# A STUDY OF PCK OF SCIENCE TEACHERS FOR GIFTED SECONDARY STUDENTS GOING THROUGH THE NATIONAL BOARD CERTIFICATION PROCESS

by

## SOONHYE PARK

(Under the Direction of J. Steve Oliver)

### ABSTRACT

The purpose of this study was to obtain a better understanding of the nature of pedagogical content knowledge (PCK) and its development. This study examined the nature of PCK that candidate teachers for National Board Certification (NBC) demonstrated and the roles of the NBC process in fostering the teachers' PCK development. In order to understand how students play a role in organizing, developing, and validating teachers' PCK, how students' giftedness is related to teachers' PCK was also investigated.

This study was a multiple case study grounded in a social constructivist framework. The participants of this study were four high school science teachers who either were going through or had gone through the NBC process. Data were collected from multiple sources such as observations, interviews, teachers' written reflections, students' work samples, lesson plans, and researcher's field notes. Data analysis was conducted using three different approaches with Atlas.ti as an aid: (a) constant comparative method, (b) enumerative approach, and (c) in-depth analysis of explicit PCK.

The results showed that PCK was developed through reflection-in-action and reflectionon-action in the context of practices. Teacher efficacy emerged as an important component of PCK, which led to the construction of the hexagon model of PCK. Students had a great deal of impact on PCK development, particularly students' misconceptions played a significant role in shaping PCK. Because PCK development required teachers to integrate different components of PCK and individual teachers developed one or many of the components in a variety of ways, however, their PCK was idiosyncratic to some degree.

In addition, instructional challenges caused by gifted students' special characteristics influenced teachers' PCK in multiple ways. The NBC process influenced candidate teachers' PCK development through facilitating reflection, encouraging implementation of new instructional strategies, fostering inquiry-oriented instruction, improving assessment of students, and increasing understanding of students.

This study provides several implications for teacher education and research. Teacher education needs to be more subject matter-specific and emphasize reflection. Teachers' affective domains such as teacher efficacy should be also considered to improve PCK. A longitudinal study to examine the sustainability of the effects of the NBC process is suggested.

INDEX WORDS: Knowledge for teaching, Pedagogical content knowledge, Knowledge of students, Teacher knowledge development, National Board Certification, Teaching portfolios, Science teaching and learning, Identified gifted students

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# DEDICATION

To my husband, Jinhong Jung, for your support, love, and trust

and

to my son, Jiung Jung, for your endearing smile and your presence itself

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#### CHAPTER I

#### INTRODUCTION

Many research studies have suggested the centrality of teachers in educational processes (Calderhead, 1996; Doyle & Ponder, 1977; Woods, 1980). The Institution for Educational Leadership (2001) declared that "student learning depends first, last, and always on the quality of teachers" (p.1). With this growing awareness of the centrality of teachers in education, the influence of cognitive psychology has led researchers in studies of teaching to devote increased attention to teachers' knowledge and how it is developed (Borko & Putnam, 1996; Calderhead, 1996). Much of this interest was stimulated by Shulman's (1986) report that research on teaching and teacher education has undeservedly ignored research questions dealing with the content of the lesson taught. In that report, Shulman (1986) introduced the concept of pedagogical content knowledge (PCK) as a distinctive body of knowledge for teaching, in order to acknowledge the importance of the transformation of subject matter knowledge per se into subject matter knowledge for teaching.

PCK is described as an amalgam between content and pedagogy demonstrated by an understanding of how particular topics, problems, or issues are organized, represented, adapted to the diverse interests and abilities of learners, and presented during instruction (Shulman, 1986, 1987). By and large, it is the knowledge that plays a role in transforming subject matter knowledge into forms that are more comprehensible to students (Geddis, Onslow, Beynon, & Oesch, 1993; Grossman, 1990; Marks, 1990; Shulman, 1986, 1987). Because this knowledge is developed through an integrative process rooted in classroom practice (Van Driel, Beijaard, & Verloop, 2001), it represents knowledge that is "uniquely the province of teachers, their own special form of professional understanding" (Shulman, 1987, p. 8).

Numerous lines of research on teaching have emphasized that PCK plays a vital role in teachers' planning and actions when dealing with subject matter in classrooms (Clermont, Krajcik, & Borko, 1993; Smith & Neale, 1989; Van Driel, Verloop, & De Vos, 1998), shapes teachers' learning of new instructional approaches and strategies (Borko & Putnam, 1996; Smith & Neale, 1989), and influences student learning (Carpenter, Fennema, Peterson, & Carey, 1988). In a study elaborating the knowledge bases for teaching, Grossman (1990) asserted that among the knowledge bases, PCK was anticipated as having the greatest impact on teachers' classroom actions. In this regard, it is obvious that PCK is integral to effective science teaching. Further, an understanding of this domain of knowledge and its influence on teachers' practice is necessary to foster the improvement of science teaching and science teacher education. However, in the science education field, the nature of PCK and its development have seldom been clearly identified, thus causing difficulty in using it explicitly as a conceptual tool (Magnusson, Krajcik, & Borko, 1999; Veal & MaKinster, 1999). With this in mind, this study explored the nature of PCK of experienced high school science teachers.

Grounded in the wisdom of practice, the development of PCK involves a dramatic shift in teachers' understanding "from being able to comprehend subject matter for themselves, to becoming able to elucidate subject matter in new ways, reorganize and partition it, clothe it in activities and emotions, in metaphors and exercises, and in examples and demonstrations, so that it can be grasped by students" (Shulman, 1987, p. 13). What distinguishes novice from expert teachers, then, is possession of such knowledge, "the capacity of a teacher to transform the content knowledge he or she possesses into forms that are pedagogically powerful and yet

adaptive to the variations in ability and background presented by students" (Shulman, 1987, p. 15). Accordingly, PCK has been regarded as a special body of knowledge that distinguishes the understanding of teachers from that of content specialists (Cochran, 1992; Cochran, DeRuiter, & King, 1993; Shulman, 1987). Teaching expertise, therefore, should be described and evaluated in terms of PCK as well as subject matter knowledge and pedagogical knowledge (Shulman, 1987).

Along this line, PCK has been considered as a knowledge base expert teachers have in many of the recent educational reform documents (e.g., American Association for the Advancement of Science [AAAS], 1993; National Research Council [NRC], 1996). The National Board for Professional Teaching Standards (NBPTS) also implicitly noted that PCK is a crucial element of what teachers should know and be able to do (e.g., Teachers know the subjects they teach and how to teach those subjects to students) (NBPTS, 2004). To recognize and reward outstanding teaching, the NBPTS has developed performance-based assessments in different content areas and at different levels of schooling that delineate the knowledge and skills that teachers must have in order to engage in accomplished practice (NBPTS, 1996, 2004).

By reviewing literature on the reliability of the National Board assessments, Porter and colleagues (1996) concluded that the National Board assessments can be legitimately used to distinguish between accomplished teachers and other teachers. They further argued that the NBPTS emphasized the need of teachers to have PCK, knowledge of students, reflective practice, and the ability to engage students in active learning. Throughout this study, the terms *accomplished teacher* and *expert teacher* are considered to be roughly equivalent with the caveat that *accomplished teacher* is the term most commonly associated with NBPTS.

Although it is clear that the NBPTS regards PCK as a major component of the competency that accomplished teachers have, there is a dearth of research investigating the

relationship between the National Board Certification (NBC) process and PCK. A research study that compared the teaching practices of National Board Certified teachers (NBCTs) with those of other teachers indicated that NBCTs have more sophisticated PCK than other teachers (Bond, Smith, Baker, & Hattie, 2000). From the results of this study, however, one cannot understand whether the NBCTs already have sophisticated PCK and demonstrate this knowledge through the NBC process or whether they also develop their PCK while going through the process. If teachers develop their knowledge while going through the process, the NBC can be recognized not only as reward/recognition of what teachers already have accomplished, but also as a form of professional development. In this vein, this study examined how the NBC process, in particular the portfolio creation process, influenced candidate teachers' PCK.

This study has evolved from the belief that the NBC portfolio creation process can provide teachers with opportunities to further develop several knowledge domains that contribute to PCK development: pedagogical knowledge, subject matter knowledge, curriculum knowledge, knowledge of context, knowledge of students and learning, knowledge of assessment, and educational goals and values (Morine-Dershimer, & Kent, 1999). In general, teachers prepare their portfolios for the National Board assessment by videotaping their teaching, gathering student work samples and other teaching artifacts, and providing detailed analyses of their practice. The videotapes of teaching practices and samples of student work need to be supported by commentaries on the goals and purposes of instruction, reflections on what occurred, the effectiveness of the practice, and the rationale for the teacher's professional judgment (NBPTS, 2004). In order to accomplish this task, teachers have to integrate all of the different domains of knowledge described above, which may enhance PCK development. Above all, teachers are required to systematically analyze student work, especially student responses to assignments, class work, assessment, and other instructional materials. And, through the use of videotapes, teachers need to provide as authentic and complete a view of their teaching as possible and to portray how they interact with students, the climate they create in the classroom, and the ways in which they engage students in learning (NBPTS, 2004). Those tasks may facilitate the development of teacher knowledge of students. In addition to completing the classroom-based entries, teachers are asked to document their work outside the classroom with families and the larger community and with colleagues and the larger profession (NBPTS, 2004). This task requires teachers' knowledge of educational context.

Basically, the portfolio is designed to capture teaching in real-time and in real-life settings, thus allowing trained assessors to examine how teachers translate knowledge and theory into practice (NBPTS, 2004), which is the core concept of PCK. Taken together, it is reasonable to assume that the NBC portfolio creation process may influence teachers' PCK development. This study empirically investigated this assumption in order to ascertain whether the NBC process itself actually makes teachers more effective that they otherwise would have been.

By definition, PCK includes what teachers actually do and the reasons for their actions as well as what they know (Baxter & Lederman, 1999). Because PCK concerns the teaching of particular topics (Van Driel, et al., 1998) and because the translation of teachers' subject matter knowledge into classroom practice is clearly a critical aspect of PCK, it can be expressed only when teachers deal with subject matter for a specific group of students in a specific classroom. In this regard, PCK is closely linked to teachers' actual teaching performances and classroom life. Through an investigation of the relationship between the NBC process and PCK development, therefore, one can ensure ecological validity (Kagan, 1990) of the National Board assessments.

Ecological validity refers to evidence concerning the relevance of a measurement technique to classroom life (Kagan, 1990). In other words, this concept includes concerns regarding whether teachers' performances on a particular tool or task are related to their classroom behaviors or to valued student outcomes. Thus, this study attempted to provide significant insights into not only understanding the nature of PCK and its development, but also into the ecological validity of the National Board assessments.

Meanwhile, teachers' knowledge, regardless of how it is conceptualized, is highly context specific because an individual teacher is faced with a particular curriculum and a particular group of students within a particular school. Indeed, application of teachers' knowledge is located in and dependent upon, a specific social, cultural, and educational context (Barnett & Hodson, 2000). What counts as good teaching, then, cannot be specified without knowledge about the elements that comprise this context. Given that students are one of the major components comprising the context, it is obvious that students have great influence on the development of teachers' knowledge (Kagan, 1992). Consistent with this, a growing body of research has suggested that students are a critical source of PCK development (Geddis, 1993; Lederman, Gess-Newsome, & Latz, 1994; Van Driel et al., 1998). However, there is little empirical research to show the nature of the relationship between knowledge of students and PCK.

It is commonly accepted that teachers need to adapt or tailor instructional practices to the academic ability, preconceptions, and interests of members of the classroom's student population. Many researchers (e.g., Croft, 2003; Renzulli, 1968; Sisk, 1989) have claimed that gifted students are more profoundly impacted by their teachers' attitudes and actions than are other students because they have different cognitive, affective, physical, intuitive, and societal characteristics compared to their peers (Karnes & Bean, 2001). Due to these special

characteristics, gifted students may function differently in science classrooms. They may hold different alternative frameworks (Driver & Easley, 1978) about scientific phenomena or have different "conceptual trajectories" (Driver, Leach, Millar, & Scott, 1996) of scientific concepts. Therefore, in order to meet the instructional challenges gifted students bring into science classrooms, teachers should implement specially adapted pedagogical procedures for teaching a subject.

Contrary to the common belief that gifted students will make it on their own, research suggests that it is unlikely that these students can succeed well without specialized help (Colangelo & Davis, 1997). Parallel to this concern, several sets of professional teaching standards (e.g., National Council for Accreditation of Teacher Education [NCATE], 1999; NBPTS, 2004) have stressed the importance of meeting the special learning needs of all students. With this in mind, this study sought to scrutinize how teachers' perceptions of giftedness functioned as a component of PCK. Specifically, this study examined how the instructional challenges gifted students brought into both heterogeneously or homogeneously grouped classrooms affected their teachers' PCK.

#### Theoretical Framework

For this study, I employed social constructivism as a theoretical framework that shapes "the meaning of research questions, the purposiveness of research methodologies, and the interpretability of research findings" (Crotty, 1998, p. 17). The most significant base of social constructivism originated from Vygosky's (1962, 1978) social development theory and zone of proximal development (ZPD) theory. The major theme of his theories is that social interaction plays a fundamental role in the development of cognition. According to Vygotsky (1978), Every function in the child's cultural development appears twice: first, on the social level, and later, on the individual level; first, between people (interpsychological) and then inside the child (intrapsychological). This applies equally to voluntary attention, to logical memory, and to the formation of concepts. All the higher functions originate as actual relationships between individuals. (p. 57)

The most influential concept of Vygotsky's (1978) theories has been the zone of proximal development (ZPD). The ZPD can be defined as the difference between the difficulty level of a problem a child can cope with independently and the level that can be accomplished with adult help (Bruning, Schraw, & Ronning, 1999). Social interactions between children and adults in the ZPD are the source of children's cognitive growth (Vygosky, 1978). Vygotsky's social development theory has been expanded upon by Bandura (1986) in his social cognitive learning theory.

From the social constructivist view, knowledge is not discovered, but constructed within individual minds through social interactions. We are situated within a social context and we share our everyday lives with others. Thus, our knowledge construction is either encouraged or constrained by social interactions, even though the knowledge construction is processed within our minds (Driver, Asoko, Leach, Mortimer, & Scott, 1994). While radical constructivism focuses on the matter of individual minds and cognitive processes in knowledge construction, social constructivism turns attention "outward to the world of intersubjectively, shared social constructions of meaning and knowledge" (Schwandt, 1994, p. 127). In other words, the focus is not on the meaning making activity of the individual mind but on the collective generation of meaning as shaped by conventions of language and other social processes (Schwandt, 1994).

Knowledge claims are intelligible and debatable only within a particular context or community (Fish, 1989).

In this respect, the process of knowing involves agreement and interaction with other individuals. Knowledge is negotiated with other members of the social context to the point that meaning is taken to be shared by interacting individuals (Gredler, 1997; Prawat & Floden, 1994). Stated differently, knowledge construction is the act of becoming socialized into the practices of the community in which we are embedded with its particular purposes, ways of seeing, and ways of supporting its knowledge claims. Knowledge, in brief, is socially constructed, communicated, and validated. Thus, it appears to be obvious that "key aspects of mental functioning can be understood only by considering the social contexts in which they are embedded" (Wertsch & Toma, 1995, p.159).

Along this line, teaching as a professional practice is also a social practice in that teachers' work is embedded not only in a specific problem context but also in a specific social setting. Teachers build up a repertoire of context-specific knowledge through social interaction, negotiation, and co-construction of meaning, with different social contexts providing different inputs into the individual's construction of a personal framework of understanding (Barnett & Hodson, 2000). Thus, the knowledge of teaching that teachers develop is intimately related to the specific social situations, interactions, and communities which have generated, validated, maintained, and used it. In this sense, social interaction with others, e.g., students, colleagues, administrators, parents, etc., is a part of the personal and social construction and reconstruction of knowledge of teaching (Bell, 1998).

Those social constructivist perspectives on knowledge construction provided significant guidance to this research study. First, I strove to fully take into consideration the real teaching

settings in which the teachers participating in this study were working when I investigated their knowledge development. Second, as teaching cannot exist without students, a teacher's knowledge of teaching is deeply rooted in teaching contexts where the interactions between the teacher and students occur. Thus, while exploring teachers' knowledge, I placed a great emphasis on interaction between the teacher and students.

Last, the dialectic relation between the social context and knowledge construction makes it difficult to see individual knowing as separated from where the knower is. As a researcher and observer, I recognize that my presence may have influenced the actions and activities of the teachers and students. I was aware that the teachers might change through their interaction with me and, at the same time, these changes might change my research. Consequently, the knowledge from this study was a result of mutual construction between a researcher, myself, and the researched including the teachers and social contexts in which this study was embedded (Charmaz, 2002).

#### Purpose of the Study

The purpose of this study was threefold. From a theoretical point of view, this study aimed to achieve a better understanding of the nature of PCK and its development through an examination of teachers' PCK expressed while going through the NBC portfolio creation process. This understanding provides insights into the ways teachers transform subject matter knowledge, how they relate their transformation to student understanding, and what contributes to making this transformation effective. Furthermore, it enables us to make progress in comprehending the complexity and dynamics of teacher knowledge and it development.

Another purpose of this study was to improve our understanding of the nature of the relationship between teachers' knowledge of students and PCK. Through both empirical and

theoretical research on teachers' PCK, it has been proposed that teachers' PCK is influenced by their knowledge of students including students' preconceptions, learning difficulties, and reasoning types in a specific domain (Geddis, 1993; Lederman et al., 1994; Van Driel, et al., 1998). However, insufficient attention has been paid to how students play a role in developing teachers' PCK or in what ways the knowledge of students is integrated into PCK. With these issues in mind, this study intended to improve understanding of how students influence the means through which the teachers' PCK is organized, developed, and validated. In particular, this study attempted to obtain a more sophisticated comprehension of how the giftedness of students is related to their teachers' PCK.

The other purpose was drawn from a practical point of view. PCK has been suggested as one knowledge base for science teacher education (Anderson & Mitchener, 1994; Doster, Jackson, & Smith, 1997; NRC, 1996; Tobias, 1999), based on the consensus that PCK is a distinctive body of knowledge necessary for effective teaching. It is likely that PCK is a significant requirement of being a competent or expert science teacher. In this regard, this study aimed to provide research-based implications for both pre- and in-service science teacher education programs to facilitate science teachers' professional development. In addition, the results of this study will contribute to the continuing efforts to establish the value of the National Board assessments, by showing how teachers developed their PCK through the NBC process.

#### Research Questions of the Study

The research questions of this study were as follows:

1. As expressed through the conduit of the NBC portfolio creation process,

- (a) What is the nature of the PCK that the candidate teachers for NBC demonstrate?
- (b) How do the teachers' perceptions of giftedness function as a component of PCK?

2. How does the National Board Certification Portfolio Creation Process influence these teachers' PCK?

#### Rationale of the Study

Pedagogical content knowledge (PCK) refers to what teachers know about their subject matter and how they translate subject matter into curricular events (Carter, 1990). As a number of scholars have argued (e.g., Cochran et al., 1993; Dewey, 1902/1983; Kerr, 1981, Shulman, 1986; Wilson, Shulman, & Richert, 1987), it is this pedagogical understanding of subject matter that distinguishes between subject matter experts and experienced teachers. In other words, PCK is a unique knowledge base possessed only by those individuals within the profession of teaching, and consequently the concept of PCK is useful to help understand what teachers know, what teachers ought to know, and how they might develop it. In this sense, it is meaningful to conceptualize this body of knowledge in greater detail and to understand its development.

Shulman (1986) argued that because little is yet known about the ways teachers transform subject matter knowledge, how they relate their transformations to student understanding, and how they develop these abilities, research on these themes is part of a "missing paradigm" (p.7). He further asserted that research on PCK may contribute to resolving the "blind spot" which results from a relative lack of research focusing on the knowledge of the content taught. In the field of science education, however, so far only a few studies have focused on teachers' PCK and its development (Magnusson et al., 1999). Yeany (1991) pointed out that "there is an urgent need to intensify our research efforts in science education to better understand the science teacher" (p.3). Thus, this study plays an important role in eliminating the blind spot in both in-service and pre-service science teacher education. Furthermore, it ultimately helps to empower teachers and

enhance the status of teaching as a profession in that it furthers the ideal that a profession develops theories of action by which the profession is practiced (Argyris & Schon, 1974).

