowledge on their own.
The teachers’ practice was also mediated by contextual factors that inhibited or promoted the translation of their beliefs and PCK into practice and their use of guided inquiry as an instructional strategy. These contextual factors included administrative support, availability of resources, and teacher autonomy. Heather enjoyed the support of her administration as she infused her practice with inquiry. The curriculum leader at her school was none other than Dean, one of the instructors in PBI. Heather related that Dean regularly visited her classroom, videotaped her teaching, and provided her with needed support in the form of guidance, resources, and cheerleading. Dean further supported Heather’s decision to develop new curricular materials for eighth grade and he served as a sounding board as Heather developed the Blue Book. By contrast, Jody related that she lacked administrative support as she implemented inquiry practices. She stated that administrators mandated the use of Active Physics and attendance of regular meetings intended as support for its adoption. However, Jody claimed that no one in her school was concerned with what went on in her classroom, as long as she adhered to Active Physics. She further stated, and I observed, that she constantly lacked materials needed for activities in Active Physics.

Conclusion

The beliefs, PCK, and practices of the teachers in this study underwent some change as a result of their participation in PBI. Prior to the course, their beliefs, PCK, and practices were consistent with more traditional approaches to science teaching and learning. After PBI, the teachers’ beliefs about science teaching evolved from traditional to constructivist views, namely believing that their role as a science teacher consisted of
facilitating students’ learning. Similarly, the teachers’ orientations to science teachers expanded to include an emphasis on evidence, the scientific method, and group work.

The teachers’ PCK changed as well as a result of their participation in PBI. Their knowledge of inquiry as an instructional strategy increased and was more consistent with reform documents. Furthermore, their knowledge of assessment expanded to include questions as a means to monitor students learning. Finally, the teachers’ knowledge of learners’ understandings in science were also enhanced. They referred to prior knowledge and alternative conceptions as requirements for learning and areas of student difficulty.

Finally, the change in teachers’ beliefs and PCK was accompanied with some changes in practice. The teachers’ purposes for teaching, concerns for coverage, concerns for control, previously held beliefs about students’ abilities, and contextual issues mediated this translation. As a result, Heather’s constructivist beliefs and PCK were consistent with her practice whereas Jody’s practice only reflected her traditional beliefs and PCK.
CHAPTER 5: DISCUSSION

The purpose of this study was to investigate how a professional development effort, which immerses teachers in learning science content by inquiry and models sound pedagogical practices, promotes change in teachers’ thoughts and actions about inquiry science teaching. More specifically, the study examined how Physics by Inquiry (PBI) influenced teachers’ beliefs and PCK, and how the teachers’ beliefs and PCK influenced their practice.

Findings from this study indicate that participation in PBI resulted in changes in teachers’ beliefs, PCK, and practice to different degrees. Furthermore this change was mediated by a number of individual and contextual factors. This chapter reviews the findings of this study, relating them to relevant theoretical frameworks and comparing them with conclusions in the literature. The chapter concludes with a return to the model of change proposed in Chapter 1, potential implications of the findings, and suggestions for additional research.

Beliefs and their Relationship to Practice

Teachers’ beliefs about science teaching were impacted by PBI. The teachers changed their perceptions of their role as a teacher from a traditional perspective to a constructivist perspective that emphasizes facilitation. While Heather’s practice reflected this shift, Jody’s practice did not reflect this new role. Rather, her practice reflected a naively constructivist view of her role as a teacher where she arranged the environment to allow students to engage in activities. Furthermore, while Heather believed teaching implied allowing students to socially construct knowledge with her guidance, Jody did not relinquish her belief that teaching consisted of transmitting knowledge to students.
Combined with the teachers’ goals for teaching science, these views about science teaching resulted in guided inquiry orientation to science teaching in Heather’s case, and a combination of didactic and activity-driven orientation in Jody’s case.

Even though the teachers’ beliefs about science teaching changed as a result of their participation in PBI, their beliefs about science were not modified. Heather held beliefs consistent with constructivist views of science that emphasized the role of theories in the social construction of knowledge, and her practice reflected this view. On the other hand, Jody held beliefs and practice were consistent with positivist/traditional and process views of science. She believed science consisted of a body of knowledge and that the scientific method was the way to generate this knowledge. Heather’s constructivist views of science were a result of her participation in investigations in the form of science projects for science fairs. Her experience developing those projects contributed to her view of science as a socially constructed enterprise involving the generation of theories or models. Similarly, Jody’s positivist views of science were rooted in her love of nature and her experience as a naturalist. She believed science was a great way to understand the world and its beauty and aimed to develop an appreciation of science in her students.

As mentioned in the theoretical framework, beliefs are precursors to change and might be held in clusters within a central-peripheral system (Rokeach, 1968). An individual may possess beliefs that are incompatible or inconsistent. The incompatible beliefs would need to be held side by side and examined for the incompatibility to be resolved (Green, 1971). Finally beliefs are rooted in vivid memories of past experiences (Richardson, 1996). The findings of this study indicate that teachers’ beliefs about science and science teaching were not always compatible, but that they were rooted in
early experiences with science as well as PBI. For example, Heather’s beliefs about science and science teaching were compatible. On the other hand, Jody’s beliefs about science and science teaching were incompatible; they were consistent with positivist/traditional and constructivist respectively.

A useful framework by which to interpret these findings consists of Haney and McArthur’s (2002) conceptualization of a hierarchy of beliefs. These researchers postulate that at least two kinds of beliefs are in operation when preservice teachers are learning social constructivist strategies: core and peripheral. Haney and McArthur defined core beliefs as those beliefs that were both stated and enacted. Peripheral beliefs were defined as the constructivist beliefs that were stated, but were not enacted due to external factors. Haney and McArthur (2002) further classified core beliefs into three categories: constructivist beliefs, conflict beliefs, and emerging beliefs. Two of these categories are relevant to this study. Constructivist core beliefs are aligned with constructivist theory and are put to practice. Conflict core beliefs are those beliefs that are enacted but are in opposition to constructivist theory. The conflict core beliefs are those that make it difficult for teachers to operationalize their constructivist beliefs (Haney & McArthur, 2002).