In addition, this study fills the gaps revealed in research on PCK in the field of science education. First, most research on teachers' PCK in the science education area has focused on how beginning teachers learn to transform their knowledge of subject matter into a form appropriate for teaching (e.g., Clermont et al., 1993; Hashweh, 1987; Shulman, 1986, 1987), on pre-service science teachers' PCK (e.g., Van Driel, De Jong, & Verloop, 2002), and on direct expert-novice comparisons (e.g., Clermont, Borko, & Krajcik, 1994). There exists little research deeply investigating the cases of experienced science teachers' PCK at high school levels. Second, the hypothesized central role of students in developing PCK is commonly accepted, but few studies have directly assessed the impact of teachers' knowledge of students on teaching science in order to put that claim to an empirical test. Last, still unsolved is the issue of whether the PCK necessary for teaching the gifted is different from that desired for teaching average students in science classrooms.

Whether the concept of PCK is useful depends on to what extent teachers' PCK is personal. In this regard, this research identified common patterns in PCK of individual experienced science teachers and in the development of this knowledge expressed through the NBC process. Consequently, this research led to the establishment of a body of knowledge which constitutes an addition to existing knowledge bases for teaching. This body of knowledge might function as a "framework for helping prospective and experienced teachers develop their repertoire of responses, understandings, and magical tricks" (Grimmett & MacKinnon, 1992, p. 441). This effort can further bridge the disparity between the theory and practice of teaching. For instance, the results of the study might be used as case material in teacher education, and as an important source upon which prospective teachers might reflect.

This study is also significant in that it provides understanding of whether the NBC process itself makes teachers better. Several studies have provided evidence for the positive impacts of NBCTs on the quality of teaching and student achievement (Bond et al., 2000; Goldhaber & Anthony, 2004). As those studies employed quantitative methods, however, they rarely provided explanations about how NBCTs make a difference in student achievement or how the National Board assessment process itself influences their effectiveness. From quantitative results, one can judge whether or not NBCTs are different from non-NBCTs in target areas, which may be regarded as an indicator of the validity of the National Board assessments. Nevertheless, one cannot understand how those differences are meaningfully constructed in individuals' minds through their participation in the NBC process. In this vein, this study helps to understand how the NBC process impacts teachers' professional development, especially in terms of their PCK development, and how this development is related to students' learning experiences.

#### Summary

In this chapter, I have discussed the purpose of the study, the research questions, the rationale of the study, and the theoretical framework that guided this study. In the next chapter, I delineate the historical background of research on PCK and define the concept of PCK through a comprehensive review of relevant literature. Furthermore, I discuss the possible sources of PCK development, assessment of PCK, and National Board for Professional Teaching Standards (NBPTS) assessments.

#### CHAPTER II

#### LITERATURE REVIEW

#### Historical Background of Research on Pedagogical Content Knowledge

Research on teachers' cognition has increased since the early 1970s (Calderhead, 1996). The research on teaching in the late 1960s was characterized by a behaviorist stance that sought to describe teaching in terms of sequences of behavior, and then to investigate the relationship of that behavior to students' learning. Although behaviorist studies were once widely accepted within the contemporary research community and were believed to provide direct utility for improving teaching and teacher education (see Stallings, 1987), dissatisfaction with their narrow focus has grown among educational researchers (Calderhead, 1996; Feiman-Nemser & Floden, 1986). In particular, the results of process-product research that seeks to find 'effective' variables in teaching behavior have been criticized in that this kind of research does not acknowledge the complexity of the teaching enterprise (see Munby, Russell, & Martin, 2001). In this vein, the attention in research on teaching shifted from teacher behavior to teacher cognition with increasing recognition of the key roles of teachers in educational practices. In order to emphasize the impact of this shift on teacher education, Clark and Peterson (1986) have described this change as moving from prescription to description.

Since the 1980s in the U.S., teacher education has undergone consistent scrutiny and faced frequent attack by politicians and policy makers concerned with the quality of teachers produced (Bullough, 2001). For example, the report, *A Nation at Risk* (National Commission on Excellence in Education, 1983), pointed to weaknesses in teacher preparation when it stated:

Teacher preparation programs need substantial improvement...Too many teachers are being drawn from the bottom quarter of graduating high school and college students. The teacher preparation curriculum is weighted heavily with courses in 'educational methods' at the expense of courses in subjects to be taught. (p. 22)

With this concern, the Carnegie Forum on Education and the Economy (1986) proposed in *A Nation Prepared: Teachers for the 21<sup>st</sup> Century* the creation of a National Board for Professional Teaching Standards (NBPTS) to establish high standards for what teachers need to know and to be able to do and to certify teachers who meet these standards.

Responses to these challenges to teacher education have varied (see Cochran-Smith & Fries, 2001), but most often they have centered on the need to professionalize teaching (Bullough, 2001). Teacher educators have looked for a better means of supporting arguments for teaching as a profession. For instance, teacher educators in *Tomorrow's Teachers* (Holmes Group, 1986) suggested a means to professionalize teaching by replacing methods courses with subject specific pedagogical courses. This report stated that future teachers need to "study the subjects they will teach with instructors who model fine teaching and who understand the pedagogy of their material" (Holmes Group, 1986, p. 16).

Doubts about the value of teacher education have resulted in efforts to make a case for teaching as a unique intellectual enterprise involving special forms of knowledge and skill (Bullough, 2001). Within that frame of reference, Shulman (1986) introduced the concept of pedagogical content knowledge (PCK) as a distinct body of knowledge that distinguishes the understanding of teachers from that of content specialists. Consequently, the concept of PCK appears to empower the claim of teaching as a profession. Carlsen (1999) asserted that PCK was

invented for two different but related sets of reasons: one set theoretical/empirical in nature and the other political.

Bullough (2001), however, argued that several teacher educators had suggested the concept of PCK before Shulman (1986) introduced PCK (e.g., Brooks, 1907; Lucky, 1907). He concluded that Shulman had the great advantage of presenting PCK within a social and academic context because of the prominence of constructivism in educational thought and the weakening of disciplinary truth claims under the influence of postmodernism. Regardless of the argument on the origin of the concept of PCK, it is obvious that the inception of PCK by Shulman (1986) inspired researchers studying teaching to focus on the concept. As Nelson (1992) described, "in his 1985 presidential address, Lee Shulman tossed off the phrase 'pedagogical content knowledge' and sparked a small cottage industry devoted to the scholarly elaboration of the construct" (p. 32).

Additional work by Shulman and his students through a research project entitled *"Knowledge Growth in Teaching,*" funded by the Spencer Foundation, provided evolving conceptions of the domains of teacher knowledge, the description of PCK, and its place within the constellation of knowledge categories for teaching. In 1987, PCK was listed by Shulman as one of seven knowledge bases for teaching, removing it as a subcategory and placing it on equal footing with content knowledge, general pedagogical knowledge, curricular knowledge, knowledge of learners, knowledge of educational contexts, and knowledge of the philosophical and historical aims of education. Later work by Shulman and his students continued to explore PCK, sometimes subsuming it under content knowledge, but ultimately recognizing its role in the integration and transformation of other forms of knowledge (Wilson et al., 1987). Also, a growing number of studies have investigated PCK in different subject areas, including social studies and history (e.g., Gudmundsdottir, 1987), English (e.g., Grossman, 1990), mathematics (e.g., Marks, 1990), and science (e.g., Tamir, 1988).

On the other hand, there were several criticisms of Shulman's knowledge base of teaching and the concept of PCK. A central issue is whether or not it is possible in practice to make a clear distinction between subject matter knowledge and PCK. McEwan and Bull (1991) asserted that neither objectivism nor constructivism provides grounds for Shulman's distinction between subject matter knowledge and PCK. They went on to argue that all knowledge is pedagogical in various ways because it must be communicated. This claim was supported by Fernandez-Balboa and Stiehl's (1995) work to show that the traditional scholar knowledge-teacher knowledge dichotomy is problematic. Consequently, McEwan and Bull (1991) concluded that PCK is therefore not justifiable.

Marks (1990) also highlighted the ambiguities in PCK by presenting examples in which it is impossible to distinguish PCK from either subject matter knowledge or pedagogical knowledge. He claimed that those ambiguities in PCK are inherent because the concept of PCK is derived from other types of knowledge. This criticism was reiterated by Stones (1992). He regretted the way in which it had become a 'decontextualized buzz word' (1992, p. 11). Also, he stated that the term was 'of little functional help in analyzing and practicing teaching and could actually be counterproductive by isolating one aspect of pedagogical theory and practice' (1992, p. 11).

Consistent with this, Fenstermacher (1994) stated that "although Shulman and his colleagues clearly focus on the topic of teacher knowledge in ways that have deepened our understanding of the interconnections between content knowledge and pedagogical knowledge, their epistemological framing is difficult to isolate and analyze" (p. 16). He concluded that it has

both practical and formal elements, each requiring testing and justification. Fenstermacher (1994) suggested that the practical challenge be to provide "good reasons" for taking action and in support of claims for knowledge (p. 44).

Another criticism on the concept of PCK is associated with Shulman's intentions to coin the concept. Sockett (1987), for instance, criticized Shulman's article (1987) for the link between the intellectual and the political by claiming that it is possible to explicate the detailed knowledge base of teaching from the study of teachers in action. Sockett (1987) stated that Shulman's knowledge base of teaching lacks attention to context, an adequate description of the moral framework of teaching, and sufficient attention to the relationship between reason and action. He then concluded that Shulman's analysis is assessment-driven. Meanwhile, Cochran-Smith and Lytle (1990) were concerned with the lack of teachers' voice in research leading to the knowledge base of teaching.

These doubts, however, have little apparent impact on the use of PCK as a tool in research on teaching and teacher education. PCK has been used as a major organizing construct in reviews of the literature on teachers' knowledge (e.g., Borko & Putnam, 1996) and is now a commonly accepted construct in the educational lexicon. Magnusson and colleagues (1999) argued for the uniqueness and importance of PCK within science education research and teacher preparation, taking a strong stance on the existence of PCK as a separate domain of knowledge of teaching.

Recently, several research studies revealed that PCK is a central element of both teachers' practical knowledge and craft knowledge, which represent teachers' accumulated wisdom with respect to their teaching practice (e.g., Van Driel et al., 2001; Van Driel, et al., 1998). In addition, Barnett and Hodson (2000) provided evidence that PCK is one of the major knowledge domains that expert science teachers utilize. They delineated that PCK is "the professional knowledge that members of the wider society expect teachers to possess, though they are usually unaware of its subtlety and complexity" (p. 438).

### Conceptualization of Pedagogical Content Knowledge

#### Knowledge Bases for Teaching

It is widely accepted that teaching any subject is a highly complex cognitive activity in which the teacher must apply knowledge from multiple domains (Leinhardt & Greeno, 1986; Resnick, 1987; Wilson et al., 1987). In this regard, teachers obviously have diverse, somewhat idiosyncratic knowledge bases for teaching that may be continuously changing and restructuring (Calderhead, 1996). Several scholars have suggested a number of models of knowledge bases for teaching as shown in Table 1. While researchers differ in their definition of various domains of teacher knowledge, four knowledge bases for teaching have appeared: pedagogical knowledge, subject matter knowledge, pedagogical content knowledge, and knowledge of context as indicated in Table 1.

For this study, I employed those four domains of teacher knowledge, which are parallel to Grossman's (1990) perspective with some modification. Figure 1 shows an overview of knowledge bases for teaching that underlie this study. The boxes in the figure designate the major domains of knowledge for teaching and components of each knowledge domain. In order to appreciate the context specific nature of teacher knowledge, all domains of teacher knowledge are presented as embedded in the shaded context in Figure 1. The arrows that link the domains of knowledge illustrate the reciprocal influence between PCK and the other domains of knowledge. PCK is influenced by the other knowledge domains, but that the resulting PCK can stimulate development of the other knowledge domains in turn.

### Table 1

## Knowledge Bases for Teaching

_	Scholars					
Knowledge of	Elbaz (1983)	Leinhardt & Smith (1985)	Shulman (1987)	Wilson, Shulman, & Richert (1987)	Tamir (1988)	Grossman (1990)
Self	0					
Educational goals & Objectives	0		0	0		
Subject Matter	0	0	0	0	0	0
Curriculum	0	0	0	0	0	
Instruction	0	(lesson structure)				
РСК			0	0	0	0
Context (Students)			Т	S	S	0
Pedagogy			0	0	0	0
Other Content				0		

#### S: One knowledge domain: knowledge of students

T: Two separate knowledge domains: knowledge of context & knowledge of students

Although I categorized these units within a larger domain called teacher knowledge, it does not mean that the categories represent an actual storage system in teachers' minds. Instead, I perceive the categories of teacher knowledge as "a heuristic device for helping us think about teacher knowledge" (Borko & Putnam, 1996, p. 677). Moreover, I agree with Borko and Putnam's (1996) caution against conceptualizing teachers' knowledge as being organized into abstract, isolated, discrete categories. Rather, teacher knowledge is richly contextualized and embedded in the practice "from which it arose and in which it is used" (p. 677).



Figure 1. Knowledge bases for teaching. [Modified from Grossman (1990)]

While Shulman (1987) used the term "content" knowledge, I prefer "subject matter" knowledge because the knowledge actually encompasses both the substantive (content) and the syntactic (process) components of a given discipline (Schwab, 1964) as Tamir (1988) suggested. Pedagogical knowledge refers to knowledge about teaching. This domain of knowledge includes knowledge of learners and learning, knowledge of classroom management, knowledge of instruction and curriculum, knowledge of assessment, and knowledge of educational goals. Knowledge of context includes knowledge of the nation, states, and districts in which teachers work including expectations and constraints posed by them, knowledge of school settings, and knowledge of communities and students including the students' backgrounds, families, particular strengths, weaknesses, interests, and ability levels. PCK is a form of teacher knowledge and is distinct from other forms of knowledge. In general, PCK refers to teachers' interpretation and transformation of subject matter knowledge in the context of facilitating student learning (Van Driel et al., 1998). Several studies have shown that a lack of subject matter knowledge (e.g., Smith & Neale, 1989) and a lack of pedagogical knowledge (e.g., Marek, Eubanks, & Gallaher, 1990) have been linked to the ineffective use of subject-specific strategies. This implies that the development of PCK requires drawing upon knowledge from each of the other domains of teacher knowledge. Along this line, I operationally defined PCK as knowledge developed in combination with two or more of the other knowledge bases for teaching in this study. In the next section, I conceptually define PCK.

## Conceptions of Pedagogical Content Knowledge

There is no agreed-upon definition of PCK, and the inconsistency of the definitions may be explained by the research agendas from which they arise. There are many definitions, each pointing to a different quality, characteristic, context, attribute, behavior, etc. It is the high level of specificity of PCK with respect to students' characteristics, subject matter, contexts, and pedagogy (Cochran et al., 1993) that makes defining PCK more challenging. Consequently, PCK is seldom clearly defined or used explicitly as a conceptual tool in the field of science education. In this section, I set forth a comprehensive working definition of PCK for this study drawn from the literature on PCK in the fields of both teacher education and science education.

The term, PCK, originated with Shulman's 1985 presidential address to the American Educational Research Association. Shulman (1986) defined PCK as a particular form of content knowledge that "goes beyond knowledge of subject matter per se to the dimension of subject matter knowledge *for teaching*" [emphasis in original] (p. 9). PCK is "a particular form of content knowledge that embodies the aspects of content most germane to its teachability"
(Shulman, 1986, p. 9). The key components of PCK include understanding of the ways of representing subject matter that make it comprehensible to others on the one hand and understanding of specific learning difficulties and student conceptions on the other (Shulman, 1986). In a later article, Shulman (1987) included PCK in what he called "the knowledge base of teaching," stating that PCK is of special interest because "it identifies the distinctive bodies of knowledge for teaching" (p. 8). Accordingly, PCK has been regarded as a particular body of knowledge that distinguishes those who expert subject matter "teachers" from expert subject matter "knower" (Berliner, 1986, pp. 9-10).

Since the inception of PCK by Shulman (1986), a growing number of scholars have worked on the concept (e.g., Cochran et al., 1993; Geddis et al., 1993; Grossman, 1990; Marks, 1990; Magnusson et al., 1999; Wilson et al., 1987). Some of these scholars tried to redefine PCK by modifying Shulman's (1986, 1987) definition. In a case study investigating pre-service teachers' PCK, for example, Geddis and colleagues (1993) defined PCK as knowledge that plays a role in transforming subject matter into forms that are more accessible to students. Carter (1990) reviewed literature on teacher knowledge and concluded that PCK is what teachers know about their subject matter and how they transform that knowledge into classroom curricular events. Magnusson and colleagues (1999) perceived PCK as a teacher's understanding of how to help students understand specific subject matter.

Taken together, it is transformation of subject matter knowledge for the purposes of teaching that is at the heart of the definition of PCK, though the definition of PCK varies according to different scholars. In other words, it is commonly believed that PCK is an adaptation of subject matter knowledge for pedagogical purposes through a process Shulman (1987) called "transformation," Ball (1990) labeled "representation," Veal and MaKinster (1999)

termed "translation," Bullough (2001) regarded as "professionalizing," and Dewey (1902/1983) referred to "psychologizing."

Another common way of conceptualizing PCK is to identify the components constituting PCK and view PCK as an integration of those components. Table 2 summarizes the conceptualizations of PCK of various scholars. Grossman (1990) expanded somewhat on Shulman's (1987) concept by defining four central components of PCK: (a) knowledge and beliefs about the purposes for teaching a subject, (b) knowledge of students' understanding, conceptions, and misconceptions of particular topics in a subject matter, (c) knowledge of curriculum and curriculum materials , and (d) knowledge of instructional strategies and representations for teaching particular topics.

Marks (1990) also broadened Shulman's (1987) concept by including knowledge of subject matter per se and as well as knowledge of media for instruction. Based on the results of his empirical study, Marks (1990) asserted that PCK included knowledge that is not so much the modification of subject matter knowledge in light of pedagogical concerns as the application of general pedagogical principles to particular subject matter contexts. He refers to this PCK as content-specific pedagogical knowledge. This point has been supported by several scholars (e.g., Sanders, Borko, & Lockard, 1993; Tamir, 1988) who used the term, content (subject matter) - specific pedagogical knowledge, instead of PCK. Sanders and colleagues (1993), for example, stressed the supporting function of general pedagogical knowledge, and thus interpreted PCK as a specification of pedagogical knowledge rather than a more highly resolved vision of subject-matter knowledge of specific topics and general pedagogical knowledge.

# Table 2

# Components of Pedagogical Content Knowledge from Different Conceptualizations [Extended

	Knowledge of								
Scholars	Purposes for Teaching a Subject Matter	Student Understanding	Curriculum	Instructional Strategies and Representations	Media	Assessment	Subject Matter	Context	Pedagogy
Shulman (1987)	D	0	D	0			D	D	D
Tamir (1988)		0	0	0		0	D		D
Grossman (1990)	0	0	0	0			D		
Marks (1990)		0		0	0		0		
Smith & Neale (1989)	0	0		0			D		
Cochran, DeRuiter, & King (1993)		0		Ν			0	0	0
Geddis, Onslow, Beynon, & Oesch (1993)		0	0	0					
Fernandez- Balboa & Stiehl (1995)	0	0		0			0	0	
Magnusson, Krajcik, & Borko (1999)	0	0	0	0		0			
Morine- Dershimer & Kent (1999)	0	0	0	Ν		0	0	0	0

from Van Driel, Verloop, & De Vos (1997)]

D: Author placed this subcategory outside of PCK as a distinct knowledge base for teachingN: Author did not discussed this subcategory explicitly (Equivalent to blank but used for emphasis)

O: Author included this subcategory as a component of PCK

Cochran and colleagues (1993) defined PCK as "the manner in which teachers relate their pedagogical knowledge to their subject matter knowledge in the school context, for the teaching of specific students" (p. 1). Based on a constructivist view of learning and teaching, they renamed PCK as pedagogical content knowing (PCKg) to acknowledge the dynamic nature of knowledge development. This perspective emphasizes that PCK is more knowing in action as an active process rather than a set of knowledge bases in combination. PCKg is defined as "a teacher's integrated understanding of the four components of pedagogy, subject matter content, student characteristics, and the environmental context of learning" (p.266). Ideally, PCKg is generated as a synthesis from the simultaneous development of these four components.

In a study examining the generic nature of PCK among college professors, Fernandez-Balboa and Stiehl (1995) expanded Shulman's (1986, 1987) conceptualization of PCK to mean "something that all those who communicate ideas to others must have" beyond something that only good teachers have (p. 294). The results of their study suggested five generic PCK components: knowledge about (a) the subject matter, (b) the students, (c) numerous instructional strategies, (d) the teaching context, and (e) one's teaching purposes (Fernandez-Balboa & Stiehl, 1995).

To summarize, it appears that researchers have elaborated and expanded on Shulman's (1986, 1987) concept mainly by identifying the constituent components based on their beliefs or the findings from empirical studies. Among scholars, differences occur with respect to the components they integrate in PCK, and to specific labels or descriptions of these components. However, most scholars agree on Shulman's (1986) two key components of PCK: (a) knowledge of instructional strategies incorporating representations of subject matter and understanding of specific learning difficulties and (b) student conceptions with respect to that subject matter (see Table 2).

Finally, reviews and analysis of the literature on PCK contribute to a comprehensive working definition of PCK for this study: PCK is teachers' understanding of and their enactment of how to help a diverse group of students understand specific subject matter using multiple instructional strategies, representations, and assessments while working within the contextual, cultural, and social limitations in the learning environment. By this definition, PCK consists of two dimensions: understanding and enactment.

#### Components of Pedagogical Content Knowledge for Science Teaching

Along with the working definition of PCK, I conceptualized PCK for science teaching as consisting of five components drawn from the work of Grossman (1990), Tamir (1988), and Magnusson et al. (1999). They were as follows: (a) orientations to science teaching, (b) knowledge of students' understanding in science, (c) knowledge of science curriculum, (d) knowledge of instructional strategies and representations for teaching science, and (e) knowledge of assessments of science learning. Figure 2 depicts these components and the relationships among them. Although they are not mutually exclusive, it is conceptually useful to regard them as distinct components.

In order to emphasize the interrelatedness and integration among the components, I represented them in a pentagonal form with PCK at the center. This implies that the development of one component may simultaneously encourage the development of others, and ultimately enhance PCK. However, PCK that comprises effective teaching requires the integration of all the components in highly complex ways. It is only when teachers are able to integrate all the components of PCK and apply them at the right time for the right students in the right context that effective teaching will occur (Fernandez-Balboa & Stiehl, 1995). Thus, lack of coherence among components can be problematic in developing PCK and increased knowledge of a single component may not be sufficient to stimulate change in practice.



Figure 2. Pentagon model of pedagogical content knowledge for science teaching.

However, this model is not exhaustive. It is a product of the literature review combined in a synthesis with personal experience and discussion. In beginning the actual research, I used this model as a conceptual basis for the study. Actually, as I learned about the enactment and possession of PCK by teachers through this study, I had to both reconsider or redefine the components of PCK and add a new component in the model. As a result, the hexagon model of PCK was developed. What follows is the description of each component of PCK represented in the pentagon model. In order to better convey the emergence of the findings occurred, discussion about the new component and hexagon model will be conducted in the Findings Chapter.

*Orientations to teaching science*. This component refers to teachers' beliefs about the purposes and goals for teaching science at different grade levels (Grossman, 1990). The

significance of this component is that these beliefs serve as a concept map that guides instructional decisions about daily objectives, student assignments, the use of particular curricular materials and instructional strategies, and assessment of student learning (Borko & Putnam, 1996). Research has documented that teachers resist the opportunity to implement innovative teaching approaches or curriculum materials that contradict their beliefs about the purpose of teaching a subject and how that subject should be taught (Cronin-Johns, 1991; Feldman, 2002; Mitchener & Anderson, 1989; Porter & Freeman, 1986).

In shaping teachers' orientations toward teaching science, I believe that their beliefs about the nature of science play a critical role. It has been suggested that teachers' beliefs about the nature of science influence not only explicit lessons about the nature of science, but also shaped an implicit curriculum concerning the nature of scientific knowledge (Brickhouse, 1990). Hillock (1999) provided substantial evidence to show great differences in how ways of teaching amount to differences in the ways of thinking about the nature of knowledge, and in particular with regard to epistemology.

To summerize, the transformation of knowledge from other knowledge domains into PCK is not a straightforward matter related primarily to simple possession of that other knowledge. Rather, PCK includes an intentional act in which teachers chose to reconstruct their understanding to fit a situation. Therefore, PCK is influenced by teachers' beliefs about the purpose for teaching a subject at a particular grade level, which are largely shaped by their understanding about the nature of knowledge.

Magnusson et al. (1999) identified several orientations toward teaching science by reviewing related literature, which I adopted for this study: process, academic rigor, didactic, conceptual change, activity-driven, discovery, project-based science, inquiry, and guided inquiry (see Appendix A for details).

*Knowledge of students' understanding in science.* To generate appropriate explanations and representations, teachers must have some knowledge about what students already know about a topic and what they are likely to have difficulty with in learning the topic. Numerous lines of studies have shown that students' preconceptions sometimes act as impediments for scientific understanding and other times serve as building blocks toward coherent scientific knowledge (e.g., Barnett & Hodson, 2000; Driver, et al., 1994). Therefore, this component includes knowledge of students' misconceptions of particular topics, learning difficulties, motivation, and understanding of diversity in ability, learning style, interest, developmental level, and need.

*Knowledge of science curriculum*. This is teachers' knowledge about curriculum materials available for teaching particular subject matter as well as about both the horizontal and vertical curricula for a subject (Grossman, 1990). Knowledge about the horizontal curricula is demonstrated by teachers' knowledge of the goals and objectives for students in the subject they are teaching as well as the articulation of those guidelines across topics addressed during the school year. On the other hand, knowledge about what students have learned in previous years and what they are expected to learn in later years is included in teachers' knowledge about the vertical curriculum.

In addition, teachers should know the importance of various topics relative to the curriculum as a whole, which enables them to modify activities included in reference materials and eliminate ones they judged to be tangential to the targeted conceptual understandings. This understanding is defined as "curricular saliency" by Geddis and colleagues (1993). Curricular

saliency plays a pivotal role in assisting teachers to deal with the tension between "covering the curriculum" and "teaching for understanding." (Geddis, et al., 1993).

*Knowledge of instructional strategies and representations for teaching science*. This component is comprised of two categories: subject-specific strategies and topic-specific strategies (Magnusson, et al., 1999). These two categories of strategies differ in their scope. Subject-specific strategies are general approaches to science instruction that are consistent with the goals of science teaching in teachers' minds. Learning cycle (Karplus & Their, 1967; Lawson, Abraham, & Renner, 1989), conceptual change strategies (Roth, Anderson, & Smith, 1987), and inquiry-oriented instruction (Tamir, 1988) are examples of subject-specific strategies for science teaching. On the other hand, topic-specific strategies refer to specific strategies that apply to teaching particular topics within a domain of science. This category of strategies consists of topic-specific representations and topic-specific activities.

*Knowledge of assessment of science learning.* Novak (1993), drawing on Schwab, stated, "every educational event has a learner, a teacher, a subject matte, and a social environment. I would like to suggest a fifth element – evaluation" (p.54). In accordance with this, I believe that knowledge of assessment of student understandings is an important component of PCK for teaching science. This component consists of knowledge of the dimensions of science learning that are important to assess within a particular unit of study, and knowledge of the methods by which that learning can be assessed (Tamir, 1988). Teachers' knowledge of methods of assessment, both formal and informal, includes knowledge of specific instruments, approaches, or activities that can be used during a particular unit of study to assess important dimensions of science learning. There are a number of methods of assessment, some of which are more appropriate for assessing some aspects of student learning than others. In addition, every assessment device or technique has advantages and disadvantages, and employing a particular device or technique is a critical part of knowledge of assessment in science teaching.

Sources of Pedagogical Content Knowledge Development

Through this review of both empirical and theoretical research on teachers' PCK, several sources of PCK have been identified: teaching experience, professional development programs, knowledge of students' understanding, subject matter knowledge, mentors, etc. Table 3 summarizes these sources of PCK development and relevant research studies.

Although some of those studies examined the effect of professional development programs on PCK, their focus is placed on short-term workshops. Clermont et al. (1993), for example, examined how PCK of pre-service science teachers developed through participation in a short, intensive workshop on specific teaching strategies. In addition, most of the studies were carried out with pre-service teachers. As a result, there is a lack of research to investigate how inservice teachers develop their knowledge for teaching through professional development programs. Two survey studies conducted by the NBPTS revealed that the NBC process is perceived as an excellent professional development experience by candidates (NBPTS, 2001a, 2001b). Thus, it is meaningful to examine how a self-directed professional development process such as the NBC process influences teachers' knowledge development.

A comprehensive review of the literature on PCK revealed agreement about the nature of PCK development in the following areas: (a) PCK develops over time as an outcome rooted in classroom practice; (b) while teaching experience is a major source of PCK development, adequate subject matter knowledge is prerequisite for PCK development; (c) PCK development is promoted by increased understanding of students' preconceptions, learning difficulties, and

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reasoning types in a specific domain, and (d) the sources of PCK development interact in

complex ways.

Table 3

Sources of the Development of Pedagogical Content Knowledge

Sources	Scholars			
Teaching Experience	Barnett & Hodson (2000) Cochran, DeRuiter, & King (1993) Cochran & Jones (1998) Grossman (1990) Lederman, Gess-Newson, & Latz (1994) Shulman (1987) Van Driel, Verloop, & De Vos (1998) Van Driel, De Jong, & Verloop (2002)			
Knowledge of Students' Understanding	Clermont, Borko, & Krajcik (1994) Geddis (1993) Lederman, Gess-Newson, & Latz (1994) Van Driel, Verloop, & De Vos (1998)			
Subject Matter Knowledge	Grossman (1990) Marks (1990) Sanders, Borko, and Lockard (1993) Smith & Neale (1989) Shulman (1987) Van Driel, Verloop, & De Vos (1998)			
Professional Development Programs (e.g., workshops, educational coursework, professional conference, etc)	Barnett & Hodson (2000) Clermont, Borko, & Krajcik (1994) Clermont, Krajcik, & Borko (1993) Grossman (1990) Van Driel, De Jong, & Verloop (2002)			
Observation of Classes	Grossman (1990)			
Pedagogical Knowledge	Marks (1990) Sanders, Borko, and Lockard (1993)			
Previous Construction of PCK	Marks (1990)			
Mentors	Clermont, Borko, & Krajcik (1994) Van Driel, De Jong, & Verloop (2002)			
National Board Certification Process	Not found			

#### Assessment of Pedagogical Content Knowledge

There are several challenges one may encounter in assessing teacher cognition (Kagan, 1990). First, the concept of teacher cognition is ambiguous because researchers use the term to refer to different constructs including beliefs, knowledge, reflections, or self-awareness. Another salient difficulty in evaluating teacher cognition is that it cannot be assessed directly for many reasons: The cognition is frequently unconsciously held; teachers are often unable or unwilling to accurately represent it; beliefs are context-specific and connected with other beliefs (Bingham, Haubrich, White, & Zipp, 1990). Thus, it is necessary to access teacher cognition indirectly, for example, through extended interviews, stimulated recall, and observation of a teacher's performance (Haertel, 1990), and then make inferences from what they say, intend, and do. Those methods, however, are very time-consuming to develop, administer, and analyze. This is a third problematic aspect of teacher cognition. Moreover, it is difficult to determine appropriate methods for rendering comparative judgments about teacher cognition (Kagan, 1990). Those challenges also apply to the study of PCK. PCK is a highly complex construct that is not easily assessed (Baxter & Lederman, 1999).

# Concept Mapping and Card Sorting

Since Shulman (1986) introduced the term, PCK, a great number of researchers have developed various methods to assess PCK. One of the approaches commonly used is concept mapping. This method has been used to measure knowledge structures as represented by key terms and the relationships among those terms. Shulman and his students extensively used a card sorting technique. This technique basically includes concept mapping. In a card sort task, a set of cards are provided by the researcher with each card containing a particular concept, idea, principle, etc. A teacher who is a participant in the research is then asked to place the cards in an arrangement that best illustrates the relationships among the items contained on the cards.

However, both concept maps and card sort tasks have been criticized in that they are too restrictive. Each approach requires either a particular format or use of particular ideas in the representation of one's conceptual schema. Thus, a researcher only learns how the research subject views the ideas presented by the researcher or a representation that is restricted to a particular hierarchical format.

Also, concept mapping studies are inherently problematic. One of the weaknesses of concept mapping studies is that researchers typically use concept mapping to assess only short term rather than long term changes among teachers (Kagan, 1990). Researchers have not examined whether the desired changes were sustained after a particular course was completed. Therefore, concept maps are best used to measure short term changes that might be ultimately transient and of little value in understanding PCK.

Another drawback of concept mapping is associated with the assumption underlying this method that concept maps reflect the organization of information as it resides in the long term memory of the individual who drew the map. Phillips (1983) strongly opposed this assumption in that two individuals demonstrating the same performance may hold very different knowledge organized in different ways. Considering that most research has failed to validate that a concept map is an accurate representation of how knowledge is stored in memory, the ambiguity surrounding exactly what the resulting map represents is surely another concern with concept mapping. In summary, because the complexity of teachers' PCK cannot be captured by a single instrument, research designs in which only one method or instrument is applied are problematic

#### Multiple Method Evaluation

As Kagan (1990) argued, the complexity of teachers' knowledge requires more than one instrument to assess it. Accordingly, many studies of PCK have employed multiple methods. For instance, some studies used interviews in combination with questionnaires, stimulated recalls, and video/ audio taping (e.g., Van Driel et al., 2002) or structured interviews, combined with video taping and journal writing (e.g., Smith & Neale, 1989). Hashweh (1987) designed a wide array of tasks to evaluate teachers' content knowledge and general pedagogical knowledge. He found that the data he collected also provided insights into PCK. His initial goal was to evaluate teachers' knowledge of content in biology and physics and their knowledge of learning. As he explored these two types of knowledge by using a variety of techniques, however, a third type of knowledge appeared repeatedly. Hashweh (1987) found that as the teachers talked about their subjects and their teaching, they frequently introduced content-specific examples. He referred this as pedagogical content knowledge.

In order to assess teachers' subject matter knowledge, Hashweh asked teachers to do three tasks: summarize a topic, draw concept maps, and sort exam questions. He also conducted a clinical interview focused on the teachers' understanding of teaching for conceptual change to examine the teachers' conceptions of learning. He investigated the teachers' instructional planning by asking them to plan a lesson using a chapter from a science text that he provided. Finally, he asked the teachers to respond to a series of critical episodes to comprehend their view of instruction. As a result, Hashweh (1987) provided a rich view of PCK by using an array of techniques, which underlines the importance of multiple sources of data in studying teachers' knowledge. Another approach to mining rich data regarding teachers' PCK dealt with an in-service activity. Smith and Neale (1989) studied teachers' PCK in the context of an in-service program designed to support "conceptual change not only in teachers' substantive content knowledge, but also in their ideas about teaching science and their knowledge of children's ideas" (p.186). They built their program around the conceptual change model of instruction (Smith & Neale, 1989), which focused on common misunderstandings held by students. Smith and Neale (1991) worked with teachers during a four-week summer workshop and followed them during the school years as well. To monitor changes in teachers' knowledge and beliefs through the workshop, they videotaped the teachers' instruction before and during the summer workshop, interviewed them, and asked them to write journals. They triangulated the data from all three sources and carefully analyzed them.

Clermont and colleagues (1994) compared the nature of the PCK between experienced and inexperienced science teachers in teaching two selected target concepts, air pressure and density. In a summer in-service program, they used clinical interviews, videotape assignments including the critical-stop task in order to identify the teachers' PCK. In a similar vein, Van Driel et al. (2002) investigated the development of PCK within a group of pre-service chemistry teachers during the first semester of their one-year post-graduate teacher education program. The subjects in this study were 12 pre-service chemistry teachers who had obtained a Master's degree in chemistry before entering a one-year post-graduate teacher education program. For this study, Van Driel and colleagues (2002) designed a qualitative in-depth study and employed a multiple method approach. Data were collected from pre- and post-program questionnaires, interviews with pre-service teachers and their mentors, and an audio recording of a specific workshop session in the teacher education program. Given the complex nature of PCK, a multiple method approach seems to be necessary to study PCK. The assessment of PCK is difficult and fraught with hazards, as it requires evaluating all aspects of what a teacher knows, what a teacher does, and the reasons for the teacher's actions (Baxter & Lederman, 1999, p. 158). Assessment of any component of PCK in isolation from the other two incurs a significant risk of distorting meaning and interpretation. Furthermore, as Kagan (1990) stated, "the use of multiple method approaches appears to be superior, not simply because they allow triangulation of data but because they are more likely to capture the complex, multifaceted aspects of teaching and learning" (p. 459). This approach, however, is inherently time-consuming and labor-intensive.

National Board for Professional Teaching Standards Assessments

The National Board for Professional Teaching Standards (NBPTS) was established in 1987 and is supported by the US Department of Education and private funding. Its mission is to operate a national voluntary system to assess and certify teachers who meet its rigorous standards of teaching performance. The National Board's standards have been guided by five core propositions that articulate what teachers should know and be able to do (NBPTS, 2004): (a) Teachers are committed to students and their learning, (b) Teachers know the subjects they teach and how to teach those subjects to students, (c) Teachers are responsible for managing and monitoring student learning, (d) Teachers think systematically about their practice and learn from experience, and (e) Teachers are members of learning communities. In accordance with these propositions, a review study on teacher assessments (Porter, et al., 1996) showed that the NBPTS assessments place a great emphasis on teachers' knowledge of students, ability to engage students in active learning, reflective practice, and PCK. The NBPTS has developed performance-based assessments which are designed to assess not only the knowledge teachers possess, but also the actual demonstration of their skills and professional judgment as applied daily in the classroom (NBPTS, 2004). These assessments consist of portfolios including videotapes and essays, and assessment center exercises. The portfolio exercises include descriptions of the teaching and learning in the teacher's classroom, videotapes of and commentaries on the teacher's interactions with students, and examples of and commentaries on student work (Porter et al., 1996). The assessment center exercises require teachers to devise instructional plans, analyze examples of student work, view and respond to videotapes, and participate in simulations (Porter et al., 1996). In brief, this certification process is designed to engage teachers in teaching for individual student attainment (Pershey, 2001). *Validity and Reliability of the NBPTS Assessments* 

The National Board has conducted research on validity, reliability, and fairness of the NBPTS assessments. Several studies showed that the assessments in the Middle Childhood/Generalist and Early Adolescence through Young Adulthood/Art areas have acceptable content validity (Jaeger, 1996a, 1996b) and construct validity (Jaeger, 1996b). Drawing on the work of Jaeger's (1996b) study on the reliability of the NBPTS assessments, Porter et al. (1996) asserted that the assessments can be legitimately used to distinguish between accomplished teachers and other teachers.

A team of researchers (Bond et al., 2000) at the University of North Carolina at Greensboro conducted a comprehensive study to compare the teaching practices of National Board Certified Teachers (NBCTs) with those of other teachers, and to compare samples of student work from classes taught by the two groups of teachers. They found that NBCTs scored higher on all 13 dimensions of teaching expertise than did teachers who sought but did not achieve the NBC. The differences were statistically significant on 11 of the 13 dimensions. The dimensions include attributes such as having an extensive knowledge of subject matter, the ability to adapt and improvise instruction, formulating lessons that are challenging and engaging, and promoting academic achievement by emphasizing both personal accomplishment and intellectual engagement.