As a result of their participation in PBI, it seems that Heather and Jody developed different types of beliefs according to Haney and McArthur’s framework. Heather developed core beliefs about science teaching while Jody developed peripheral beliefs. Heather’s core beliefs consisted of constructivist views about facilitation and were observed in her classroom where she allowed students to socially construct knowledge with her guidance. Her beliefs about science represented a second set of constructivist
core beliefs that mediated the translation of her beliefs about science teaching into her practice.

Jody’s beliefs about science teaching were peripheral. Even though she developed constructivist views about science teaching as facilitation, her practice did not reflect this view. Rather, her practice reflected her more didactic notions of teaching as the transmission of knowledge, with the naively constructivist element of arranging the environment to allow students to practice the process of science. In Jody’s case, her positivist/traditional beliefs about science and her didactic beliefs about teaching acted as conflict core beliefs. They hindered her expressed constructivist beliefs from translating into her practice.

The positive change identified in teachers’ beliefs about teaching is consistent with findings from other studies that investigate the influence of constructivist/conceptual change professional development efforts on preservice and inservice teachers’ beliefs about science teaching (Luft, 2001; Stofflet, 1994; Glasson & Lalik, 1993; Cronin-Jones, 1991). Luft’s (2001) finding concerning teachers’ development of an enhanced view of their interaction with their students that allowed them to guide students towards accepted scientific ideas is a case in point.

Finally, the coherence between Heather’s beliefs and practice and the inconsistency between Jody’s can also be explained in light of past literature. Considering Jody’s case, most studies that investigated the relationship between teachers’ beliefs about science teaching and learning and their practice found no general correspondence between these beliefs and classroom behavior. Similar to Jody’s case, reasons for this inconsistency consisted of teachers’ existing belief structures (Cronin-
Jones, 1991) and their commitment to existing curricula (Johnston, 1991). These and other factors, such as concerns for control, will be discussed in a later section. By contrast, the only studies that reported a correspondence between teachers’ beliefs and practices stated that the change took place when sufficient time and professional support were available (Glasson & Lalik, 1993; Tobin, 1993; Appleton & Asoki, 1996). These findings are consistent with the findings from Heather’s case. The factors of time and professional support will be explored in a later section.

Pedagogical Content Knowledge and its Relationship to Practice

As mentioned previously, the study participants’ PCK changed as a result of their participation in PBI. The teachers exhibited changes in their knowledge of instructional strategies, learners’ understanding of science, and assessment. However, this change was not uniform across the two teachers. Furthermore, not all the changes in the teachers’ PCK were accompanied with changes in practice. The following sections discuss findings for each of the components of PCK, their relationship to practice, and compare these findings to conclusions in the literature.

Knowledge of Curriculum

Heather and Jody’s knowledge of physical science curricula and their beliefs about the science curriculum as a fixed body to deliver did not change and translated into their practice. Even though Heather decided against adopting the school science book and developed new inquiry-based curricular materials based on her experiences in PBI, her beliefs about the curriculum can be considered fixed because she still relied on a fixed matrix of content, dictated by the state and district curricula, and designed to ensure coverage of topics needed for the Ohio Graduation Test. Similarly, Jody adhered
faithfully to the *Active Physics* text in her day-to-day teaching. She also believed that she had to keep pace with other teachers in her district using the text. This implied a concern for coverage of content in both teachers. This finding is consistent with Prawat’s (1992) notion of fixed content, which is dominated by a concern for delivery of content instead of more substantive issues relating to content selection and meaning making on the part of the students. Prawat argues that this view of content and curriculum runs counter to constructivist views of teaching and learning.

**Knowledge of Instructional Strategies**

Heather and Jody became knowledgeable about constructivist subject- and topic-specific instructional strategies. They cited inquiry and guided inquiry as instructional strategies specific to teaching science. Heather’s and Jody’s knowledge of the meaning and role of inquiry in science teaching changed. Inquiry became more than involving students in hands-on activities. It involved both hands-on and minds-on processes, thus actively engaging students’ minds through the use of questions, reliance on evidence, and group work. Interestingly, Heather’s new understanding of inquiry translated into her practice, whereas Jody’s did not. In her classroom, Heather relied on guided inquiry instructional strategies where students collaboratively engaged in the construction of models. By contrast, despite her knowledge of inquiry strategies, Jody’s practice was characterized by the use of hands-on activities where students engaged in activities designed to help them discover knowledge in groups, independent of the teacher. Furthermore, Jody consistently transmitted knowledge she held to students by emphasizing definitions, real-life examples that were not familiar to students, and dictations of correct answers to textbook questions.
This finding is consistent with those from other studies that investigated the influence of professional development efforts on teachers’ knowledge of subject-specific instructional strategies. Several studies reported increases in teachers’ knowledge and understanding of inquiry as a result of their participation in inservice professional development (Bell et al., 2003; Posnanski, 2002; Radford & Ramsey, 1996). Similar to this study, Bell (2003) reported that teachers’ knowledge of the use of evidence and explanations increased. The only aspect of the change in teachers’ knowledge of inquiry as an instructional strategy that was not reported in the literature is the emphasis on group work. This aspect might not have been highlighted in the other studies because it can be taken for granted that inquiry entails group work. However, this aspect is important to emphasize because the teachers’ participation in cooperative groups during PBI and their first-hand experience with the challenges and rewards of this strategy played an important role in the teachers’ adoption of this strategy in their practice.

This study did not particularly investigate teachers’ knowledge and use of topic specific strategies. However, what was apparent was that Heather, whose curriculum contained several units that paralleled units taught in PBI, relied on guided inquiry as an instructional strategy and incorporated topic-specific strategies and representations she encountered in PBI. By contrast, Jody’s school curriculum was structured in a different way than the PBI curriculum. She did not teach any units that directly paralleled content covered in PBI. Rather, her units were structured around themes like communication. In all units, Jody used didactic and activity-driven instructional strategies. Topic specific strategies and representations she used were derived from the *Active Physics* text.
Finally, while studies that rely on self-report of teachers’ practices indicate that increases in teachers’ knowledge of inquiry lead to increases in teachers’ use of inquiry in most cases (Bell et al., 2003; Westerlund et al., 2002; Luft, 2001; Hogan & Berkowitz, 2000, Supovitz et al., 2000), findings from this study indicate that it is not always the case. Heather’s knowledge of inquiry translated into practice and most of her instruction was conducted through guided inquiry. Heathers’ adoption of guided inquiry might be a result of a conceptual change process that she went through. Prior to PBI, Heather was dissatisfied with her traditional mode of teaching. PBI provided her with an alternative (guided inquiry) that she experienced, understood, and found useful based on her learning within the course. As a result, guided inquiry was intelligible, more fruitful (Posner, Strike, Hewson, & Gertzog, 1982), and hence more desirable than her prior didactic strategies. For that reason, heather adopted the new strategy.

On the other hand, Jody’s knowledge of inquiry did not translate into practice. Her practice was didactic and relied on hands-on activities. A possible reason for this inconsistency might be the conflict between the tenets of inquiry and Jody’s conflict core belief of naïve constructivist, in which she equated activity with learning. In addition, several individual and contextual factors may have inhibited the implementation of the new knowledge. These factors will be discussed in a later section.

Knowledge of Learners’ Understanding of Science

The teachers’ knowledge of learners’ understanding of science was also modified towards more constructivist views. Their knowledge included the role of prior knowledge and alternative conceptions in promoting or inhibiting student learning, topic-specific alternative conceptions, and group work as a method to promote learning. However, the
teachers differed in their knowledge of how to deal with these requirements for learning or areas of student difficulty. While Heather expressed knowledge consistent with constructivist views of student learning, Jody’s knowledge was more consistent with a positivist/traditional perspective. Heather referred to conceptual change strategies as means to address these difficulties in student learning. By contrast, even though Jody recognized the importance of prior knowledge and alternative conceptions, she believed that students overcame such difficulties when the teacher provided them with the necessary prior knowledge, or allowed them enough time to observe or interact with the phenomenon in question.

These findings are consistent with the conclusions present in the literature with respect to the positive influence of enhancement programs or professional development programs on teachers’ knowledge of students’ alternative conceptions (Berg & Brouwer, 1991, Smith & Neale, 1989, 1991). Berg and Brouwer (1991) found that the teachers in their study could list student misconceptions in the topics of force and gravity. Similarly, Smith and Neale (1989) reported that the teachers in their study could list misconceptions in the topic of light. Furthermore, consistent with Jody’s case, these researchers state that the increases in teachers’ knowledge of students’ misconceptions do not necessarily go hand in hand with their knowledge of ways to address these conceptions (Smith & Neale, 1989). In that study, instead of probing students’ reasoning, many teachers addressed alternative conceptions by providing students with more detailed explanation of the concepts at hand. In addition to addressing her students’ alternative conceptions by providing them with the necessary “correct” information, Jody allowed students more time to investigate the phenomenon, believing that the additional time will lead to
students’ enlightenment and the realization that their thinking or conclusions were faulty. Jody’s second approach to dealing with students’ alternative conceptions is consistent with her positivist/traditional core beliefs about science and may be due to her view that science consists of a preset method that is used to discover patterns that lie in nature. In that respect, Jody’s conflict core beliefs about science and teaching may have played a role in inhibiting her learning of constructivist ways to address students’ alternative conceptions, ways that might be consistent with her peripheral belief of science teaching as facilitation.

By contrast, in addition to being able to list students’ alternative conceptions in the topic of electricity for example, Heather listed conceptual change as a strategy to address these conceptions. Therefore, in her case, PBI was successful in aiding her development of knowledge of students’ difficulties in science and of ways to address these difficulties. This finding is also consistent with results from previous research (Appleton & Asoko, 1996; Hand & Treagust, 1994; Cronin-Jones, 1991). For example, Appleton and Asoko’s (1996) reported that the teacher in their study exhibited an increased awareness of students’ ideas and sometimes used challenging strategies to address them in classroom discussions. Heather’s adoption of conceptual change strategies as a method to address student difficulties might be a result of the coherence between this new knowledge and her constructivist core beliefs about science and science teaching (discussed earlier) and a possible internal process of conceptual change. In PBI, Heather expressed some misconceptions and was in a group with a member who expressed several misconceptions. In that setting, she experienced and observed conceptual change as the instructors probed the students’ reasoning and guided them
through questions and model constructions. This process might have proven intelligible and fruitful (Posner et al., 1982) to Heather because she was cognizant of her (and her group member’s) initial and final conceptions.

As mentioned before, the teachers in this study identified prior knowledge as a requirement for learning after participating in PBI. Again, this finding is consistent with the conclusions in the literature, which state that preservice and inservice programs result in change in the participants’ conceptions of learning science (van Driel et al., 1998; Meyer et al, 1999; Appleton & Asoko, 1996). For example, the preservice teachers in Meyer et al.’s (1999) study accepted that their students held a range of important ideas on topics they were being taught and realized that it was important and necessary to elicit these ideas when teaching.

The findings in this study also indicate that these changes in the teachers’ PCK of learners’ understandings in science only appeared in Heather’s practice. Consistently, Heather actively engaged her students’ prior knowledge and attempted to address their alternative conceptions through the use of conceptual change pedagogies. She relied on questioning to facilitate students’ learning and emphasized their reliance on evidence to support conclusions. This change in her practice may be part of the internal process of conceptual change described previously, compounded with the coherence of her core beliefs about science and science teaching. This translation of Heather’s PCK to practice was further mediated by several additional internal and contextual factors that will be discussed in a later section.

The discrepancy in the relationship between this component of Jody’ knowledge and her practice is consistent with findings in the literature. Even though teachers express
views of student learning consistent with a constructivist perspective as a result of participation in enhancement programs, these views do not necessarily correspond with their practice (Meyer et al., 1999; Mellado, 1998; Cronin-Jones, 1991; Johnston, 1991). In Jody’s case, these findings are reinforced by the knowledge that her core belief about science ran counter to the view of student learning espoused by PBI. In that sense, this finding is similar to the one reported by Smith and Neale (1989). These researchers identified a negative relationship between teachers’ views of science (the extent they viewed content as lying outside the child) and their attentiveness to children’s ideas and explanations during instruction. Finally, similar to this study, the above studies cite existing belief structures and commitment to existing curriculum as factors that hinder the implementation of this aspect of teachers’ PCK. As discussed earlier, Jody’s knowledge and views of the curriculum consist of a static, fixed notion of content that needs to be delivered at a specific pace, irrespective of student ideas and learning. Other factors that mediated or inhibited the translation of the teachers’ PCK into practice will be discussed in a later section.