However, there have been doubts about accountability for outcomes of the NBPTS in terms of student achievement. Wilcox and Finn (1999) criticized the work of the NBPTS for being unconnected to student learning, stating:

Board certification focuses on input measures that are inconsistent with [states'] emphases on student and school results...teachers whose students show the most improvement on the test should be the ones rewarded, not the National Board certified teachers since there is no evidence that their students do better academically. The Board has made little effort to link its credentialing process to gains in pupil achievement- the holy grail of educational reform. (p. 188)

As a response to this criticism, Goldhaber and Anthony (2004) examined the predictive validity of the NBPTS assessments. In order to determine whether the NBPTS assessments identify and certify teachers who will raise student achievement, they analyzed 610,338 year-end test scores of North Carolina third, fourth, and fifth graders from three academic years: 1996-1997, 1997-1998 and 1998-1999. As a result, they found that students of NBCTs improved an average of seven percent more on their year-end math and reading tests than students whose teachers attempted but failed to gain the certification. This performance differential was most pronounced for younger and lower-income students whose gains were as high as 15 percent. To summerize, NBCTs, based on student achievement gains, appear to be more effective than their

non-certified counterparts, and the NBPTS is successfully identifying the more effective teachers among NBPTS applicants.

#### National Board Certification Process as a Professional Development Experience

In order to assess the impact of the certification process on teachers, the NBPTS commissioned a comprehensive research survey in early 2001. This survey investigated the effect of the assessment process on NBCTs. As a result, eighty percent of the NBCTs surveyed said that the NBC process was better than other professional development experiences (NBPTS, 2001b). Sixty-one percent said that the act of going through the process has had a greater impact on them than actually achieving the certification itself. Ninety-one percent of surveyed NBCTs answered that the NBC has affected positively their teaching practices, and eighty-three percent said that they have become more reflective about their teaching. Also, sixty-nine percent of the NBCTs surveyed reported positive changes in their students' engagement, motivation, and achievement.

In order to verify these findings, the NBPTS sent surveys in fall 2001 to candidates who recently completed the NBC process to ask their opinions about the assessment process and its impacts on their teaching practice (NBPTS, 2001a). Results from this survey are parallel to the findings from the previous survey. Ninety-two percent of candidates surveyed believe that the assessment process made them better teachers. A great number of candidates said that the NBC process enhanced teacher interaction with students and parents and helped to improve collaboration with other teachers. Most candidates (96%) surveyed also agreed that the NBC process is an "excellent," "very good," or "good" professional development experience.

However, those studies provided evidence to support the effectiveness of the NBC process through teachers' retrospective perceptions of what happened, not through real time

measurement of what "actually" happened. And this leads to the complaint that what teachers say is not always what they actually do. In addition, teachers' responses to the Likert-type selfreport surveys may be influenced by social desirability and the language used in questioning (Kagan, 1990). Due to these factors, one cannot be sure that the certification process itself "actually" made better teachers and had positive impacts on student learning.

If the NBC process itself is a procedure only to identify and reward teachers who are already accomplished, the beneficiaries of the process will be restricted to NBCTs themselves in that they may receive benefits such as financial incentives, reputation, or other probable benefits. On the other hand, if it is the case that the NBC process itself is an excellent professional development experience, thus strengthening teaching practices of the teachers participating in it, the beneficiaries of the process will go beyond the teachers themselves to the students in their classrooms. This is because improvements, achieved through the professional development aspects of NBC, in teaching practice will positively impact on students' learning. Truly, the rationale for the NBPTS assessments depends on to what extent they serve as a professional development process as well as a reward/recognition of excellent teachers. In this vein, it is vital to understand how the NBC process makes a difference in teaching practices and student learning.

#### Portfolio Creation Process and Teachers' Knowledge Development

Teachers seeking the NBC are required to put together a portfolio in accordance with the specifications given in the directions and materials developed by the National Board. The portfolio offers teachers the opportunity to sample and present their actual classroom practice over a specified time period (NBPTS, 2004). The portfolio includes student work, videotapes, written commentaries, and other teaching artifacts. The portfolio consists of several entries,

which were developed in collaboration with practicing teachers who verified their feasibility in school settings and their value as both assessment entries and vehicles for professional discussion and growth (NBPTS, 2004). Each specific portfolio entry is designed to reflect activities that teachers engage in naturally during their work. Overall, each entry asks for direct evidence of some aspect of the teacher's work and an analytical reflective commentary on that evidence.

As I argued in the introductory section, the portfolio creation process requires teachers to integrate knowledge from multiple domains. In order to complete part one of the portfolio for Adolescence and Young Adulthood (AYA) Science, for example, teachers need to apply all of the different kinds of knowledge including subject matter knowledge, pedagogical knowledge, knowledge of context, PCK, etc. (See Appendix B). Therefore, I predict that there will be a relationship found between the NBC portfolio creation process and teachers' knowledge development, especially PCK development. Though, there is, as yet, little research on this issue, this study makes positive strides toward new understandings in finding and describing this relationship.

#### Summary

Thus far I have traced the historical background of research on PCK and constructed a working definition of PCK through a review and analysis of the literature. A variety of methods to assess PCK and the sources of PCK development have been examined. The NBPTS assessment has been discussed in terms of its content, validity, reliability, and predictive relationship with PCK development. What follows is a discussion of the methodology employed for this study.

#### CHAPTER III

### METHODOLOGY

#### My Epistemological and Ontological Stance

All research is guided by basic belief systems based on ontological, epistemological, and methodological assumptions (Guba & Lincoln, 1994). These assumptions, in turn, inform the methodology of a research study and shape the interpretation of findings. Accordingly, without unpacking these assumptions and clarifying them, no one can really discern what our research has said or what it is now saying (Crotty, 1998). As this study concerns teachers' knowledge, my assumptions about the nature of knowledge, how knowledge is formulated, and how we come to achieve knowledge will inevitably influence this study in various ways. With this in mind, I will attempt to clarify my epistemological stance, i.e., "a way of understanding and explaining how we know what we know" (Crotty, 1998, p. 3) as well as my ontological stance, "a way of understanding of what is" (Crotty, 1998, p. 10).

Knowledge, I believe, is not usually passively received in an unmodified form from the environment, but is actively constructed by the knower. However, we are situated within a social context, and thus share our everyday lives with others. Therefore, social interaction helps us to construct knowledge of the world around us. In this sense, knowledge construction is processed inwardly within individuals' minds through social interaction (Driver, et al., 1994). That knowledge is constructed "socially" means that knowledge is negotiated with other members of the social context to the point that meaning is taken to be shared by interacting individuals (Gredler, 1997; Prawat & Floden, 1994). In other words, knowledge construction is the act of becoming socialized to the practices of the community within which we are embedded, its particular purposes, ways of seeing, and ways of supporting its knowledge claims. Thus, knowledge is socially constructed, communicated, and validated.

While individuals construct meaning of knowledge through social interactions, simultaneously that constructed knowledge is individually internalized. Social processes are made significant when an individual personalizes them because social practice only makes sense in light of the individual knowledge one brings to the social arena. Conversely, individual meaning making involves more than personal construction of knowledge. This is because individuals are social beings and interact with others to construct mutually shared knowledge and meaning. Knowing is drawn from the context in which it takes place. Thus, knowledge construction involves both individual interpretation and social practices (Cobb, 1994; Fosnot, 1996).

Supposing that there is a continuum from least involvement to greatest involvement of social interactions in knowledge construction, radical constructivism is placed at one end of the continuum and social constructivism at the other extreme. On this continuum, I will place my position around the middle but closer to social constructivism because I tend to favor the social view of knowledge construction. I disagree with the perspective of radical constructivism, which focuses only on the personal constructs of individuals and regards knowledge just as mental representations held by individuals (Kelly, 1997).

I do not deny the existence of an ontological world. Rather, I acknowledge realities exist regardless of whether we are conscious of them or not. The world is already there. I believe, however, we can never objectively know what that reality is actually like (Von Glasersfeld, 1984). We only know about reality in a personal and socially mediated way through our experiences within the social context. In other words, even if realities exist outside the mind of the knower, they become meaningful only when the knower makes sense of them. My ontological and epistemological stance is also supported by Crotty's (1998) assertion that constructivism and realism are compatible.

In contrast to Crotty (1998), Guba and Lincoln (1994) envisioned that the ontology of constructivism is relativism. In the perspective of relativism, all realities exist in the form of multiple, intangible mental constructions, which depend on the individual persons or groups holding the constructions (Guba & Lincoln, 1994). This is the notion that there are multiple realities, and that each of us lives in our own reality. Along this line, this view assumes that the human living world is completely artificial and socially constructed. I believe, however, what they call multiple realities should be regarded as multiple interpretations of reality. The existence of reality independent of our consciousness of it does not imply that meanings exist independently of consciousness. Therefore, the existence of a world without a mind is conceivable, while meaning without a mind is not. Taken together, I hold to realism in ontology and constructivism in epistemology.

Under those philosophical assumptions, I believe that all research is a human construction. These activities are all inventions of human minds and hence no construction can be indisputably right. The value of any particular research, thus, must rely on its persuasiveness and utility rather than its proof in arguing a position (Crotty, 1998). In this respect, I hope that my research helps people enlarge their constructions of meaning and lead to a better understanding of the constructions of others. Furthermore, I wish that my research will provide benefits to people who really need them. In particular, I want my research to inform or improve educational practice because I believe that is a major criterion in determining whether or not the research is valid.

#### **Research Design**

A multiple case study was designed for the purpose of this study. This approach evolved from the notion that detailed case studies of teaching using a variety of observational and interview procedures have frequently resulted in well documented and insightful accounts of teachers' thoughts and practices (Calderhead, 1996). In this regard, Carter (1990) suggested that case methodology be used to tap the sources of teacher knowledge and ways of thinking about learning to teach. Also, "most individuals find specific cases more powerful in their decisions than impersonally presented empirical findings, even though the latter constitute better evidence" (Shulman, 1986b, p. 32). In other words, although principles are authoritative, cases are memorable and stay in memory as the basis for later decision-making. Therefore, I believe that case studies can influence teachers' practices and thus student learning, which must ultimately be one of the purposes of educational research.

# **Participants**

The participants for this study were four experienced high school science teachers who either were participating or had participated in the National Board Certification (NBC) process. I selected the four teachers as participants of a larger study about NBC. At the time of this study, three of them (i.e., Amy, Lucy, and Jane) were going through the NBC process and taught chemistry to gifted students in either homogeneously or heterogeneously grouped science classrooms. All three teachers worked in the same high school, Chattahoochee River High School (CRHS; pseudonym), in northeast Georgia. Each of the three teachers is female and White. The other teacher, Susan, was already National Board certified and taught biology and physical science to identified gifted students in a heterogeneously grouped science classroom. Susan worked in a different high school, Oconee River High School (ORHS; pseudonym), from the others in northeast Georgia. The case of this teacher was used to elaborate the findings from the cases of the three teachers going through the NBC process. All the participants had more than 5 years teaching experience. Table 4 presents background information about the participants. A detailed description of each participant follows the table. For confidentiality, all were given pseudonyms.

Table 4

#### **Background Information of Participants**

	Amy	Lucy	Jane	Susan	
Education	B.S/M.Ed	B.S/B.Ed/M.Ed	B.ed/M.Ed/Specialist	B.S/M.S	
Science background	Physics & Chemistry	Physics & Chemistry	Biology & Chemistry	Biology	
Teaching years	21 years	11 years	8 years	10 years	
NBC	Candidate	Candidate	Candidate	NBCT (2004)	

*Amy*. At the time of this study, Amy had 21 years of teaching experience. She earned her Bachelor's degree in physical science and her Master's degree in secondary education. She started teaching with a provisional teaching certificate. When this research was conducted, she was a department head and was teaching College Preparatory (CP) and honors chemistry in CRHS. She perceived that she had strong subject matter knowledge. Two key elements she took into consideration in planning classes were students' interests and engagement. Her major goal for teaching chemistry to high school students was to help develop conceptual understanding whereby the students can connect scientific concepts with their everyday lives. She has actively participated in teacher professional development programs and National/Regional science teacher conferences.

*Lucy*. At the time of this study, Lucy had 11 years of teaching experience. She double majored in chemistry and secondary education during her undergraduate years. She was pursuing her Master's degree in science education while she was going through the National Board Certification process. She taught Advanced Placement (AP) classes right out of college and has taught AP classes and gifted classes in CRHS. She had earned an endorsement for teaching gifted students. She was confident in her science subject matter knowledge. Her major goals for teaching chemistry were parallel to Amy's (e.g., scaffolding conceptual understanding rather than acquiring factual knowledge). Lucy frequently collaborated with Amy in planning and teaching. In particular, they often cooperatively created units and implemented them in Amy's honors class and Lucy's gifted class. They actively discussed each other's teaching and provide feedback on it. One time, Amy and Lucy presented units they had co-developed at the National Science Teacher Association (NSTA) conference.

*Jane*. At the time of this study, Jane had 8 years of teaching experience. She had earned her Bachelor's degree in biological education and her Master's degree in science education. She was pursuing her Specialist degree in science education while she was going through the National Board Certification process. She was teaching CP and honors chemistry at CRHS. Like Amy and Lucy, Jane considered conceptual understanding as a primary goal for teaching science. She has been actively working for a local education association and had participated in many professional development programs. Her major interest was the use of technology in teaching science. *Susan.* At the time of this study, Susan had 10 years of teaching experience. She earned her Bachelor's in biology and her Master's degree in phytopathology. She was teaching AP and CP biology, and Advanced College Preparatory (ACP) physical science in ORHS. She is originally from South America, and she has a strong accent in her spoken English. She was National Board Certified in 2004. She believed strong science subject matter knowledge as one of her major teaching strengths. Her primary goal for teaching science was to help students relate what they learn to their everyday lives through doing science. To this end, she invited many guest speakers in the science fields to her classrooms and arranged field trips within the state or to other states. She took advantage of the facilities and human resources at the university near to ORHS to provide her students with opportunities to do science and to understand what scientists actually do.

I chose secondary school science teachers as participants of this study for two reasons. First, PCK is subject- and topic-specific knowledge, so that all arguments about PCK center on subjects. However, the role of subject is very different in elementary and secondary level schools in that subjects are a central component of secondary schools. In addition, secondary teachers are more subject-centered while elementary teachers are more child-centered (Brookhart & Freeman, 1992). Therefore, I assumed that I could obtain richer information regarding PCK with secondary teachers.

Second, it is commonly argued that adequate subject matter knowledge is necessary for PCK development as PCK concerns teaching a particular topic within a subject (Grossman, 1990; Shulman, 1987; Van Driel et al., 1998). In contrast to elementary teachers, secondary teachers have typically completed a major in their subject speciality (Ball & McDiarmid, 1990). They have also taken more concentrated content-specific course work than their elementary counterparts. Because of this, PCK would appear especially salient in secondary teachers' teaching practices.

#### Data Collection

As shown in the literature review, the assessment of PCK is very difficult, as it requires a combination of approaches that can collect information about what teachers know, what teachers do, and the reasons for their actions (Baxter & Lederman, 1999). Due to this complexity, I employed a multiple method approach by using a variety of sources of data to study teachers' PCK. The sources of data for this study included classroom observations, semi-structured interviews, lesson plans, teachers' written reflections, students' work samples, and researcher's field notes.

#### Non-Participant Observation

PCK concerns the teaching of particular topics and guides the teachers' actions when dealing with subject matter in the classroom. Accordingly, the translation of teachers' knowledge into classroom practice is clearly a critical aspect of PCK. Moreover, teachers' actions are a more accurate representation of what they know and believe than the usual array of self-report measures (Van Driel et al., 2001). Since teachers cannot verbalize all of their practice, what they know may be uncovered better from their performances than from what they say. Also, what teachers say does not always reflect what they do. Therefore, classroom observation is necessary to examine teachers' PCK.

In this regard, I observed three subject matter units for each candidate teacher for NBC using a non-participant observation method: one unit at the beginning, one at the midpoint, and one at the end of the entire portfolio creation process. For each unit, I observed at least three

lessons. With the National Board certified teacher, Susan, I observed one unit of her choice. All classroom observations were audiotaped and transcribed verbatim for later analysis.

Because it is not possible to observe everything, I, as an observer had to have a framework for observation to make manageable the complex reality observed (Patton, 1990). As a result, I set five target elements for the observations: (a) science content representations used in teaching, (b) interactions with students (e.g., linking students' prior knowledge to instruction, planning instruction based on students' ability levels, motivation, and interests, and responding appropriately to individual students while teaching, etc.), (c) classroom implementation (e.g., instructional strategies, student-centered instruction, questioning strategies, classroom management skills, etc.), (d) assessments of student learning, and (e) elaboration of subject matter knowledge (e.g., depth-topic knowledge, breadth-domain knowledge (Alexander, 2003), and flexibility).

As Blumer (1969) pointed out, data from observation contain inevitable inferences because a human observation involves a judgment of evaluation based on what is observed in the situation. Thus, clear and greatly detailed pictures of the scene are necessary in order to make observation data reliable. To this end, I made short notes at the time of observation and made expanded notes as soon as possible after each observation as Silverman (1993) recommended. Also, I recorded problems and ideas that arose during each period of observation in a reflection journal.

### Semi-Structured Interviews

Interviewing is one of the most common and powerful ways in which we try to understand the world from the subjects' points of view, to unfold the meaning of peoples' experiences, and to uncover their lived world (Kvale, 1996). Furthermore, as an interview elicits actual thoughts of research participants (Shore, 1986), it is an effective way to understand what the teachers know and why they do what they do from their perspectives. In other words, because we cannot observe everything we might want to know, interviews can provide access to the context of teachers' action (Seidman, 1998), and thereby provide a way for me to understand the meaning of that action.

In this respect, I conducted interviews with each participant as well as classroom observation. In particular, I employed semi-structured interviews through which the interviewees were able to tell "their own stories" in their own words, so that issues I had not thought of arose (Smith, 1995). As a result, during the interviews, I probed interesting emerging issues further, and adapted the interview questions to the specific context. This approach allowed me to move beyond my own experiences and ideas and to really understand the teachers' points of view.

In this study, five different types of interviews were carried out. The first-round interview was about the teachers' backgrounds and orientations to science teaching. The second- and third-round interviews were conducted in combination with observations. The second-round interview concerned planning for a class they were teaching and was conducted before observing the class. After observing the class, I interviewed the teachers about teaching that unit, and this was the third-round interview. Whenever an observation was made, second-round and/or third-round interviews were conducted. The fourth-round interview was to allow the teachers to articulate the changes in their teaching practices that occurred through the NBC portfolio creation process from their own perspective. The fifth-round interview dealt with how the giftedness of the students influenced their instructional decisions and teaching practices.

In order to develop interview questions, I created a table to encapsulate how I can come to know what I want to know (see Table 4).

# Table 5

# How Can I Come to Understand My Research Questions?

Research	What do I need to	How can I know?			
questions	know?	Possible data sources	Major interview questions		
What is the nature of PCK experienced science teachers have, as expressed in the	What is the nature of PCK?	Observation, Interviews (#1, #2, #3, #4) Written reflections, Lesson plans	<ul> <li>What is the nature of their PCK in terms of ways to represent science subject matter?</li> <li>What is the nature of their PCK in terms of ways to interact with students?</li> <li>What is the nature of their PCK in terms of teaching strategies, classroom activities, or classroom management skills?</li> <li>What is the nature of their PCK in terms of ways to assess student learning?</li> <li>What is the nature of their PCK in terms of the depth and broadness of their subject matter knowledge?</li> </ul>		
NBC process?	What are the sources of their PCK?	Student work samples, & Field notes	<ul> <li>How do you learn the ways you interact with students?</li> <li>How do you think students learn science concepts?</li> <li>How do you learn how students live?</li> <li>How do you learn what students like or dislike?</li> <li>How do you learn about students' prior knowledge?</li> </ul>		
	How do the teachers characterize students' giftedness?		- How would you characterize gifted students you have taught? (cognitive, affective, and social aspects)		
In what ways does the giftedness of students influence teachers' PCK, as expressed in the NBC process?	How is the teachers' understanding of students integrated into their practices?	Observation, Interviews (#1, #2, #3, #5), Written reflections, Lesson plans, Student work samples (including interview about	<ul> <li>How would you change the unit if you were to teach gifted class (honors class, CP class, or AP class)? Why?</li> <li>What do you think makes science difficult for students? How would you help the difficulties students have in learning science?</li> <li>What kinds of students' misconceptions associated with this unit have you noticed?</li> <li>How would you help them correct the misconceptions?</li> </ul>		
	How is the teachers' understanding of giftedness integrated into their practices?	student work samples), & Field notes	<ul> <li>What are instructional challenges you encountered, which were caused by unique characteristics of gifted students? How did you handle those challenges?</li> <li>How do you take into consideration the characteristics of gifted students in your teaching?</li> </ul>		

Research questions	What do I need to know?	How can I know? (Possible Data sources)	Major interview questions
How does the NBC process influence on the teachers' PCK development?	In what aspects of teaching do the teachers make changes through the NBC process? How does the NBC process influence the changes?	Observation, Interviews (#2, #3, #4), Written reflections, Lesson plans, Student work samples, & Field notes	<ul> <li>Have you recently made any changes in ways that you represent science subject matter? If so, why? How has the NBC PCP influenced the changes?</li> <li>Have you recently made any changes in ways that you interact with students? If so, why? How has the NBC PCP influenced the changes?</li> <li>Have you noticed any changes in student performance on this unit since your involvement with NBC?</li> <li>Have you made any changes in teaching strategies, classroom activities, or classroom management skills recently? If so, why? How has the NBC PCP influenced the changes?</li> <li>Have you recently made any changes in ways that you assess student learning? If so, why? How has the NBC PCP influenced the changes?</li> <li>Have you recently experienced that your subject matter knowledge is deepen or broaden? If so, why? How has the NBC PCP influenced the changes?</li> </ul>

The table consists of three parts: (a) research questions, (b) what do I need to know to answer the research questions? and (c) how can I know what I need to know? Under the "how can I know" column, I listed both possible data sources and major interview questions. By using the given research questions as a backbone, I developed all the interview questions for the five interviews (see Appendix C).