Knowledge of Assessment

Heather and Jody also added questioning to their repertoire of methods of assessment. They became aware of the importance and role of questions in monitoring student learning. However, this component of the teachers’ PCK only translated into Heather’s practice. She consistently used questioning to facilitate and monitor students’ learning and emphasized their reliance on evidence to support conclusions. Not surprisingly, this form of assessment is consistent with Heather’s constructivist core beliefs about science and science teaching, and it clashes with Jody’s conflict core
beliefs. It is noteworthy to point out that both teachers used more traditional forms of assessment to assess students’ learning, a practice they attributed to an insufficient emphasis on inquiry assessment in PBI.

The teachers added this form of assessment to a repertoire that included alternative methods such as projects, research papers, and investigations. However, as mentioned above, the teachers continued to use teacher-constructed tests to measure the conceptual understanding and application dimensions of scientific literacy. This finding addresses the question posed in the literature as to whether teachers who use teacher-constructed or curriculum-embedded “objective” tests to assess the conceptual understanding of scientific literacy are knowledgeable about others methods and dimensions (Doran et al., 1994). The teachers in this study were knowledgeable about these alternative methods of assessment; however, they chose to use the traditional forms for two different reasons. Heather reported a lack of knowledge of how to translate the results of the alternative assessments into enough grades for the report card or for sharing with parents. Jody related a lack of confidence in the alternative methods of assessment’s ability to measure student learning, especially when the students did not take these methods seriously.

Factors or Dilemmas Mediating Change

Several barriers to teachers’ implementation of inquiry-practices are discussed in the literature. Anderson (2002) proposes the use of dilemmas to denote these factors, because the term barrier implies factors external to teachers, whereas dilemmas also include internal difficulties such as beliefs, values, teaching, and the purposes of
education. Anderson states that teachers considering new approaches to education may face multiple dilemmas, many of which have their origins in their beliefs and values.

Anderson (1996) clusters these barriers and dilemmas into three dimensions, the technical dimension, the political dimension, and the cultural dimension. The technical dimension includes limited ability to teach constructively, prior commitments (e.g. to a textbook), the challenges of assessment, the challenges of new student roles, and an inadequate inservice education. The political dimension includes limited inservice education, parental resistance, unresolved conflicts among teachers, lack of resources, and differing judgments about justice and fairness. The cultural dimension includes the textbook issues again, views of assessment and the “preparation ethic,” that is overriding commitment to “coverage” because of a perceived need to prepare students for the next level of schooling (Anderson, 2002). This author states that the cultural dimension might be the most important of the three because of the centrality of beliefs and values within it.

Several factors, or dilemmas, that influence change are postulated in the literature. These factors consist of individual and/or contextual factors (Hogan & Berkowitz, 2000; Cronin-Jones, 1991; Smith & Neale, 1989; Gess-Newsome & Lederman, 1993). Individual factors such as beliefs, concerns for coverage, views of assessment etc. lie within Anderson’s (1996) cultural dimension of dilemmas. Contextual factors such as lack of resources, resistance, lack of support, and lack of sustained professional development lie within the political dimension of Anderson’s framework. Several individual and contextual factors that inhibited the development of PCK and its adoption in practice have been identified in the literature (Smith, 2000; van Driel, 1998; Adams & Krockover, 1997; Clermont et al., 1993, 1994; Geddis, 1993). These researchers conclude
that, as a result of these factors, teachers adopted conventional instructional strategies, stressing procedures rather than student understanding. As mentioned previously and foreshadowed in previous sections in this discussion, several individual and contextual factors mediated change in the teachers’ PCK and practice. The following sections discuss these individual and contextual factors within Anderson’s (1996) framework, comparing them to existing literature.

*Cultural Dilemmas: Individual Factors*

The most salient aspects of the teachers as individuals, those that played a role in their acquisition of PCK and their implementation of inquiry practice, consisted of their views about science, perceptions of their role as a teacher, beliefs about students’ abilities, concerns for coverage and control, and depth of content knowledge. Some of these factors were impacted by PBI. For example, both teachers changed their perceptions of their role as a teacher from a traditional perspective to a constructivist perspective that emphasizes facilitation. However, while Heather’s practice reflected this shift, Jody’s practice did not reflect this new role. Rather, her practice reflected a naively constructivist view of her role as a teacher where she arranged the environment to allow students to engage in activities. Similarly, both teachers’ content knowledge of the physical science topics (properties of matter, electrical circuits, kinematics) discussed in PBI increased as reflected by their scores on the conceptual posttests.

The first two individual factors, beliefs about science and beliefs about their role as a teacher, were discussed earlier in the section on beliefs. These beliefs represented constructivist core, conflict core, and peripheral belief systems according to Haney and McArthur’s (2002) hierarchy of beliefs. In that respect Heather’s constructivist core
beliefs facilitated the change process whereas Jody’s conflict core beliefs inhibited the change process and the implementation of peripheral beliefs. While other researchers do not use the constructivist/conflict core belief language, the finding that teachers’ beliefs about science influence and predict their practice is consistent with conclusions in the literature (Prawat, 1992; Brickhouse, 1990; Duschl & Wright, 1989). Finally, it is important to point out that Jody’s conflict core beliefs were incompatible with the assumptions behind the *Active Physics* curriculum. She held positivist views of science and naively constructivist views of science teaching, while the curriculum was based on a constructivist view of science and science teaching. The importance of this point is magnified when we consider findings from past research that investigated science teachers’ adoption of specific curricular programs as a result of their participation in workshops (Cronin-Jones, 1991; Mitchener & Anderson, 1989). These researchers concluded that, in many cases, teachers modified or refused to implement the programs they were knowledgeable about because they were not in agreement with their goals. Similarly, while Jody was knowledgeable about the goals and underlying assumptions of *Active Physics*, and while she professed beliefs that were in agreement with these goals, her conflict core beliefs about science and teaching ran counter to these goals and thus prevented her successful implementation of the curricular program.

Haney and McArthur’s framework can also be applied to the third individual factor that mediated change, namely teachers’ previously held beliefs about their students and their abilities. This belief mediated the translation of PCK into practice. It represented a constructivist core belief in Heather’s case and a conflict core belief in Jody’s case. Heather believed her students were capable of learning and would exert the
effort needed to learn in a different way, namely through inquiry, whereas Jody believed that her students lacked the necessary background to engage in this new way of thinking and learning and were incapable of such forms of independent learning. Combined with her constructivist core beliefs about science and science teaching, Heather’s belief about her students’ ability facilitated her construction and adoption of constructivist, inquiry knowledge and practices. By contrast, combined with her conflict core beliefs about science and teaching, Jody’s conflict beliefs about students and their abilities inhibited her construction and implementation of constructivist/inquiry knowledge and practice, as well as her peripheral beliefs about science teaching. Other researchers have also concluded that teacher beliefs about students as fixed entities (Prawat, 1992) or as lacking the necessary skills for autonomous learning (Cronin-Jones, 1991) impeded their implementation of constructivist practices.

A fourth dilemma mediated the change in teachers’ practice. This factor consisted of the teachers’ concern for control and coverage. Prior to PBI, Heather and Jody were concerned with maintaining control of their classrooms. After PBI, Heather’s concern shifted and was more focused on student learning and the reliance on evidence. This shift was consistent with her constructivist core beliefs. However, Jody remained focused on monitoring student behavior in an effort to maintain classroom control. For that reason, most of her time in class was spent asking students to take their seats, gather their materials, stay on task, and stop talking. This concern and these practices are not conducive to inquiry practices. This finding is consistent with Prawat’s (1992) assertion that a fixed view of content, one dominated by a concern for delivery of content instead of more substantive issues relating to content selection and meaning making on the part
of the students, is not conducive to constructivist teaching practices. Similarly, the teachers faced dilemmas of coverage. As mentioned previously, both teachers viewed the curriculum and its content as a fixed entity, dictated by the State and district curricula, designed to ensure coverage of topics needed for the Ohio Graduation Test. This concern is consistent with Prawat’s (1992) notion of fixed content, which is dominated by a concern for delivery of content instead of more substantive issues relating to content selection and meaning making on the part of the students. Prawat purports that this view of content and curriculum runs counter to constructivist views of teaching and learning.

A final factor that influenced the construction of PCK consisted of the depth of content knowledge that the teachers held with respect to the content they were teaching. As mentioned previously, Heather taught several topics that were consistent with topics from PBI. In that respect, she was teaching content she knew extremely well. She could list students’ alternative conceptions in these topics and she could rely on a repertoire of topic-specific strategies and representations used in PBI to aid in student learning. By contrast, the parts of Jody’s curriculum that were observed did not include topics discussed in PBI. Together with the fact that Jody was teaching outside her area of certification and had taken only two physics courses prior to PBI, this implied that she did not have as deep of content knowledge of these topics as she did of topics discussed in PBI. This point becomes even more important in light of Jody’s discussion about how PBI increased her sense of self-efficacy for teaching physics. Interestingly, similar findings about the role and depth of content knowledge in the construction of teachers’ knowledge are reported in the literature (Lederman, Gess-Newsome, & Latz, 1994; Sanders, Borko, & Lockard, 1993; Smith & Neale, 1989). For example, Smith & Neale
(1989) found an inservice workshop focusing on conceptual change to be unsuccessful in developing PCK because participants were still constructing a “deeply principled conceptual knowledge of the content” (p. 17). Hence, this and other studies indicate the importance of depth of content knowledge as a precursor to the development of PCK.

Political Dilemmas: Contextual Factors

Findings in this study indicated that several political dilemmas or contextual factors mediated the change in teachers’ practice and their implementation of approaches consistent with constructivist/inquiry perspectives. In addition to the political dilemmas described by Anderson (1996) and the contextual factors identified in the literature, Hatch (1999) identified structural influences that impinge on all teachers’ decision and actions. In Hatch’s study, the structural influences consisted of curriculum, resources, number of students, textbook, testing procedures, rules, and time constraints. The contextual factors identified in this study as mediators of change are consistent with several of Hatch’s structural factors and Anderson’s (1996) political dilemmas. They included administrative support, availability of resources, and teacher autonomy.

Heather and Jody enjoyed different levels of administrative support, which might have contributed to their differential adoption of inquiry. Heather enjoyed the support of her administration as she infused her practice with inquiry. The curriculum leader at her school was none other than Dean, one of the instructors in PBI. As mentioned previously, Heather related that Dean regularly visited her classroom, videotaped her teaching, and provided her with needed support in the form of guidance, resources, and cheerleading. Dean further supported Heather’s decision to develop new curricular materials for eighth grade and he served as a sounding board as Heather developed the Blue Book.
contrast, Jody related that she lacked administrative support as she implemented inquiry practices. She stated that administrators mandated the use of Active Physics and attendance at regular meetings intended as support for its adoption. However, Jody claimed that no one in her school was concerned with what went on in her classroom, as long as she adhered to Active Physics. She further stated, and I observed, that she constantly lacked materials needed for activities in Active Physics. Similar to the findings in the literature (Smith, 2000; van Driel, 1998; Adams & Krockover, 1997; Clermont et al., 1993, 1994; Geddis, 1993), these contextual factors inhibited or facilitated the translation of teachers’ PCK into practice and their use of guided inquiry as an instructional strategy.

Implications for Teacher Education

Several implications for preservice and inservice teacher education can be drawn based on the findings of this study. The findings suggest that it is foolish to assume that a professional development effort (whether inservice or preservice) that is divorced from teachers’ beliefs and contexts will result in lasting changes in practice. Within this premise, five implications are suggested.