For Susan, I asked the same questions as used with the other teachers in a retrospective way. Once the interviews were scheduled, I sent possible interview questions to the participants a few days prior to the interviews to help them become familiar with the questions and to encourage them to begin contemplating possible responses. All interviews were audiotaped and transcribed verbatim for later analysis. The entire observation and interview procedure with each participant is summarized in the tables in Appendix D. The tables include the date each observation or interview was conducted, what kinds of data were collected at that date, and how each observation or interview was indicated in the text of this study.

#### **Other Data Sources**

Lesson plans, students' work samples including assessments were collected as data sources. Moreover, I asked the teachers to write reflections on their teaching, which they might include in their NBC portfolios. I recorded field notes by hand during and right after each classroom observation. In addition, I wrote a reflective journal throughout the research process. The entire data collection procedure is summarized in Appendix D.

Description of Research Context

#### **Research Sites**

This study was conducted in two school sites: Chattahoochee River High School and Oconee River High School.

*Chattahoochee River High School (CRHS).* The Chattahoochee River high school is one of the Lanier County public schools. Located in the northeast portion of metropolitan Atlanta, the Lanier County school system is comprised of 94 schools: 60 elementary schools (grades pre-K to 5), 17 middle schools (grades 6-8), and 17 high schools (grades 9-12). Among the students in Lanier County, more than 100 languages are spoken. Diversity is greatly increasing. Lanier County developed its own curriculum and assessment system for grades K-12 called the Academic Knowledge and Skills (AKS). The AKS for each grade level (or subject area at the high school level) spells out the essential things that students are expected to know and be able to do in that particular grade or subject.

The student enrollment of CRHS as of October 7, 2003 was 3,556, of which 66.2 % were White, 13.1 % African-American, 11.2 % Asian/Pacific Islander, 7.8 % Hispanic, 1.6 % multiracial, and 0.1 % American Indian/Alaskan Native. Approximately 13.98 % of the students enrolled in the 2005 academic year were eligible for free or reduced cost meals, which was lower than the Georgia state average of 34.0 %. The average Scholastic Achievement Test (SAT) score of CRHS was 1047 in 2004, which was slightly higher than the state average, 987. The passing rates of the Georgia High School Graduation Test for grade 11 were 98 % in English/Language Arts and 99 % in mathematics in 2003. CRHS's graduation rate was 80.5 % in 2004.

CRHS offers instruction in 18 AP subject areas. In addition, CRHS provides gifted education programs for students who are identified and placed in gifted education based on criteria established by the Georgia General Assembly and the Georgia State Board of Education. A student's eligibility for gifted education is evaluated in four areas: mental aptitude, achievement, creativity, and motivation. The science department of CRHS consists of 25 teachers and offers AP, Honors, gifted, and CP science classes.

The median family income for the city where CRHS is located is \$89,905, which is much higher than the state average of \$46,703. The population of the city has grown by 485.0 % since 1990. In particular, the influx of Asian and Hispanic immigrants is the most rapidly increasing population segment.

*Oconee River High School (ORHS).* The Oconee River High School (ORHS) is one of the Herrick County public schools. Located in North Georgia, the Herrick County school system is comprised of 20 schools: 13 elementary schools (grades pre-K to 5), 4 middle schools (grades 6-8), and 3 high schools (grades 9-12). The student enrollment of ORHS as of October 7, 2003 was 1,591, of which 58.8 % were African-American, 28,7 % White, 2.8 % Asian/Pacific

Islander, 8.0 % Hispanic, and 1.7 % multi-racial. Approximately 48.88 % of the students enrolled in 2005 academic year were eligible for free or reduced cost meals, which was higher than the Georgia state average of 34.0 %. The ORHS does not provide gifted education programs.

The average SAT score of ORHS was 968 in 2004, which was slightly lower than state average, 987. The passing rates of the Georgia High School Graduation Test for grade 11 were 93 % in English/Language arts and 92 % in mathematics in 2003. ORHS's graduation rate was 53.0 % in 2004. The science department of ORHS consists of 11 teachers and offers AP, CP, and Advanced College Preparatory (ACP) classes in biology, physical science, ecology, and oceanography.

The median family income for the city where ORHS is located is \$26,326, which is much lower than the state average as a whole, which is \$46,703. The population of the city has been grown by 20.0 % since 1990. A major employer in this city is a large university some of whose faculty and students send their children to the public schools. Though not always the most privileged economically, children in Herrick County are afforded many educational benefits due to the proximity of the University.

#### Instructional Contexts

*Amy's honors chemistry class*. This course was introduction to the study of matter and energy. This class consisted of 24 students in Grade 10, whose ages ranged between 15 and 17. Ten students were male and fourteen are female. Among them, approximately fourteen students were planning to major in science in college. None of the students were in special education including ESOL (English Speakers of Other Languages), and about one third had been in gifted programs at one time and another. Very few had jobs that interfered with studying, but 18 students played in an organized sports league. Seven out of 24 spoke languages other than
English at home (e.g., Armenian, Spanish, Cantonese, Korean, and Swedish). There was only one African American student. According to the results of the multiple intelligence test that Amy administered to understand her students' learning styles, the bodily-kinesthetic style dominated (18 out of 24). Amy's classroom had seven lab tables, one back demonstration table where she put out chemicals/specialty items for student use, multiple references, and a computer work station with Internet access for student use.

*Amy's CP chemistry class.* This course was introduction to the study of matter and energy. This class consisted of 29 students in Grades 10 through 12, whose ages ranged between 15 and 18. Ten out of 29 students spoke other languages than English at home (e.g., Chinese, Pakistani, Vietnamese, Philipino, Yoruba, Spanish, Indian, and Romanian). The class contained 7 African Americans. Although a few students wanted to major in science, most had other career interests. None of the students were in special education programs, but one student was in the ESOL program. According to the results of the multiple intelligence test that Amy administered to understand her students' learning styles, the majority of the students learned best by doing.

*Lucy's gifted chemistry class.* This course was introduction to the study of matter and energy. This class consisted of 18 students in Grade 10, whose ages ranged between 15 and 17. Ten students were female, and eight were male. All were college bound and English proficient, though five spoke another language at home. Eight out of 18 were Caucasian, two were African-American, four were Indian, and two were Korean. Students in this class had to complete an independent science research project. It became evident that the students in this class knew each other well because some of them had been grouped in gifted classes for years. The multiple intelligence test revealed that many students had a blend of body-kinesthetic and linguistic intelligences, while some were logical-mathematical. Although all students were gifted, three students had ADHD. Lucy's classroom had seven well-equipped lab tables, one back demonstration table, and a computer work station with Internet access for student use. Her classroom included an LCD projector to display student computer presentations on an overhead screen. Lucy's classroom was connected with Amy's classroom through a preparation room, which both share.

*Lucy's AP chemistry class*. This course was equivalent to introductory college chemistry. This class was composed of 10 females and 4 males, whose ages ranged between 16 and 18. All were college bound and English proficient, though six spoke another language at home (e.g., Chinese, Hindi, and Korean). Although most of them were identified gifted students, there were two students who were diagnosed with ADHD or OCD (Obsessive-Compulsive disorder). Many of them participated in clubs and academic teams, and four had part-time jobs. Because seven out of fourteen were interested in pharmacy and other medical fields, Lucy often used medical examples in this class

*Jane's CP chemistry class*. This course was introduction to the study of matter and energy. This class consisted of 26 students in Grade 10, whose ages ranged from 15 to 17. The number of male and female students was even. None of the students were in special education including ESOL, and five students had been in gifted programs at one time or another. Fourteen out of 26 were Caucasian, three were African American, three were Asian, three were Hispanic, two were Black Caribbean, and one was Indian. Over 25 % of them spoke languages other than English at home. For all but one of the students, this course was the students' first time taking chemistry. Overall, the students struggled academically and about 60% of them had come in for additional help after class. One student had an attention problem due to an inability to focus for extended time, and two students had behavioral issues including excessive talking. Jane's classroom had eight lab tables including one larger back lab preparation/demonstration table, which was utilized as the eighth station to allow for more student involvement. One student computer workstation was also available. The science computer lab, consisting of enough computers for each student to have his/her own, was just across her classroom, so that she could frequently use the computer lab for her classes.

Jane's honors chemistry class. In this course, the study of matter and energy were explored in greater depth and with greater emphasis on mathematics than the college preparatory curriculum. The class consisted of 25 sophomores and one junior, ranging in age from 15 to 17 years. Two were African American, two were Asian, two were Latin American, one was Arabic, one was Indian, and the rest of them were Caucasian. Three of these students only spoke their native language at home. None of the students was in special education or ESOL classes. Approximately half of them had been in the gifted program. The parents of the students in this class were very involved in their children's education and were primarily of middle to high socioeconomic status. Most students tended to like history and language arts over science and math; however, students had behavior problems which resulted in long absences, and one student was highly unmotivated. About half of the class preferred to learn while doing, instead of through listening, reading, or writing.

### Teaching Units Observed

*Statue unit*. This unit was for Amy's honors chemistry and Lucy's gifted chemistry class. Students received a scenario in which they were chosen to be on the Board of Directors for the new and fictitious Worth Museum of Art and Science. One of the students' jobs was to choose one of the four statues to go outside of the new museum based on scientific evidence. The four statues consisted of different elements in different designs. The figures below are reproduced exactly from the teachers' instruction to the students. Additional information regarding each statue's size and design, each element's volume, etc. was also given to the students.



Statue 1Statue 2Statue 3Statue 4

Students were asked to make a decision on which statue would be feasible and longest lasting based on chemical and physical properties of the elements that constituted the statues. In order to understand each element's chemical and physical properties, the students designed and conducted a series of scientific experiments on samples from the elements. They then needed to make a written recommendation on their choice based on scientific data they gathered and they presented it using a PowerPoint presentation. This unit was planned for 6 to 7 class periods.

*Pottery unit*. This unit was for Amy's honors chemistry and Lucy's gifted chemistry class. This unit consisted of four inquiry labs: Clay tile lab, glaze lab, chemical bonding lab, and pottery forgery lab. In the clay tile lab, students measured the amount of water in clay and made tiles. They were expected to learn the concepts of percent composition, the mole, and hydrates through the clay tile lab. Next, students made glazes for the tiles with base glaze and seven different chemical colorants, and investigated how different glazes react to the heat in a pottery kiln. The chemical bonding lab was an inquiry lab to determine properties of ionic and covalent compounds. Students were then asked to create a painting/drawing/cartoon that exhibits the differences/similarities between covalent and ionic bonding. In the pottery forgery lab, students identified which vase is a forgery using electron configurations and atomic structure. *Mendeleev Manor unit.* This unit was for Amy's and Jane's honors chemistry, and Lucy's gifted chemistry class. This 6 week unit was developed to teach chemical reaction by inquiry. In this unit, students were expected to learn stoichiometry involved in chemical reactions and problem solving skills through a real life lab scenario. The scenario involved a town, Mendeleev Manor, established by Granny DeMole. Granny DeMole had passed on and left her last will and testament challenging each student to determine why her town was mysteriously abandoned in 1988 and to recover her favorite metals (copper, silver, zinc, and gold) from the town. To solve these problems, the students were given a packet of information that includes: Granny's notes, a map of the town, the last issue of the town's newspaper (Mendeleev Muse), a copy of Granny's will, a metal file from Finster's escape from prison, 2 pennies from the town mint, a piece of copper wire from the copper mine, and a chunk of copper (II) sulfate from the copper mine.

The student who figured out the mystery and isolated the most and purest metals received a Mole of play money dollars. Students were to use their prior knowledge of properties of matter, types of chemical reactions, and molar relationships of balanced equations, to determine where the metals were in the town, and to isolate them from most reactive to least reactive. In the end, students determined that the town was abandoned because of leaching from the copper mine. Sulfuric acid was used to recover copper in copper mining and which placed acid in the town stream Vitriole. The table below describes the major activities students conducted in this unit.

The activities were organized in the order of complexity of the reaction and the stoichiometric calculation. The amounts of each metal that each student collected were recorded in a chart with a degree of purity rating. Each student received clever points for clever lab ideas or research ideas relating to this scenario.

### Table 6

## Major Activities of the MendeleevManorUnit

Activities	Target concepts	Student product	
1. Cu lab: Isolating Cu from CuSO <sub>4</sub>	Discovery of stoichiometry, reaction rate, separation, % yield	Lab design, Cu	
2. Zn lab: Isolating Zn from penny	Stoichiometry, molarity, solubility, % yield, excessive reactant	Zn, PowerPoint	
3. Ag lab: Isolating Ag from AgNO <sub>3</sub>	Stoichiometry, molarity, solubility, limiting reagent, % yield	Lab design, Ag	
4. Gold lab: Investigating "Au" pennies, culminating activity	Stoichiometry, molarity, solubility, limiting reagent, % yield, Law of conservation of mass, using properties to ID chemicals	Brass pennies, essay	

*Crime unit*. This unit was for Lucy's AP chemistry class. The lab scenario given to students involved five unknown compounds from the scenes of seven murders that the State Bureau of Investigation was trying to solve. The Bureau enlisted the help of the students in CRHS to identify the unknown compounds. Each lab group was given two days to design and conduct three tests including at least one quantitative test to identify their compounds. At the second day of the lab, the State Bureau of Investigation provided students with a narrowed list of compounds including seven chloride salts, two organic acids, and sucrose and offered a suspect list. Students then had to decide the identify of their compounds and research common use for their compound to link to a suspect. The list of suspects was as follows.

1. Pete Hasselhoff - Manager aquatic sports and tanks

2. Alton Green - Pastry chef

- 3. Doris Nightingale Cardiac nurse
- 4. Ted Vlasic Pickle maker

## 5. Avey Molar - Dentist

6. Marie Crick - Biotechnician specializing in isolating RNA & DNA

7. Lemony Picket - Citrus grove owner

*Six substances found on planet earth unit.* This unit was for Amy's college preparatory class. This unit was developed to provide students with an opportunity to apply the concepts they learned such as chemical reactions, stoichiometry, solutions, acids/bases, kinetics, equilibrium, and gases in order to draw logical conclusions about the given issues. The unit consisted of three parts. Each part involved small group discussion first and then whole group discussion second.

Part 1: The students were given 6 containers and told to discuss in small groups whether or not these were heterogeneous or homogeneous and support with observations. If they chose homogeneous, they had to further decide if it was an element, compound, or mixture. Last, they had to guess the identity. (Bag A: clay, Bag B: a homogeneous liquid (oil, syrup, soap, or urine), Bag C: an element, Bag D: a compound, Bag E: copper, and Bag F: sugar, salt, or sand)

Part 2: Students were asked to go back to their small groups and determine: Bag B (liquid) - Suggest substances that the liquid might be and determine one or more tests to prove or disprove your suggested substances.

Bag C (element) - Determine if the element is a metal or nonmetal.

Bag D (compound) - Determine if the compound is ionic or covalent.

Bag E (copper) - Prove that this brownish red wire is copper.

Bag F (sand, sugar, or salt) - Determine physical/chemical tests you can do to eliminate the possibility that the white substance is sand, sugar, or salt.

Part 3: Students summarized the major findings through discussion and Amy showed how understanding properties of matter would guide the major topics of study for 2<sup>nd</sup> semester.

### Data Analysis

The data from the multiple sources were analyzed through three different analysis approaches: (a) constant comparative method, (b) enumerative approach, and (c) in-depth analysis of explicit PCK.

### Constant Comparative Method

I first analyzed the verbal data using the constant comparative method (Glaser & Strauss, 1967) with Atlas.ti as an aid. The constant comparative method is a form of inductive analysis. Grove (1988) stated the purpose of this method is as a means to generate explicit categories which can help to provide an understanding of the data. In this regard, the data analysis focused on the identification of regularities or patterns in the statements made by the participants, without using a pre-established system of categories or codes. Accordingly, I developed categories on the basis of the data, through an interactive process during which the data were constantly compared (Charmaz, 2000; Glaser & Strauss, 1967). Charmaz (2000) suggested some points of comparison that might be considered by the analysis. These included comparisons of: (a) different people, (b) data from the same individuals with themselves at different points in time, (c) incident with incident, (d) data with category, and (e) a category with other categories (Charmaz, 2000).

Along with the constant comparative method, the data analysis procedure occurred in several steps. The first phase of the process involved "coding" the data set and "comparing" these codes. I coded observation and interview transcripts, written reflection through a process of "open coding" (Strauss & Corbin, 1990). Coding is a form of shorthand that distills events and meanings without losing their essential properties (Charmaz, 1999). Consequently, this process was to reduce data to "units of analysis" (LeCompte, 2000), "the smallest piece of information about something that can stand by itself" (Lincoln & Guba, 1985, p. 345). The units of analysis

were identified through the process of looking for frequency, omission, and declaration (LeCompte, 2000).

Next, as the units of analysis emerged, common elements, patterns, and relationships within these units were formed for each participant and across all participants. Third, these elements, patterns, and relationships were organized in categories and subcategories by comparing and contrasting them in terms of their properties and dimensions (Glaser & Strauss, 1967). Whereas "properties are the general or specific characteristics or attributes of a category, dimensions represent the location of a property along a continuum or range" (Strauss & Corbin, 1990, p. 117).

To continue, networks were created. A network is "a map of the selected [categories and subcategories] which shows how they relate to on another" (Bliss, Monk, & Ogborn, 1983, p. 8). In other words, the categories were integrated by grouping and rescanning similar categories and detecting the relationships among those categories. In this regard, the networks delimited the emerging theory by comparing properties across categories and domains in order to test the integrity of their group membership. LeCompte and Preissle (1993) called this process as theorizing.

Afterwards, negative cases that seemed not to follow the patterns and categories identified were sought in order to disconfirm or support the original theory. Finally, as new units, patterns, categories, and subcategories became scarce, the data were considered "saturated" (Glaser & Strauss, 1967), and the data analysis ended. The whole process from identifying units to forming networks was an ongoing cyclical process, one in which I as a researcher had to use my tacit knowledge and intuition in searching for look-alike, feel-alike patterns (Lincoln & Guba, 1985). The data from lesson plans, students work samples, and field notes were analyzed through the same procedure. Then, they were compared or contrasted across data sets in order to elaborate, enhance, illustrate, or clarify the results from others. All data from multiple sources were triangulated for the trustworthiness of this study (Patton, 2002).