A first implication concerns the primordial role of teachers’ beliefs in any change process. Ignoring these beliefs is equivalent to ignoring the importance of prior knowledge in student learning. Examining and exploring teachers’ beliefs before and after a professional development effort is crucial. Without a close examination of these beliefs before teachers begin a program, teacher educators might remain unaware of conflict core beliefs that might hinder the teachers’ knowledge construction or change in practice. Furthermore, an early examination of beliefs might lead the teacher educator to
modify planned program activities to cater to or address teachers’ existing beliefs. Similarly, without a close examination of teachers’ beliefs during the professional development program, teacher educators cannot be confident that the teacher participants are prepared to implement constructivist/inquiry practices. This exploration of teachers’ beliefs could be the first step in promoting a conceptual change process of teacher learning.

This implication coincides with those identified by other researchers with respect to preservice teacher education (Haney & McArthur, 2002; Posnanski, 2002; Luft, 2001; Hogan & Berkowitz, 2000; Smith, 2000). These researchers suggest that without a close examination of the beliefs of preservice teachers, teacher educators cannot be confident that the students are prepared to implement constructivist practices as a result of their participation in methods courses and field experiences.

Based on the first implication, the study’s findings also have implications for the inclusion of an action research component within professional development programs. In that respect, I recommend that professional development efforts include an action research component that invites and engages teachers in reflection on their beliefs and the influences of these beliefs on their practice. For example, science teachers should be invited to reflect on their beliefs about their students, their students’ ideas, science, and how their students learn. Teachers should also be invited to reflect on their beliefs about teaching in general and teaching science in particular. Following reflections on their beliefs, teachers should engage in action research whereby they examine the influence of their beliefs on their instructional practices. Furthermore, teachers should be invited and engaged in reflection on how their beliefs and actions influence student learning. This
implication coincides with Haney and Lumpe’s (2002) suggestion for preservice teacher education courses based on past findings that indicate that action research opportunities enable novice teachers to reflect upon their beliefs and actions by focusing on student learning (Tabachnick & Zeichner, 1998).

A third implication is based on previous recommendations in the literature that state that reform endeavors need to be situated in practice (Supovitz & Turner, 2000; Loucks-Horsley et al., 1998; Fullan, 1982). For example, a component of the professional development effort should take place during the school year. At that time, professional development leaders interact with participating teachers as the latter share their trials and tribulations with implementing new strategies. In this manner, professional development leaders provide the teachers with support and advice as they collaborate with them to address problems as they arise in the teachers’ classrooms. Situating professional development in practice makes it more authentic as it deals with problems of practice encountered in the teachers’ specific contexts. Furthermore, it engages teachers in concrete teaching tasks that are based on their experiences with students.

A fourth implication of the findings of this study concerns the importance of immersing teachers in learning content knowledge through inquiry as well as emphasizing and modeling the different inquiry-based instruction. Courses similar to *Physics by Inquiry* in all science areas should be developed and offered to preservice and inservice teachers. In this manner, teachers’ content knowledge and knowledge of inquiry practices is enhanced as it is experienced and observed. This implication coincides with the recommendations for effective professional development and is echoed by other researchers who also found that the depth of teachers’ knowledge of the content and of
inquiry impacted their practice (Hogan & Berkowitz, 2000; Supovitz & Turner, 2000; Loucks-Horsley et al., 1998; Radford & Ramsey, 1996; Bell et al., 1993; Fullan, 1982).

A fifth implication of the findings of this study concerns the importance of acknowledging teachers’ individual and contextual factors that mediate knowledge construction and implementation. These factors include administrative support, concerns for coverage and control, and teacher autonomy. More importantly, it is the teacher educator’s responsibility to address these factors whenever necessary. In that respect, I advocate the inclusion of collaborative aspects in the professional development programs. Collaborations could be incorporated between different teachers, teachers and teacher educators, or teachers, researchers and teacher educators. This implication coincides with recommendations made by Posnanski (2002), Hogan & Berkowitz, (2000), and Supovitz et al. (2000). It is recommended that this collaborative component of professional development efforts be sustained, that is, it is available to the teacher through an extended period of time (Hogan & Berkowitz, 2000; Supovitz & Turner, 2000; Loucks-Horsley et al., 1998; Fullan, 1982).

Conclusion and Suggestions for Future Research

Based on the study’s theoretical framework, the change examined lies within the normative-reeducative perspective which represents a voluntary and naturalistic approach to change that is enhanced through deep reflection on beliefs and practices (Chin & Benne, 1969; Richardson & Placier, 2001). Within this perspective, first-order or second-order change could occur (Cuban, 1988). First-order change consists of minor changes in the organization of the classroom, the curriculum, and other factors. Second-order change entails different ways of thinking, teaching, and learning.
The teachers in this study voluntarily signed up for the PBI professional development program. As a result of their participation in that program, first- and second-order changes occurred within the thoughts and practices of the participants. Heather’s change was a second-order change, exemplified by the changes in her beliefs, knowledge, and teaching practice. Jody’s change was first-order primarily, as evidenced by her restructuring of the classroom to promote group work. Jody’s change was primarily first-order in nature because, even though her beliefs and knowledge underwent a second-order change, the changes in her beliefs and knowledge were not accompanied by changes in practice.

The difference in the type of change that occurred in the two teachers can also be explained through the normative re-educative perspective emphasis on teachers’ cognition, and factors (such as beliefs) that influence the outcomes of the change process (Richardson, 1996). Several other factors that influence change are postulated in the literature. These factors consist of individual and/or contextual factors (Hogan & Berkowitz, 2000; Cronin-Jones, 1991; Smith & Neale, 1989; Gess-Newsome & Lederman, 1993) or cultural, political, and technical dilemmas (Anderson, 1996). Primary mediators for the change in teachers’ knowledge and practices consisted of their constructivist or conflict core beliefs (Haney & McArthur, 2002) about science and teaching. The teachers’ core beliefs represented part of the individual or cultural dilemmas. Several other cultural and political dilemmas (individual and contextual factors respectively) were identified, including beliefs about students’ abilities, concerns for coverage and control, depth of content knowledge, administrative support, availability of resources, and teacher autonomy. The presence or absence of these dilemmas
facilitated or inhibited the development of PCK and its adoption in practice. When present, these dilemmas resulted in the teacher adopting conventional instructional strategies, stressing procedures rather than student understanding.