## Enumerative Approach

In order to reduce the subjectiveness of qualitative coding and to facilitate identifying the characteristics of each teacher's PCK, I employed the enumerative analysis approach (LeCompte & Preissle, 1993). The purpose of the enumerative approach is to quantify verbal data. In order to quantify observation data, I created the "PCK evidence reporting table" (see Appendix E) based on the pentagon model of PCK. The PCK evidence reporting table consists of the five components of PCK presented in the pentagon model. For each component, sub components were developed through a comprehensive literature review.

Using those components and sub components as a pre-established set of codes, I coded the observation transcripts again with Atlas.ti as an aid. At the same time, I tallied the occurrences of each sub component in the PCK evidence reporting table. In the case that clarification was needed for coding, I referred to pre- and post-observation interviews and written reflections associated with the observation that was being coded and made notes in the margins of the PCK evidence reporting table. As the analysis proceeded, some of the components and sub components in the PCK evidence reporting table were reorganized and modified, and new sub components were added. The results from the enumerative approach were compared with and integrated into the results from the constant comparative method in order to provide methodological triangulation (Denzin, 1978).

## In-Depth Analysis of Explicit PCK

In order to promote the capture of evidence of the nature of PCK, I analyzed teaching segments that revealed PCK explicitly in depth. The teaching segments of explicit PCK were identified based on the operational definition of PCK in this study: PCK is knowledge developed in combination with two or more of the knowledge bases for teaching. When a teaching segment of explicit PCK was identified, I made a detailed description of the segment grounded in observation, pre-and post-observation interviews, written reflections, and the other data sources that were connected with the teaching segment. Then, I described the reasons for what the teachers did as well as I could know them using the relevant data. Finally, based on the holistic understanding of the teaching segment, I recorded what the teacher knew in terms of the components of PCK. An example of this in-depth analysis of explicit PCK is presented in Appendix F.

### Trustworthiness

From a constructivist perspective, in order to judge the quality of qualitative research, Lincoln and Guba (1986) suggested four alternative sets of criteria as follows:

Credibility as an analog to internal validity, transferability as an analog to external validity, dependability as an analog to reliability, and confirmability as an analog to objectivity. (p. 76)

In combination, they viewed these criteria as addressing "trustworthiness." With respect to these criteria, I used several strategies in order to enhance the trustworthiness of the study. In terms of credibility, I sent interview and observation transcripts and tentative interpretations to the participants to check for accuracy and plausibility (Patton, 2002). Negative case analysis (Denzin, 1989) was also used to establish the credibility of this study. Searching for negative cases as the

pattern was developing made me conscious of pattern limitations and incorporate these limitations into explanations and interpretations (LeCompte & Preissle, 1993).

In addition, triangulation of multiple data sources and multiple analysis methods increased dependability, confirmability, as well as credibility of this study. Triangulation of data sources involved comparing and cross-checking the consistency of information derived at different times and by different qualitative methods (e.g., interviews, observations, written reflections, lesson plans, student work samples, and field notes). The results drawn through different analysis methods (e.g., constant comparative analysis, enumerative approach, and indepth analysis of explicit PCK) were compared and integrated through triangulation of analysis methods.

The confirmability was be further enhanced by reflective journal writing. Detailed field notes contributed to building dependability. In terms of transferability, I described research context as rich and thick as I could, so that readers can determine whether the findings are transferable (Merriam, 1998; Yin, 1994).

#### Summary

In this chapter, I presented the proposed research methodology for my investigation of PCK of science teachers going through the National Board Certification process. The study employed a multiple case study design. Major data sources included semi-structured interviews, classroom observations, written reflections, student work samples, archives, and field notes. The data analysis was conducted utilizing three analysis approaches: the constant comparison method, enumerative analysis, and in-depth analysis of explicit PCK. I have also addressed ways I maneuvered to enhance trustworthiness of this study and the philosophical stance underlying this

study. Detailed descriptions of research sites, participants, instructional contexts, and teaching units were presented. In the next chapter, I present the findings of this study.

#### CHAPTER IV

## FINDINGS

In this chapter, I describe findings that are related to the PCK of experienced science teachers who are going through the National Board Certification (NBC) process. This chapter consists of three sections. First, I discuss what the nature of PCK that experienced science teachers possess is. Second, I argue how the teachers' perceptions of gifted students function as a component of their PCK. Last, I examine how the NBC process serves as a conduit for teachers to develop their PCK. All teachers' and students' names in this study are pseudonyms.

The Nature of PCK of Experienced Science Teachers

The data analysis revealed that the nature of PCK experienced science teachers was demonstrated in the following aspects: (a) PCK included the nature of both knowledge-in-action and knowledge-on-action; (b) Teacher efficacy was one of the components of PCK; (c) Students influenced the ways that PCK was organized, developed, and validated; (d) The teachers' understanding of students' misconceptions was a major factor that shaped PCK in planning, actual teaching, and assessment; and (e) PCK was idiosyncratic in some of its enactments. *PCK: Knowledge-In-Action and Knowledge-On-Action* 

PCK was manifested as a feature of knowledge-in-action which is defined as knowledge developed and enacted in the act of teaching through "reflection-in-action" (Schon, 1983, 1987). This feature was nicely captured in Jane's statement that "a lot of things I do are just reactive instead of proactive based on my prior experience in teaching a particular concept, feeding off what the students are interacting with me." In particular, this aspect of knowledge-in-action of PCK became salient in situations when a teacher encountered an unexpectedly challenging moment in a given teaching context. In order to transform the challenging moment into a teachable moment, the teacher had to integrate all components of PCK accessible at that moment, and apply them to students through an appropriate representation. Accordingly, the development and enactment of PCK is an active and dynamic process.

For example, in Lucy's class during the statue unit, students were asked to test as many chemical and physical properties of a variety of metals as they could during the lab. The students boiled, bent, hit, and did whatever they wanted to do to the metals. When students hit zinc with hammers, it shattered rather than bent as was expected. In that situation, the teacher was surprised by the outcome. Lucy noticed that the zinc was oxidized and that began to build a conjecture that its characteristics might have been significantly changed as a result. She also realized that this incident might cause students to develop misconceptions about the identifying characteristics of metals. Thus, she initiated a discussion about that incident asking, "Why do you think the zinc shattered while the other metals bent when you hit them?" She then ended up leading a discussion about differences between compounds and elements which the students would learn in a later class. After the class, Lucy reflected on that event in this way:

When they hit all the metals, most of them bent, but the zinc shattered. Well, zinc is a metal and it shouldn't shatter...I think a lot of it had kind of oxidized. So I thought that could be a teaching moment. We kind of talked about, when zinc is already in a compound, does it still have the properties of the metal? That brought that concept out. Kids are always thinking that an ionic compound because among other things it contains a metal, they think it'll have all those properties of a metal. And a lot of them think the metals could be brittle. It was

interesting to confront those misconceptions through the discussion. (Lucy, Postinterview #1)

This statement implies that Lucy actively integrated her knowledge of subject matter, science curriculum (i.e., the differences between compounds and elements following the properties of metals in science curriculum), and students' misconceptions associated with metals at the unforeseen moment, and then applied the resulting PCK to the students through discussion. Consequently, she was able to use this challenging event as a conduit to help students arrive at an understanding of the differences between elements and compounds.

What if Lucy had only subject matter knowledge about the properties of metals? She might not have developed this event as a discussion topic. She might have asserted "Zinc should not have shattered because it is a metal. This zinc must be oxidized." As a result, the students would not have had the opportunity to think about that event. On the other hand, what if Lucy had only general pedagogical knowledge? She might not have figured out what was wrong with respect to that event. Thus, it was PCK that enabled Lucy to transform the unexpectedly challenging moment into a teachable moment.

PCK was also revealed as a feature of knowledge-on-action that is knowledge developed and enacted through "reflection-on-action" (Schon, 1983, 1987) undertaken after the teaching practice is completed. Through reflection on their actual practices, teachers realize the need for expansion or modification of their planning or repertoires for the topics taught. As a result, they make new additions to, reorganize, or modify their existing body of PCK for teaching the topics. Accordingly, the development and enactment of PCK is a stable and static process. In Amy's lab about the properties of metals, the same incident that happened in Lucy's lab occurred, that is, the zinc shattered. Unlike Lucy, Amy did not mention the incident during the lab, though she noticed that it should not have happened. After the class, she reflected on the incident in this way:

One of the things I really thought about was safety in planning this unit, because the students were developing tests like heating the metals....So I gave them zinc in chunky pieces. Well, when they were doing a test to see if it was malleable, it shattered. So now they're under the mistaken impression that zinc is not malleable. So next year when I do this, what I want to do is I'll give them each metal in different forms. I thought about giving the sheet metal to start with, but those edges are so sharp. The corners of the metals are very sharp. I'll cut them. I wish I had thought about it differently. (Amy, Post-interview #1)

This statement provides a picture of how teachers reconstruct their understanding of teaching a specific topic through reflection on their teaching. Amy provided students chunky zinc because of a safety issue. However, during the class, she sensed that the chunky form caused the zinc to shatter, which resulted in students' misconceptions about zinc. After the class, Amy hammered chunky zinc and realized that the chunky piece "appeared" brittle because they had little pieces that jut out and easily broke off. Then, she hit a little zinc piece and saw it was malleable. She thought that if students had observed more carefully and taken the little pieces that had broken off, they could have seen that zinc is malleable. Reflecting on the incident, she came to reshape her lesson plan on the statue lab in a way to reconcile the conflict between safety and students' misconception. Moreover, she made an addition to her repertoire for the post lab for the statue lab in order to confront the students' misconception about zinc. She stated,

I noticed that is a misconception that is coming up, so that's something I want to work on in the post lab. They'll present their findings from the lab and discuss them in the post lab next Friday. I hope they bring up this issue. And if not, I'll bring it up. I'll say, "Guys, nobody mentioned this. Let's talk about this." (Amy, Post-interview #1)

In the post lab, no student was surprised that the zinc shattered. Amy asked the students if they expected zinc to be brittle or malleable. She showed them the chunky zinc and demonstrated to them how small pieces are malleable, though large pieces break up easily. With this result, she emphasized the importance of careful observation in the science process. She also showed strip zinc and demonstrated how malleable it is.

As discussed so far, the PCK which teachers possess consists of both knowledge-inaction and knowledge-on-action. These aspects of PCK are not mutually exclusive. Rather, they constantly influence each other either inside or outside classrooms through reflection, with the result that PCK for the topics being taught is constructed, reconstructed, and validated. As shown in Amy's example, she developed knowledge-on-action as to the zinc's malleability through reflecting on the zinc shattering event after the class. The knowledge-on-action, then, motivated her to bring up the event in the next class in which she had to sometimes respond to students' unpredicted questions. Through responding to the questions, she might improve her knowledgein-action, which might in turn foster the increase of the knowledge-on-action. As a result, both aspects of PCK impacted the PCK growth synergistically.

## Teacher Efficacy: A New Component of PCK

Through the in-depth analysis of explicit PCK, teacher efficacy emerged as a new component of PCK to be added to the five components of PCK previously shown in the pentagon model. Teacher efficacy is commonly described as a type of self efficacy pertaining to teaching and which refers to teachers' beliefs in their ability to affect student outcomes (Tournaki &

Podell, 2005). In this respect, teacher efficacy is typically considered as a comparable component of belief, not knowledge. However, Kagan (1992) viewed beliefs as a form of knowledge referring to beliefs as a "particularly provocative form of personal knowledge" (p. 65). She further argued that most of a teacher's professional knowledge can be regarded more accurately as belief.

Moreover, Nespor (1987) argued that teachers' beliefs play a major role in defining teaching tasks and organizing the knowledge relevant to those tasks. The contexts and environment within which teachers work and the problems they encounter are often ill-defined and deeply entangled (Nespor, 1987; Richardson, 1999). In order to solve those ill-defined problems, teachers need to go beyond the information contained in the problem instruction, use background knowledge, and make assumptions or decisions (Nespor, 1987). In other words, teachers have to reexamine the knowledge, which they already have, from many different perspectives. And thus it follows that this more "affective" or provocative form of knowledge is playing an important role in the reexamination.

Given that the study of this affective component was not within the original intent of the study, I have linked it most closely to teacher efficacy, and can say that in this process, teacher efficacy plays a critical role in defining problems and determining teaching strategies to solve the problems, therefore leading to the reorganization of knowledge. Taken together, it is reasonable to view teacher efficacy as a component of teachers' knowledge. In brief, teacher efficacy can be defined as a teacher's knowledge of self in terms of his or her own capability in teaching a particular subject.

In this study, PCK is defined as a construct that includes both teachers' understanding and enactment of those things that teachers do. Teacher efficacy is considered as a promoter of a teacher's movement from understanding to action (Gibson & Dembo, 1984; Raudenbush, Rowan, & Cheong, 1992; Woolfolk, Rosoff, & Hoy, 1990). It is assumed that the mere possession of understanding needed to teach is not sufficient for effective teaching. The understanding must be enacted in the specific teaching context. In this regard, teacher efficacy serves as a bridge between teachers' understanding and their enactment, and thus links these two major aspects of the body of knowledge necessary for effective teaching. Consequently, teacher efficacy can be seen as a component of PCK.

Through using the in-depth analysis of explicit PCK, 20 cases of explicit PCK were identified from the multiple data sources. Each case was then analyzed in terms of the teacher's actions, knowledge bases, and reasons for the actions. Appendix F shows an example of the analysis. As a result, in 15 cases out of 20, teacher efficacy was identified as a component of PCK (see Table 7).

#### Table 7

Orientations to science teaching	Knowledge of science curriculum	Knowledge of students' understanding in science	Knowledge of assessment of science learning	Knowledge of instructional strategies and representations	Other components (Teacher Efficacy)
19	8	19	6	18	15

*Results of In-Depth Analysis of Explicit PCK (N=20)* 

In general, teacher efficacy is an aspect of teachers' beliefs about their ability to perform the actions necessary to teach (Ross, 1994; Smylie, 1988). Jane's statement below gives a glimpse of what teacher efficacy is:

My plan book is more of yeah, I'll read some new materials, get some ideas, but for the most part I feel like I know how I'm going to teach it, how I'm going to guide them to get it. (Jane, Post-interview #1)

This statement implies that Jane believed in her ability to have students reach understanding.

Teacher efficacy is drawn from the concept of self-efficacy that evolved from Bandura's (1986) social cognitive theory. The main idea of the social cognitive theory is that individuals' perceptions of themselves mediate their behaviors. Thus, individuals pursue activities and situations in which they feel competent and avoid situations in which they doubt their capability to perform successfully (Bandura, 1997; Pajares, 1992). Along this line, when teachers believe their capability to execute their PCK effectively, the PCK will be certainly enacted in actual classrooms.

Lucy's post lab for the statue lab provided a representative example of how teacher efficacy plays a role in the enactment of PCK. In an interview conducted before the post lab, Lucy described how she would lead the class to challenge students' misconceptions associated with the properties of elements and compounds. She said,

I have some misconceptions that usually occur. There are some [misconceptions] that I think will happen [in today's class]. So I'll listen for them and if they seem to have it, but I'm not quite sure, I will ask a question that if they have the misconception that will trip them up. And I'll try to get them to think about it from a different angle so that they can correct their own misconception. I'm quite skilled in that. I'll get them correct the misconceptions. (Lucy, Pre-interview #2)

During the post lab, this perceived confidence often urged Lucy to tackle students' misconceptions and encounter any possible challenges. When a student asked whether copper

carbonate is conductive or not, she sensed that some students might hold the misconception that when an ionic compound contains a metal, it has all the properties of a metal. This was one of the common students' misconceptions she had discovered. Thus, she asked a series of questions such as whether rust would have any properties of a metal because iron was a part of the compound. In order to push students to assess whether they hold the misconception that ionic compounds never conduct electricity, Lucy initiated a discussion about conductivity, asking why iron (III) oxide did not conduct electricity as a solid compound in the past lab. Then the following discussion occurred:

S1: Ionic compounds don't conduct electricity.

Lucy: Ionic compounds don't conduct electricity and iron (III) oxide is an ionic compound, so it doesn't conduct electricity. Is this what you meant? [Yes] Okay, when are ionic compounds dissolved in water?

S2: Ionic compounds are very soluble in water because water is polar.

Lucy: What happens when an ionic compound is dissolved in water?

S2: The ions in the compound are separated.

Lucy: Then?

S2: Oh! They can conduct electricity! So, it depends.

S4: An ionic compound is going to conduct electricity when it is dissolved in water, but not as a solid. (Lucy, Observation #2)

This selection of discussion portrayed how Lucy's PCK for teaching the topic was demonstrated through her teaching. She integrated her subject matter knowledge and knowledge of student understanding and applied them to the students through an instructional strategy, questioning. In her written reflection on this lab, she described how she could affect students' understanding of the concepts:

Listening carefully to justification of lab designs and data analysis and careful questioning allowed me to detect and immediately correct any misconceptions that students may have developed. (Lucy, Written reflection)

This successful experience fostered her teacher efficacy, which was evident in the interview with her after the post lab. She said,

I got a lot of evidence I supported the kids getting correct concepts. I tried to go with them in their thinking and show them where they might have gotten off. Did it change their mind about one part of how they were thinking? Yes, I was able to correct their misconceptions. (Lucy, Post-interview #2)

From this statement, it appeared that teacher efficacy was strengthened through successful teaching experience. Research has shown that higher teacher efficacy encourages the establishment of higher professional goals and manifests as a willingness to try new teaching strategies (Berman, McLaughlin, Bass, Pauly, & Zellman, 1977; Guskey, 1988). These characteristics can subsequently lead to greater success in the classroom, which in turn stimulates higher teacher efficacy (Ross, 1995). This study cannot provide evidence that teacher efficacy affects actual teaching practices, because it is beyond the scope of this research. However, based on the previous research (e.g., Berman, et al., 1977; Guskey, 1988; Stein & Wang, 1988), it can be expected that Lucy's enhanced teacher efficacy might facilitate her acquiring and implementing new teaching strategies, which might foster her PCK and effectiveness, thereby increasing her perception of success. This suggests that teacher efficacy is likely to be linked to PCK.

However, teacher efficacy appeared to be domain specific. While Lucy manifested high level of teacher efficacy in getting students correctly directed toward a valid understanding of the concepts, she felt that she was less efficacious for having the students take notes to record what they learned. She confessed,

I often have hard time to have the kids take the notes. I don't have the skills needed to train them that way. I know they need to learn how to study to succeed

in college. But I don't think I am good at doing that. (Lucy, Pre-interview #3)

This statement suggests that Lucy's teacher efficacy in challenging misconceptions did not transfer to her belief in her ability to make students effective note takers. In other words, teacher efficacy is a specific rather than a generalized expectancy.

In a study that examined within-teacher variation in teacher efficacy, Ross and his colleagues (1996) found that teachers feel efficacious when teaching particular subject matter to certain students in specific settings, and they can be expected to feel more or less efficacious under different circumstances. This characteristic of teacher efficacy is compatible with the context and topic specific nature of PCK. Overall, teacher efficacy appears to be one of the components of PCK.

### Impact of Students on PCK

Students affected teachers' PCK development in several ways. First, when students posed challenging questions, this facilitated both deepening and broadening of the teachers' subject matter knowledge, which is prerequisite for PCK development. When teachers encounter students' questions about which they do not possess answers, the teachers feel they "need to get the answers for them. So that makes them look for things and questions that have never occurred to them" (Susan, Interview #1).