Based on these findings, five implications for teacher education programs (both preservice and inservice) were recommended. These implications suggest that preservice and inservice teacher education courses should:

1. Examine and explore teachers’ beliefs before and after a professional development.

2. Include an action research component within professional development programs.

3. Be situated in practice to make learning more authentic.

4. Immerse teachers in learning content knowledge through inquiry as well as emphasize and modeling the different aspects of inquiry-based instruction.

5. Acknowledge teachers’ individual and contextual factors that mediate knowledge construction and implementation and develop collaborations for support.

In order to develop more understanding of the complex change process that teachers go through as a result of reform-oriented education and the factors that mediate it, additional research is needed. One area of this research concerns the influence of professional development courses similar to Physics by Inquiry that explore teachers’ beliefs on the change in these teachers’ thoughts and action. For example, are such
programs more effective than programs that do not explore teachers’ beliefs? Do such programs promote lasting change in teachers’ beliefs, knowledge and practice?

Another area that requires further research is the potential of professional development programs that incorporate action research components and base learning in practice on the change in teachers’ thoughts and actions. For example, is the learning experienced in such programs more meaningful than learning in others? What types of action research questions promote lasting change in teachers’ beliefs, knowledge, and practice?

A third area for future research consists of investigations of the different types of teacher support that mediate change in teachers’ thoughts and actions. For example, do teacher-teacher educator collaborations lead to fruitful inquiries into practice and meaningful action research components that promote lasting change in teachers’ beliefs, knowledge, and practice? What aspects of administrative support are most conducive to lasting change?

A fourth area for future research concerns the influence of teachers who participate in programs like Physics by Inquiry on the student learning and classroom culture. Does participation in similar programs increase student learning? What is the nature of the student-teacher interaction in these cases as compared with teachers who do not go through the program?

A final area of future research concerns studies similar to this one, which focus on the influence of the different contexts (urban, rural, and suburban) and the nature of the change processes that occur in these settings. These studies might emphasize the meaning of constructivist practices in general and particularly regarding inquiry. The studies
should further consider and explore teachers’ beliefs and knowledge as they relate to the change process.

Summary

This study relied on two qualitative case studies to investigate the influence of a professional development effort that immersed teachers in learning science content by inquiry and models sound pedagogical practices, on the change in teachers’ inquiry thoughts and actions.

Participants in this study consisted of 2 female middle school physical science teachers who participated in Physics by Inquiry. One taught in an urban setting and the other in a suburban setting. Data sources included standardized and semi-structured interviews, open-ended classroom observations, and a collection of classroom artifacts. The resulting data were examined with the intent of discerning influences on and changes in teachers’ beliefs, knowledge, and practice towards constructivist/inquiry based practices. Data were also examined to determine the factors that mediated change in teachers’ thoughts and actions.

The findings of this study indicate that, as a result of their participation in that program, first- and second- order changes occurred within the thoughts and practices of the participants. Furthermore, several cultural and political dilemmas that mediated the change process were identified. These dilemmas included beliefs about students’ abilities, concerns for coverage and control, depth of content knowledge, administrative support, availability of resources, and teacher autonomy. These factors facilitated or inhibited the development of pedagogical content knowledge and its adoption in practice. These findings were compared with the existing literature on teacher change, beliefs and
pedagogical content knowledge in an effort to more firmly establish a conceptual framework regarding the factors that influence the change process. Implications of these findings suggest that to promote lasting change, professional development programs should (a) explore teachers’ beliefs, (b) be situated in practice, (c) immerse teachers in learning content knowledge through inquiry, (d) emphasize and model the different aspects of inquiry-based instruction, (e) incorporate an action research component, and (f) acknowledge and tend to individual and contextual factors that mediate change by developing collaborations for support.
APPENDIX A

COT: Knowledge/Conceptions of Science and Teaching Science

Adapted from Grossman 1990

Introduction: First I’ll be talking to you as someone who knows about the field of Science, and we’ll be talking a little bit about your undergraduate and graduate background in Science. At this point, we won’t be talking about teaching Science, but rather about the study of Science as a discipline.

1. Can you tell me about your background in Science? Tell me about your courses, undergraduate and graduate, favorite and least favorite. What areas did you concentrate on? Specialization? What do you feel are your strengths in Science? What areas do you feel relatively weak in? What areas were easy for you? Difficult? Tell me about some of the most important Science experiments you performed as an undergraduate.

2. What do you think it means for someone to know Science? If someone is a self-proclaimed expert in Science, what would you expect them to know?

3. Could you talk about the major areas that make up Science (or each of the disciplines in science) as a field or discipline? Tell me how the areas and disciplines are related to each other. (Could you draw a map of the different areas and their relationships?)

4. Now I’d like to talk to you as a Science Teacher. What made you decide to become a science teacher? [Probe for reasons for teaching and reasons for teaching science]
5. Tell me about what you see as the reasons for studying science in middle and high school. What are your goals for your students? What areas would you want to cover in your classes? [Probe for conceptions of teaching process skills, content, nature of science, inquiry]

6. What do you think makes science difficult for students? What areas do you think they might have problems with? What is easy for middle and high school students? What could make the study of science easier for students? [Probe for both process skills, content, nature of science, and inquiry]

7. Tell me about the classes you are teaching this semester. How are the classes organized? What topics or units are you teaching? Are you familiar with these topics? Have you studied them before? Have you taught them before? Tell me about the students in your class.
APPENDIX B

CTS: Conceptions of Teaching Science

Peter Hewson and Mariana Hewson, 1989

Task Protocol

1. In your view, is there science teaching happening here?

2. If you cannot tell, what else would you need to know in order to be able to tell?
   Please give reasons for your answers.

3. If you answered “yes” or “no,” what tells you that this is the case? Please give reasons for your answer.

Instances about Physics

1. Teacher in a middle school at the start of a topic on crystals, asking the class,
   “What can you tell me about the crystals I’ve passed around the class?”

2. A student at home watching a TV program on the use of solar power in generating electricity and heating homes.

3. Two 11th grade students in a library working on a set of kinematics problems from the physics textbook given for homework.

4. College professor lecturing on Einstein’s special theory of relativity to a small group of first graders.

5. Teacher in front of an 11th grade physics class, describing the steps used in the “free body” method of solving dynamics problems.

6. Teacher reads an 11th grade physics student’s statement that “the current leaving the bulb is less than the current entering it” and asks “What happens to the current inside the bulb?”
7. Teacher, at the end of a demonstration of magnetic induction using a model of a transformer, distributes a drawing and asks students to label the apparatus used in the experiment from memory.

8. Junior high school student in class, holding a polystyrene cup containing iced water saying, “The cup really prevents the cold from getting into my hand.”

9. A student at home following a recipe for blueberry muffins.

10. A teacher, writing a self-study resource center program at home on using a triple beam balance to measure the weight of an object.
APPENDIX C

Teachers’ Pedagogical Philosophy Interview (TPPI)

(Developed by Lon Richardson and Patricia Simmons, Salish 1 Research project 1994)

1. How would you describe yourself as a classroom teacher?
2. What role model do you have for yourself as a classroom teacher?
3. Describe a well-organized classroom. When you have your classroom running the way you want it, what is it like?
4. How did you form this model of the well-organized classroom?
5. How long did it take you to develop this model of teaching?
6. What do you consider to be the founding principles of teaching? If you had to write a book describing the principles that teaching should be built on, what would those principles be?
7. How do you learn best?
8. How do you know when you have learned?
9. How do you know when you know something?
10. What are facts, laws, and theories in science?
11. How are facts arrived at?
12. How do you distinguish among facts, laws, and theories in science?
13. When you picture a good learner in your mind, what characteristics of that person lead you to believe that they are a good learner?
14. What is science?
15. In what ways do you learn science best?
16. When you learn science, is it different than learning mathematics or history?

17. What are the founding principles of science?

18. How do you decide what to teach and what not to teach?

19. How do you decide when to move from one concept to another?

20. What learning in your classroom do you think will be valuable to your students outside the classroom environment?

21. Describe the best teaching/learning situations you have ever experienced.

22. In what way do you try to model that best teaching/learning situation in your classroom?

23. What are some of the impediments or constraints for implementing that kind of model in your classroom?

24. What are some of the tactics you use to overcome these constraints?

25. Are there any things at the local/school/state levels that influence the way you teach? What are some examples of this?

26. What are values?

27. How do you arrive at these values?

28. What are some of the things you value most about science?

29. How do you believe learn best?

30. How do you know when your students understand a concept?

31. How do you know when learning is occurring, or has occurred in your classroom?

32. How do you think your students come to believe in their minds that they understand something?
33. In what ways do you manipulate the educational environment (classroom, school, etc.) to maximize student understanding?

34. What science concepts do you believe are the most important for your students to understand by the end of the school year?

35. How do you want your students to view science by the end of the school year?

36. What values do you want to develop in your students?

37. What are some of the things you believe your students value most about their educational experience in your classroom? When they leave here they say, “I really liked her class because….”

38. How do you accommodate students with special needs in your classroom?

39. What do you believe are your main strengths as a teacher?

40. In what areas would you like to improve as a teacher?

41. When did you realize you were becoming a good teacher, understanding that you were having a positive effect on your students and satisfied that you were doing the right thing?

42. Were your undergraduate education/pedagogy courses beneficial to you when you began teaching? Why or why not?

43. Were your undergraduate science courses beneficial to you when you began teaching? Why or why not?

44. What changes would you make in undergraduate education/pedagogy courses, if you could, to make the experience more meaningful?

45. What changes would you make in undergraduate science courses, if you could, to make the experience more meaningful?
46. In reference to the teaching model or teaching package that you have
developed...if you had to divide that up into a pie chart, how much of the chart
would come from undergraduate training. Graduate training, your on-the-job
experience, or anything else that you can think of?
APPENDIX D
Excerpt from Blue Book Table of Contents

What is Inquiry?  More Electricity
Motion & Forces  Magnetism
Measurement of Matter  Waves
Operational Definitions  Sound
Package Reasoning  Light
Mass Practice Problems
Speed, Distance, Direction &
Velocity
Momentum
Acceleration
Forces & Friction
Newton’s Laws of Motion
Gravity
Physics of Sports Project
Energy

Light & Sound Waves
Properties of Matter
Area & Volume
General Properties of Matter &
Density
Phases of Matter & other
Physical Properties
Physical vs. Chemical Changes
Chemistry of Acids, Bases & pH
Mixture & Solutions
Chromatography

Work Power & Simple Machines
Work & Power
Simple Machines
The Pulley
The Inclined Plane
The Screw
The Wedge
The Lever
The Wheel & Axle
The Gear
Rube Goldberg Project

Light & Sound Waves
Waves
Sound
Light

Atoms, Elements & the Periodic Table
30 Common Elements
Periodic Table
Elementary Chemistry
Atomic Structure
Chemical Families of the
Periodic Table
Chemical Bonding

Electricity & Magnetism
Static Electricity
Electricity Intro
Batteries
Circuits Introduction
Circuit Diagrams
Sockets
Electric Current
Measuring Voltage

Reading Science Content Help
Reading Science Content Help
Finding the Main Idea
Outlining
Taking Notes
Learning New Words

Eighth Grade Science Guide
Created and compiled by Heather
References


Bellamy, M. L. (1990). *Teacher knowledge, instruction, and student understandings: the relationships evidenced in the teaching of high school Mendelian genetics.* Unpublished doctoral dissertation, the University of Maryland, College Park, MD.


Tamir, P. (1972). Understanding the process of science by students exposed to different
science curricula in Israel. *Journal of research in science teaching, 9*, 239-245.


_Teaching and teacher education, 4*, 99-110


_Theory into practice, 29(2)*, 122-127.


science teaching. In _Handbook of Research on Science Teaching and Learning
_(pp. 177-210) city: press.

Troxel, V. A. (1968). *Analysis of instructional outcomes of students involved with three
sources in high school chemistry*. Washington, DC: U.S. Department of Health,
Education, and Welfare, Office of Education.

Tsai, C. (2002). Nested epistemologies: science teachers’ beliefs of teaching, learning

van Driel, J. H., Beijaard, D., & Verloop, N. (2001). Professional development and
reform in science education: the role of teachers’ practical knowledge. *Journal of
research in science teaching, 38*, 137-158.