An example was captured in the middle of Lucy's crime lab. On the first day of the lab, Lucy visited each group and asked how they would design tests, how they would collect data and control for variables, and how they would use their results to identify an unknown compound. Emily's group said that they would like to use a flame test. Prior to allowing students to proceed, Lucy wanted to confirm that the students understood that a flame test showed the color of a metal ion, asking a few questions to assess their understanding. But she was surprised by one student interchange. It began when a student questioned why the color of the nonmetal anion did not interfere with the visible emission spectrum of a metal cation. Lucy replied, "That's a great question, I've never thought of it. I should figure that out." She researched the question after the class and further figured out how she can facilitate students' understanding of energy level and wavelength. She reflected on this occasion later in this way:

It was interesting that the question about anions had not come up during the flame test lab earlier in the semester. I researched it that night and was able to tell them that anions usually emit waves in the invisible ultraviolet range next day. Also, I was able to strengthen inquiry by questioning them about whether electrons in an anion might also get excited and emit energy. They had to apply knowledge of visible and invisible electromagnetic waves to pose an explanation. (Lucy, Written reflection)

This reflection makes it clear that the act of responding to challenging questions resulted in Lucy's subject matter knowledge being deepened. In addition, through researching the student's question, she was able to develop effective questions to enhance students' inquiry about energy levels and wave lengths with the result that PCK for the topic was broadened. Second, students' responses to instructional strategies such as enjoyment, learning outcomes, and nonverbal reactions affected teachers' decisions to replace, modify, or validate the strategies. In the activity called "The Crime Lab," Lucy assigned PowerPoint presentations as a means for all groups to communicate their results with each other. However, during the presentations, she sensed that students were bored as a result of both listening to presentations and giving presentations. Thus, she analyzed why students responded in that way and decided for the next school year, she would replace the PowerPoint presentation assignment with what she called "wanted posters." She wrote in her reflective journal:

I realize that if all analysis and concluding have been already done, it can feel as if they are just going through the motions to get their final grade (gag). The trick is designing a method of presenting that continues to engage kids in active and authentic inquiry. The next time I teach this I will have groups make "Wanted" posters which will include a suspect, identification of their compound, and all the supporting data/research that leads to their conclusion. (Lucy, Written reflection)

While Lucy revamped her instructional strategy, Amy validated her new strategy through students' feedback, enjoyment, and assessment of learning outcomes. Amy planned and implemented the statue unit to teach elements and compounds as an inquiry-oriented approach for the first time. In the statue unit, students were asked to make a decision on which statue is best based on the chemical and physical properties of the elements composing the statues through a series of student-designed investigations. Throughout the unit, she observed that her difficult-to-teach students actively engaged in the lab and assignments. She measured this engagement informally, but consistently found that students who did not typically become

involved in science lab activities became involved. This served for her as a validation that this new strategy worked. She described it in this way:

Those students are usually likely to rebel against assignments. But in this assignment, boom, what they gave was really what I was looking for. Those kids don't seem to shine in these kinds of labs, because they don't do every little step like the super diligent students. But, they did have a chance to shine in this lab, because they got to use their good thinking and apply it. I have a girl who is not motivated to do labs and work on routine homework. But, she came to me and said "I did a good job in lab!" with excitement. This is the power of inquiry. It worked. (Amy, Post-interview #3)

This validation enhanced her instructional decision to implement the same strategy next time, as she said in the post-observation interview: "I will keep doing this inquiry unit because that proved truly powerful to teach properties of elements and compounds."

In addition, Lucy's reflection below gives us insight into how students' learning outcomes validated teachers' teaching strategies:

I collaborated with two teachers to develop a PBL (Problem-Based Learning) unit, Mendeleev Manor, involving chemical reactions, solutions, stoichiometry, solubility, acids/bases, and electrochemistry. As a result, students not only understood how to use stoichiometry in making lab decisions much better than former classes, but could use molarity and volume in stoichiometry better than past classes when these two topics were taught consecutively and not concurrently in the context of lab. Furthermore, my students' ability to combine several chemistry concepts in class discussions and to solve lab problems convinced me that PBL was powerful. (Lucy, Written reflection)

From this passage, students' achievement appeared to be critical to the rationale of Lucy' new instructional approach.

In the first phase of the statue unit, students were given their assignment together with a grading rubric for their final PowerPoint presentations. In addition, they were asked to read selections from the text and to develop lab tests to determine the different properties of the elements that would help them choose the best statue. While students were carrying out the lab tests that they chose, however, Amy realized that some of the students had not read the text and had not made adequate connections between the reading assignments and the lab. In addition, she recognized that most students focused just on physical characteristics such as color, density, melting point, durability, and conductivity and collected quantitative data. Thus, Amy modified her original lesson plan in the following way:

I created and administered a 25- question quiz to ensure they understand the core content in the reading assignment. In the future, I'll give the students the 25 content questions to answer prior to the lab activity to ensure they get the content. Also, I'll change the rubric to include a required number of physical and chemical tests instead of leaving it open ended, so students will not focus just on physical changes. But, I'm not going to specify which ones to do. I'll also emphasize they have to collect quantitative as well as qualitative data. (Amy, Post-interview #2)

This passage implies that Amy reconstructed a few instructional strategies for the statue unit, integrating her knowledge of curriculum (i.e., what are goals and objectives in this unit), knowledge of students' understanding and learning difficulties developed through interaction with students, and knowledge of instructional strategies (i.e., the use of rubric). Given that these domains of knowledge are major components of PCK, Amy seemed to make an addition to her PCK.

Last, students' creative and critical ideas stimulated teachers' innovative ideas for future classes. In Lucy's post lab for the crime lab, she and the students were discussing why all the groups got such disparate density data for the same compound. One student, Sherry, stated that she discovered that a solid compound had different densities depending on whether it was hydrated or anhydrous, and this could be a reason for the different densities across the groups. This student's idea inspired Lucy's plan for a future inquiry lab. In her written reflection, she asserted,

I realized that Sherry's findings of different densities for hydrated and anhydrous salts would make a great inquiry lab for future classes. Students would be given a compound and have to find its density, its water of hydration (calculate percent composition and construct empirical formulas), and the density of the compound in its anhydrous form. (Lucy, Written reflection)

Without Sherry's input, Lucy might not have thought of this possible lab. As a result, her body of PCK seemed to be expanded with the idea of this future lab. In this regard, students served as a resource for teachers' PCK.

Overall, students played vital roles in determining the ways that PCK was organized, developed, and validated.

# Students' Misconceptions: A Major Factor that Shaped PCK

In the planning and actual teaching process, the teachers put priority on students' misconceptions. Accordingly, students' misconceptions primarily influenced the ways that

teachers' PCK was organized and developed. Jane summarized how she prioritized students' misconceptions in planning lessons as follows:

Uncovering first their misconceptions, seeing where they are in the concept is first before I try to teach them. Then I use several ways I like to do, which are repetition, verbal, hands on. In particular, repetition, the kids are all coming at me at different rates of learning, different misconceptions so that the more repetition they do and they get stuck, I see what those misconceptions are. (Jane, Interview #1)

Jane's statement was often evident in her planning, teaching, and reflection. In an interview conducted before the class on atomic structure, she expressed her concern about possible students' misconceptions related to this topic:

I'm afraid they don't realize just how small the nucleus is in relation to the rest of the atom. The electron, you know, [has] very little mass, but is zipping around all over the place in a very large area of space, how it's a cloud. And then when we on the board just draw it nice and rigid like it's a circle, I'm afraid that's what they think. So those are probably the biggest misconceptions at this point that they're probably having. (Jane, Pre-interview #1)

This concern stimulated her to develop a simile to explain electron configuration. In the class, her plan was enacted in this way:

When we talk about an electron cloud, I want you to envision like a fan. When a fan is turned on, the blades are going so fast, you can't tell exactly where the blade is at a particular time. It just looks like it's everywhere. It's the same way with the motion of the electrons. They're moving around so fast, it's hard to pinpoint its location. (Jane, Observation #1)

Right after this explanation, a student asked a question, "Are electrons circling around the nucleus?" From this question, Jane noticed that the simile of a fan spinning led students to the misconception that electrons were circling like planets around sun. Thus, she introduced an analogy to make sure that we can never be certain of an exact route or position for an electron:

I'm going to use you as an example for trying to find electrons. Let's say we're trying to find you in Georgia. To narrow down the view a little bit more, I would say the county, Lanier. To narrow the view a little bit more, I would say the city, [city name]. And to not know exactly that you're sitting here in Chattahoochee River High School in this desk, we can't pinpoint exactly where you are because you're moving so fast and randomly, but I could know that you're in here somewhere during fourth period, you know just to narrow down that view. That's the same thing that quantum numbers do for being able to tell us about electrons. (Jane, Observation #1)

Although Jane did not plan to use this analogy, when she captured the students' misconception, she elicited the analogy from her repertoire based on how she has "been able to pretty effectively communicate to the students the content" (Post-interview #1). Reflecting on the use of the analogy, Jane expressed the need of more sophisticated PCK to make students understand the concept of quantum numbers:

Perhaps the analogy is a good hook to get them to be thinking about what quantum numbers are, and why that's important... But at the same time I can see where it might be a distracter if the analogy isn't further [supported]. I mean give them more support. Since that [quantum numbers] is such a hard concept to wrap your mind around and such a huge factor of which everything else hinges on in chemistry that it would be worth spending more time on than just oh, this is an analogy. That's what I need to work on. (Jane, Post-interview #1)

This passage suggests that teachers' understanding of students' misconceptions not only shaped planning for and the act of teaching, but also inspired the teachers' PCK development.

Moreover, students' misconceptions were a major factor that the teachers took into consideration in determining the content of assessment. For instance, in the statue lab of Amy's honors class, a group of students exposed their misconception that all the chemical tests they were doing, even conducting reactions with acids or fertilizer, included physical changes. Meanwhile, in Lucy's gifted class, it appeared that some students thought that HCl was in acid rain because they used HCl to simulate how each element reacts with acid rain. Although Amy and Lucy caught those misconceptions when they were uncovered and confronted them immediately, they wanted to make sure that the students ultimately created informed conceptions. Thus, they modified the content of their lab assessment adding problems related to chemical changes vs. physical changes and chemical reactions of metals with acid rain. As shown in this case, assessment served as a means to assess and to remedy students' misconceptions. Lucy explained,

I evaluated pretests and monitored lab performance to assess students' initial understanding of concepts. Then I mapped student progress and mastery with lab quizzes, homework, student presentations, posttests, and document-based essay tests. Progress in the lab gave me an ongoing assessment tool by which to correct student misconceptions. By [my] asking questions or by focusing students on the original lab problem, many were able to correct themselves. (Lucy, Written reflection)

This passage provides a picture of how her assessment was interrelated with her students' understanding of concepts. In this regard, it was clear that teachers' understanding of students' misconceptions impacted their decisions made throughout the entire teaching process from planning to assessment, which enhanced their PCK development.

Placing priority on students' misconceptions was closely related to the teachers' beliefs about the goals of teaching science. Interestingly, all participants perceived that a major goal of teaching science was to connect what they learn with their everyday lives. To this end, the teachers primarily focused on students' conceptual understanding rather than their acquisition of factual knowledge. Each of these teachers believed that deep understanding of a concept is essential to its application. This point is nicely captured in the following two excerpts:

I try to make everything apply to life, just try to make them realize that chemistry touches their life all the time. So, I want kids to understand enough chemistry to be able to solve the issues that they will have in their lifetime such as a shortage of petroleum, air quality, water quality. (Amy, Interview #1) Good science teaching is talking about the whys, not so worried about the facts. You can always find facts in a book or the Internet. I want the kids to do science in their real world. How far, deep they go in understanding concepts? Doing science, understanding science, those are my main goals. (Susan, Interview #1)

These statements show that the teachers aimed at developing students' deep conceptual understanding whereby "the students can relate their understanding to a bigger world than just their classes" (Lucy, Interview #1). In order to reach this goal, the teachers needed to monitor,

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redirect, and challenge students' misconceptions, because misconceptions were a major barrier that might impede their further understanding. Accordingly, the teachers' planning, enacting, reflecting on teaching, and assessment were fundamentally influenced by the misconceptions that they had detected or anticipated the students might develop. Consequently, as teachers developed better understanding of students' misconceptions, they also facilitated their own PCK development.

## Idiosyncrasy in the Enactment of PCK

Although the PCK of the four teachers had featured common characteristics as discussed so far, their PCK was idiosyncratic to some extent. Amy, Lucy, and Jane collaboratively developed the Mendeleev Manor unit and individually implemented it in their honors or gifted chemistry classes. Thus, it was possible to analyze instructional variations, particularly in terms of PCK, among them while they were teaching the same unit. Through the enumerative analysis using the PCK evidence reporting table (Appendix D), it appeared that each teacher had a distinctive pattern in the way that she represented the subject matter. During both the lab activities and the post lab class, when Amy had to answer students' questions, explain subject matter, and summarize discussion, she preferred using instructional strategies such as comparison, contrast, and making charts. Unlike Amy, Lucy made use of argument, discussion, and questioning relatively more to make subject matter more comprehensible to students. Meanwhile, Jane had a preference for visualization.

This finding brought up the question of what factors impacted the idiosyncrasy of their PCK, especially in terms of the representation of the subject matter being taught. Analysis revealed that four factors affected the teachers' preferences in representational strategies: (a) orientations to science teaching, (b) characteristics of students, (c) teaching experiences, and (d)

personal characteristics. In the case of Amy, her primary goal for teaching science was to improve students' conceptual understanding. She had taught College Preparatory (CP) chemistry more than 20 years. Through her experiences with students in CP classes, she came to realize that making subject matter more accessible to students was necessary for scaffolding CP students' conceptual understanding. Accordingly, she has striven to develop strategies such as comparison, contrasts, or charts, Those strategies have become a part of her teaching expertise that are transferable to a variety of students and a variety of topics. She illustrated this feature,

I taught CP class [a] long time and I worked a lot with the CP program throughout the county...Although most CP students will not major in science, they need to have an understanding of chemical concepts and how to use these concepts to make informed decisions in order to be responsible citizens. At one time, I was very traditional, and I taught just straight facts. And, I found that they weren't retaining it. So I really started trying to find ways to make things clearer and more understandable to students. I've always done a lot of comparison and contrast and getting charts together. I always kind of go through a pattern. I'm really good about trying to pull it all together for them and make sure they all understand it. (Amy, Interview #3)

Amy's statement suggests that her representation strategies evolved from the interaction among her beliefs about the goals of teaching science, the characteristics of her students, and her teaching experience.

Whereas Amy focused on conceptual understanding, Lucy emphasized thinking skills, even though both had the same overarching goal of teaching science that would foster the application of science into students' real world. Lucy's emphasis on students' own thinking was apparent in the catchphrase hanging on the front wall in her classroom: "The single most important thing you can bring to this classroom is your own good thinking!" She validated logical reasoning, even if it led to the wrong conclusion, because she wanted to convey to her students that "Thinking is welcome here!" and "Using scientific habits of mind over random guessing is valued" (Lucy, Post-interview #2). With this orientation to science teaching, Lucy believed that discussion was the best way to foster students' higher thinking skills, because "discussion is thinking out loud; it gives students the freedom to go in depth rather than just cover many topics in brief; it enables students to both demonstrate and witness logical scientific thinking" (Lucy, Written reflection). Thus, discussion, argument, and questioning came to constitute her favorable instructional strategies over time.

In addition, Lucy she has taught gifted chemistry since she started teaching. She has never taught CP chemistry. Her perception of the characteristics of gifted students and her emphasis on thinking skills enhanced her use of discussion. Lucy portrayed why discussion was an effective way to teach science to gifted students in this way:

My gifted students are curious, like to ponder issues on a deeper basis, and like to find unique ways to solve problems. In order to satisfy their curiosity and focus their energy into exploring chemical concepts, scientific reasoning, and real world applications, I frequently use inquiry labs and class discussion. My students are quite skilled in these areas. They probe each other in lab and in discussion, feeding off each others' ideas. (Lucy, Written reflection)

As implied in this passage, her preference for discussion and argument has been developed through the understanding of gifted students' characteristics and subsequent educational needs over time.
The idiosyncratic nature of teaching practices related to the nature of PCK was demonstrated somewhat differently by the other two teachers. Jane's visualization and Susan's making detailed notes were mainly informed by their personal characteristics. Jane conceived of herself as a visual learner because she was able to learn better with drawing or writing. Her preference for visualization as a learner resulted in her frequent use of visualization as a teacher. Whenever she explained subject matter or answered students' questions, she frequently drew pictures, concept maps, or flow charts to make students understand better. During whole class discussion, she led the discussion using figures to create a summary of what students said on the board. In Susan's case, making detailed, well-organized notes was her major representational repertoire. She is originally from South America, so she has a strong accent in her pronunciation of English. She worried that her students might miss what she said because of her accent, so that she started making detailed notes. She described,

I do have a disadvantage with the other teachers. My accent is very heavy. Some of the kids, while they get to know me, have trouble understanding what I'm saying. The way I can fix that is having a back up with my notes. So the kid that doesn't understand can read and can copy what I'm saying. (Susan, Pre-interview #1)

This account demonstrates that teachers' personal background needs to be considered in order to understand them as individuals and as enactors of their teaching practices. To summarize, even though the teachers taught the same topic with the same lesson plan, their instruction varied according to their orientation to science teaching, the characteristics of students, their teaching experiences, and their own personal characteristics.

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These idiosyncratic characteristics show that teaching is a complex cognitive activity, which is highly context specific. In this study, individual teachers demonstrated their idiosyncratic representational repertoires during the selected time periods. However, it does not imply that each teacher's strategies are fixed. In other words, it does not mean that Lucy always uses discussion more than other representational strategies. She might employ direct lecture involving visualizations to teach a different topic to a different group of students in a different teaching context, or her preference for discussion might change over time. Indeed, application of teachers' knowledge is dependent on context and interaction with students.

This claim was supported by application of the teachers' PCK to resolve students' misconceptions. All of the four teachers recurrently asserted that misconceptions need to be challenged immediately because they will hinder students' further understanding. Accordingly, whenever they detected students' misconceptions, the teachers used several instructional strategies to confront them as soon as possible. However, sometimes they did not address the misconception that they uncovered. Rather, they allowed time to have students draw the conclusion themselves. Lucy explained,

Sometimes I did not correct misconceptions immediately hoping that students would discover and correct them on their own. I discussed the misconception later with the whole class, noting why it was wrong and what the students discovered. (Lucy, Written reflection)

This description suggests that there were instructional variations within a teacher's teaching across teaching episodes. Both idiosyncrasies across individual teachers' PCK and variations within a teacher's PCK imply that teaching is contextually bound and PCK is a special body of teachers' knowledge necessary to successfully perform teaching within complex and

various contexts. Furthermore, the idiosyncrasy signifies that there is no single right PCK for teaching a particular topic that can transfer across all contexts, which provides important insights into the complexity of teaching.

# Teachers' Perceptions of Giftedness and PCK

In the previous section, I argued that students influenced teachers' PCK development in multiple ways. Here, I discuss how gifted students' unique characteristics and subsequent special needs function in their teachers' PCK development. Particularly, I examine the ways that the instructional challenges caused by gifted students' characteristics affect teachers' PCK. In this study, gifted students are defined as those who have been identified and placed in gifted education programs based on criteria established by the Georgia General Assembly and the Georgia State Board of Education (Georgia Department of Education, 2005). *Instructional Challenges Gifted Students Bring into Science Classroom* 

Through the data analysis, it appeared that the teachers have encountered several instructional challenges that gifted students brought into both homogeneously and heterogeneously grouped classrooms. Specifically these instructional issues resulted from the gifted students' special characteristics. In this study, heterogeneously grouped classroom refers to a class that has both identified students and other students, and homogeneously grouped classroom refers to a class that contains only those students identified as "gifted." The instructional challenges identified by the teachers in this study included as the following students' characteristics: (a) asking challenging questions, (b) being impatient with the slowness of others/getting easily bored, (c) having perfectionist traits/ having a fear of failure, (d) disliking routine, drills, and busy work, (e) being critical of others, and (f) being aware of being different from others.

*Asking challenging questions*. Gifted students tended to have intellectual curiosity, creativity, and inquisitive attitudes (Clark, 1988). Because of these characteristics, they asked unusual and insightful questions that sometimes embarrassed the teachers. Jane described this feature in this way:

They tend to ask a lot more questions than others. And they'd like to oftentimes do that in front of the rest of the class, which sometimes interrupts other students' learning. They often ask questions I don't know the answer. They typically want to know why, how. Sometimes it's mentally exhausting. (Jane, Interview #2) This statement demonstrates that both the frequency and the content of questions that gifted

students asked could cause challenges to their teachers.

Being impatient with the slowness of others/getting easily bored. One of the characteristics of gifted students is that they have the ability to acquire and retain information more quickly than other students (Clark, 1988). Due to this, gifted students are likely to get easily bored with a regular curriculum. Accordingly, teachers, especially in heterogeneously grouped classrooms, often face challenges in meeting both gifted students' and other students' educational needs. Amy's description below portrays this challenge:

Trying to have a balance between things that will reach them [gifted students], but things that won't frustrate my students who plug away. Trying to plan stuff and do things that will reach both types, which is my biggest challenge. (Amy, Interview #2)

The challenge also appeared in homogeneously grouped gifted classrooms. Lucy said, You know, even in my gifted class, they are different from each other. Some kids get it the first time and so they're frankly a little bored when I'm going over it the second or third time for other kids. I think when I really start to get frustrated myself was when I realized that the kids are sitting there and doing their

homework saying, "Why do I have to hear this again?" (Lucy, Interview #2) From this statement, many gifted students were occasionally impatient with the slowness of others. It was clear that the teachers needed to develop and apply PCK to reach all students having different levels of ability.

Having perfectionist traits/ having a fear of failure. Perfectionism tends to be more common in gifted students (Frasier & Passow, 1994). This trait is frequently accompanied by stress, anxiety, or self-criticism. Lucy's experience below illustrates it:

I teach gifted kids, and a lot of them have anxiety attacks and things like that. So I've had every once in awhile a parent who will call me and say, "I've tried to tell my child that they don't need to worry about this, but they don't believe me. Can you tell them?" (Lucy, Interview #2)

This perfectionist attitude was expressed as procrastination and fear of failure, particularly among gifted underachievers. Their fear of failure caused gifted students to use denial as a selfdefense mechanism. Susan conveyed her concern about gifted students' denial in this way:

Some of the gifted students want to achieve everything to be perfect. But their coping mechanism is to not care. Because if they cared, their way of caring is a very, it's just too much stress. They just can't handle it. So they cope by not caring, even though they would probably [do] some of the best work, because they're such perfectionists. (Susan, Interview #2)

In this regard, the teachers had to come up with instructional strategies to aid gifted students to handle perfectionism.

*Disliking routine, drills, and busy work.* The teachers routinely attested to their difficulties in having gifted students do homework and take notes. Gifted students often have the ability to learn quickly and a preference for complexity, so they are likely to resist doing simple work such as repetitive practices or note taking. Two excerpts below give a glimpse of this attribute:

They like a challenge. I've had some gifted students who don't like to do homework because they see homework as more busy work. If it's extra practice, lots of times they don't want to do that. (Jane, interview #2)
I often have a hard time to have gifted kids take the notes. They are really awful about taking notes because they've learned everything up to now by osmosis. But they need to learn how to study to succeed in college. (Lucy, Interview #2)
As implied in these passages, the teachers had to search for means to make regular basic

school work challenging to the gifted students.

*Being critical of others.* Many gifted students are critical of others and have high expectation of others as well as themselves (Frasier & Passow, 1994). Hence, teachers often needed to take into consideration this characteristic in grouping students. This trait sometimes caused a challenge to their teachers, as depicted in Susan's statement:

Gifted students are like sponges. They absorb everything that I say, but also they have an opinion. They tell me if they think I am wrong. They don't accept any mistakes sometimes. So I have to make sure of everything before I go to class. I have to make sure that I'm really explaining it correctly. So I always have to revisit stuff. (Susan, Interview #2) This statement indicates that gifted students' critical attitudes might hurt teachers' feelings on one hand, but they might force teachers to be better prepared for classes than they might otherwise be.

*Being aware of being different from others*. When gifted students are teased by their peers regarding their intellectual abilities, social and emotional stress can result. In order to avoid this stress, some students learn not to answer in class, to stop raising their hands, and to minimize their abilities. This feature is nicely captured in Lucy's statement describing gifted students as Xs in a world of Os:

I have a kid who said, "I'm a totally different kid when I go to other classes [not gifted classes]. I never talk, because kids always make fun of me. They just look at me like I'm weird." He was like, oh my gosh, almost the center of every class discussion. So a lot of times, these gifted kids feel like big time Xs in a world of Os. I had never really gotten a glimpse into that until that kid was talking about it.

(Lucy, Interview #2)

This statement suggests that gifted students need peers or adults who recognize and appreciate their talents to cope with issues brought about by their differences. In this regard, gifted students' emotional issues were one of the challenges with which the teachers had to deal. *Instructional Strategies to Meet the Challenges Gifted Students Bring into the Classroom* 

In the four teachers' practices, the instructional challenges caused by gifted students' unique characteristics served as a stimulus to the development of PCK. As they perceived the problems associated with gifted students, they strived to apply specially adapted pedagogical procedures to help gifted students to reach their potential. Their efforts were categorized under the following seven labels: (a) differentiation of instructional materials and assessment, (b) variety in instructional modes and students' products, (c) grouping strategies and peer tutoring, (d) individualized support, (e) strategies to manage challenging questions, (f) strategies to deal with perfectionism, and (g) ensuring a psychologically safe classroom environment.

*Differentiation of instructional materials and assessment.* Differentiation refers to an instructional strategy to tailor instruction to create appropriately different learning experiences for different students (Beecher, 1996). The teachers frequently used differentiation in order to prevent gifted learners from getting bored and to allow them to attain optimum levels of learning. For instance, they developed differentiated instructional materials according to students' ability levels. Susan explained in what ways she modified materials to address gifted students' needs:

Gifted kids are going to take less time doing something than the other kids. So I try to provide more advanced problems or activities, not more of the same thing. I want to do things with them that don't appear as punishment. Like if they do ten problems and they finish in five minutes, I don't see why I am going to give them another twenty problems just because they finished ten. (Susan, Interview #2) Susan's declaration suggested that instructional materials be not quantitatively but qualitatively

modified for gifted students. Lucy supported this claim, saying,

Instead of covering more material, I usually cover the same amount of material, but more in depth for my gifted class. So they have a greater understanding. A lot of times we're like, "Oh, the gifted kids, they should be able to do more." No, sometimes they need to do less because they'll turn a molehill into a mountain. (Lucy, Interview #2)

This statement implies that gifted students had a tendency to place too much emphasis on the trivial details of a science activity and thus miss the larger conceptual issues that were considered most important by the teacher. As a result, the teacher felt that including fewer topics in the lesson might be more appropriate for the gifted learner. In order to provide differentiated learning experiences to all students including gifted students, Amy, Lucy, and Jane developed their own thematic units such as the Water unit, and problem-based units such as the Statue unit and the Mendeleev Manor unit. In those units focusing on intra-and interdisciplinary connections, every student was supposed to engage in intellectually challenging learning activities at their own ability levels with the result of the mastery of core concepts. The teachers tailored the degree of the openness of questions and the extent of guidance to scaffold all students' learning according to their understanding levels. Amy illustrated the differentiated aspect of the problem-based units as follows:

What I had to think about in preparing this [the statue unit] is trying to come up with different things that each would have a different problem to bring in. I kept telling them, "Guys, this lab has many, many layers. I want you to see how deep you can dig and how much you can dig." So, we were talking about a central theme like properties of things, we still had room for bringing up a property that we hadn't discussed. The central theme is just like a little thread. Kids are doing whatever they want to do around the thread at their pace in their ways. (Amy, Post-interview #3)

Through differentiation, lower achieving students as well as higher achieving students benefited, as Lucy wrote below:

One struggling student was empowered by the inquiry process of the Mendeleev Manor unit. She said to me, "Even though my lab group made lots of mistakes, in the end, I think our mistakes made me learn more about stoichiometry." Another student was so empowered by the independence she gained in lab that she invented her own techniques and came in after school to try them. When at the Governor's Honors Program (a prestigious 6 week summer program), she proposed new techniques for making and investigating uses of Ferrofluids. (Lucy, Written reflection)

Overall, when the teachers realized the need of challenging tasks for gifted students, they came up with the ideas of differentiating instructional materials and developing thematic units, which provides evidence of their PCK development. Implementation of these strategies ended up profiting all ability levels of students.

Besides the differentiation of curriculum, the teachers modified assessment to meet gifted students' special needs. They created "clever points" to boost students' higher level thinking skills and engagements. Amy explained,

What I wanted to get them to do is be able to do something outside of the class. So I came up with the idea of clever points. While they were doing this inquiry unit, it's a long nine-week unit, if they could come up with an especially clever idea, if their team did, they got clever points. And I kept up with clever points on a chart on the wall in the room. And I had students who never looked up anything, who were bringing in articles and saying, "See, this supports what we're trying to do." (Amy, Pre-interview #7)

The implementation of the clever points appeared not only to encourage gifted students but also to promote other students' self-directed learning. Amy described how the clever points worked for her diverse groups of students: I implemented clever points for students who came up with clever ideas or contributed to an extra special insight or researched idea. This was fantastic for my quiet students who sometimes are too shy to toot their own horn, my unmotivated but bright students who need a reason to go above and beyond, my weak students who could use research to earn points, and my bright, studious students who like to do extra work. These students are engaged and performing at an extremely high level. They were working bell to bell and even after school. They are thinking like scientists. (Amy, Post-interview #8)

In addition to clever points, Jane added bonus questions which required higher level thinking skills at the end of tests or quizzes to stimulate gifted students' thinking skills. She provided an example of the bonus questions, stating,

I usually make higher level thinking questions, not something that we have directly covered in class. For example, this was one of the bonus questions. We had done cation replacement, but not the anion replacement. We had done many types of bridges to calculate like moles or atoms or formula units, but had never had them calculate like one atom of a particular element has what mass. So that was a bonus question on a test to see if that would appeal and see if they can think in a different way to get at the answers. So I try to not putting that as par, as standard, for the other students, but to reach a little bit higher and see if they can apply information. (Jane, Interview #2)

This statement indicates that the modifications in assessment could be a useful strategy to maximize gifted students' potential. In conclusion, the teachers often differentiated instructional materials and assessment to provide challenging tasks to gifted students.

*Variety in instructional modes and students' products.* Differentiation was also achieved through variety. The teachers employed diverse types of instructions such as demonstrations, simulations, labs, computer-assistant instruction, discussions, etc. They also asked students to create diverse types of products that reflect individual students' potential. Students' products are defined as "the tangible evidence of student learning" (Maker & Nielson, 1996, p. 186). The products included written (e.g., writing essays, science journaling, writing a story, research report, etc.), visual (e.g., Valentine chemistry cards, drawing, etc.), performance (e.g., experiments, simulations, problem solving, science fair, etc.), and oral forms (e.g., PowerPoint presentation, group discussion, arguments, etc.).

In particular, given the understanding that gifted students prefer instructional strategies that emphasize independence, the teachers used a science fair as an opportunity for gifted students to "jump right into self-selected topics and pull their strengths and thinking" (Amy, Interview #2). Sometimes, students' products were formed through assignments. Jane's statement below illustrates her rationale for providing different kinds of assignments:

I try to give assignments that will pull the different talents of gifted whether it is verbal or whether it is mathematical or whatever area specifically in science that they're gifted. For example, I asked them to write a persuasive essay based on the elections, on their main ideas with science like national security. And one of my honors class students was to write a very persuasive essay on those stances as a campaign manager for one of the candidates. He really came out in that arena as being gifted in his verbal expression...By making different kinds of assignments, I try to appeal to whatever kind of intelligence they're most strong with. (Jane, Interview #2) This statement suggests that varying the types of products was an effective strategy to allow students to develop their talents and proceed at their own established pace through selected activities.

As an effort toward creating instructional variation, the teachers provided options. For example, in a review section of a test, Amy offered the choice of either listening to her review or working on extra problems as a small group, as shown in the following teaching segment:

Guys, you look at your test. I'm going to have a seminar now to review this concept. So you can either do that, or I've got a problem you can work in the back of the room. You can move back there and work with a group on that. (Amy,

Observation #4)

It is with options such as these that students are able to optimize their learning while making greatest use of their interests, abilities, needs, and learning styles. To summerize, in order to challenge all students including gifted students, the teachers differentiated instructional materials and curriculum, varied instruction, products, and assessment, and offered options.

*Grouping strategies and peer tutoring*. Another strategy that the teachers employed to meet gifted students' needs in heterogeneously grouped classrooms was to use both grouping and peer tutoring. They sometimes grouped gifted students together to meet their specific cognitive and affective needs. Amy said,

I sometimes put my students who are gifted together because they understand each other, listen to each other, so their ideas can flow, and therefore can go on a tangent. So I think sometimes putting them together is helpful. (Amy, Interview #2) Amy's statement indicates that similar-ability grouping provided peer stimulation and emotional support. Meanwhile, peer tutoring was frequently used for students to develop social skills and learn from others. Susan asserted the advantages of peer tutoring in this way:

Like today I put them in groups and had them help each other with a review sheet that we did. I have kids that normally just sit there passively when I'm going over a review sheet, but today I saw them listen to their peers and say, "Oh, you mean this?"...I think there's a lot of good thinking and that probably helped a lot of different types of kids. The kids that got it initially could re-explain it to the kids who weren't getting it and it reinforced it for both of them. (Susan, Post-interview #3)

Unlike Susan's peer-tutoring strategy for class time, Jane ran peer-tutoring sessions every Thursday after school for the students who needed extra help. Students' participation in the session was on a voluntary basis. During the session, Jane recognized that peer-tutoring helped one of her gifted students serving as a tutor to improve his self-confidence. In her reflection, she wrote,

Ben is exceptionally bright, tends to ask thoughtful questions, and displays critical thinking in class. Ben has been identified as gifted, but he emitted a poor selfimage and had low expectations of himself. He works very well with students and is very patient and deliberate in his explanations. Students who come to a peer tutoring session request his help. The students tutored by Ben have shown great gains in their performances in class. Ben seems to get more confident in himself. (Jane, Written reflection) From both Susan's and Jane's declarations, it was likely that peer-tutoring allowed gifted students to continue their own educational progress, understand the needs of others, and develop skills for working with others.

*Individualized support.* Teachers' personal instructional assistance to students served as a means to stimulate and satisfy gifted' students' intellectual curiosity. The teachers gave individual attention and provided individual support whenever a student needed help. The following two excerpts are representative examples:

I think my enthusiasm and my rapport that I have with kids are huge. I call them all the time. I call the kids five times more than I call the parents. I call and say, you know, you look like you were struggling with this in class. Can I help you? (Lucy, Interview #2)

A lot of times, how I handle the differences in their understanding is I just encourage kids to come after school. My classroom's always pretty full before and after school...If I see in their writing that they're exploring other ideas, I write detailed comments on their paper. (Jane, Post-interview #4)

Considering the time constraints and the demand of covering curriculum, taking extra time outside class periods for individual support is an effective way for the teachers to commit to individual students' learning.

*Strategies to manage challenging questions*. When the teachers faced challenging questions from students, they considered them as a learning opportunity. Susan spoke about it in this way:

Although my background is biology, I don't know about all the things in biology. It's almost impossible to know everything. So you have to be ready to accept those challenges and take them as learning opportunities. When gifted students ask questions that I don't know the answers, I feel like I need to get the answers for them. So that makes me look for things and questions that have never occurred to me. So I'm learning. (Susan, Interview #1)

As Susan's statement implies, students' questions stimulated teachers to broaden and deepen their subject matter knowledge, which might facilitate their PCK development. The teachers oftentimes used students' questions to initiate other students' thinking skills. Jane emphasized the importance of this strategy:

I think students can often learn a lot more from each other than they can from someone standing in the front of the room seven hours a day everyday. So, when those moments arise where gifted students ask challenging questions, I try to pull in what they already know and ask them further questions. Instead of let me just tell you what it is, I want them to work at finding answers together. And that process is more than just finding the answer. The most important part is that they think about it and they model that for other students. Other students learn from them. (Jane, Interview #2)

Jane's account gives us insight into the importance of teachers' PCK in determining the quality of students' learning. If a teacher discards a student's difficult question because of the lack of PCK to handle the question, then his or her students will be deprived of a chance to think about and learn from it. Only when teachers possess appropriate PCK can they transform a challenging question into a teachable event whereby all parties, their students as well as themselves, improve their understanding.

*Strategies to deal with the perfectionist trait.* In order to help gifted students to manage their perfectionist traits, the teachers encouraged them to set realistic goals. This strategy was often featured in Lucy's gifted class. When her students were working on science fair projects, she helped them to make realistic plans, taking into consideration their perfectionist attitude. She said,

If you are sitting here and you have not set up your project or anything, I want you to think why. If between September and November 16th you haven't been able to do that, you have to think what [would] make you able to do that in the next couple of days, okay? My major point is not to be unrealistic about your plan. You know, sometimes you have to say you know what? That's just not going to work. (Lucy, Observation #3)

In addition to setting realistic goals, the teachers employed strategies to help students develop self-acceptance and recognize their limitations. Susan's statement below exemplifies those strategies:

I deal with perfectionism a lot and we talk about the trade off. "You can do perfect on this, but you cannot get all this stuff done, because you don't have time for all the other stuff. You are not getting sleep. You're getting stressed out." And we go back and forth, just making them aware of own perfectionism. Sometimes I ask them write down their strengths and weaknesses. That helps a lot. (Susan, Interview #2)

From Lucy's teaching and Susan's explanation, it assumes that their understanding of gifted students' perfectionist traits fostered the development of pedagogical strategies to deal with them.

When those strategies are integrated within a specific subject matter, it will contribute to their PCK development.

*Psychologically safe classroom environment.* In order to make learning about elements and compounds interesting and relevant to students' lives, Amy developed a one-page scenario in which a fictitious town that was established in 1953 was mysteriously abandoned in 1988. A granny from this town passed away and left a will in which she asked their grandchildren to recover her four favorite metals, which are copper, zinc, silver, and gold. Amy planned to ask her students to conduct experiments to recover all of those four metals and figure out why the town was abandoned. When she read the scenario, a student said, "What if granny was murdered?" That spurred Amy's thinking about rewriting the scenario. Then Amy asked the students to write a scenario in which how the granny was murdered and various chemistry concepts were included. As a result, one boy wrote an outstanding ten-page story, which was very creative. He is one of the identified gifted students in Amy's honors class. Reflecting on this happening, Amy said,

That reached him. And I read his story, all ten pages out loud to the class. It was really exciting. He was not one much for doing homework. But he was good at writing. I had another one who not only wrote a scenario, but also designed a lab to solve the problems. And we did her lab in class one day. She set it up. So, go with the spur of the moment and create things that they seem interested in. He blurts out, "Granny was murdered!" and I just latched onto that, and said, "Everybody has to design a scenario." Just being able to, when you see that something reaches them, being attentive to that and trying to just go with that. If you're very rigid and you're thinking we have to cover these objectives today, and

you're not considering their ideas, then you're going to miss out with gifted students sometimes (Amy, Post-interview #7).

Amy's statement provides a clear portrait of how a teacher's attitude of allowing spontaneity grants power to the teacher to turn a trivial event into an effective teaching opportunity. Also, it gives us significant insights into an environment conducive to eliciting students' creativity and talents. Students are more likely to express their ideas and demonstrate their talents in a psychologically safe environment. When students come up with a unique idea, they might not take the risk of being rejected, being wrong, or making a fool of themselves, unless they are in a safe environment. Thus, a classroom where every idea is valued and mistakes are viewed as learning opportunities is more encouraging of creativity. Considering that creativity is one of the gifted students' characteristics (Clark, 1997) and creativity further plays an important role in developing students' scientific ability (Torrance, 1992; Perkins, 1992; Csikszentmihalyi, 1996), it is important to maintain a psychologically safe classroom environment.

In the psychologically safe environment, individual differences were also accepted and valued. Among the concerns the teachers had in teaching gifted students were the emotional issues caused by the feeling of being different. In order to address these issues, Lucy often initiated discussion about being gifted in her gifted class in this way:

You guys are the gifted kids, okay? You guys have a lot of opportunities that some other students don't, okay? But the saddest thing is when you guys all of the sudden have doors closed because of poor grades, because you were bored or you were feeling isolated, or whatever. I understand there's a blessing and a curse for being gifted. (Lucy, Observation #5) The students, then, started expressing their difficulties, experiences, and emotions. This might not have naturally occurred if Lucy had not striven to maintain a classroom atmosphere in which every student felt that everything was accepted, understood and valued. Lucy elaborated this point as follows:

I think with the gifted kid, there's a lot of gray. In class, we talk a lot about the blessing and the curse of being gifted. They sometimes talk of how hard it is for them to get started because they're like, "My mind is swimming with all these ideas. How do I focus them?" They know I understand what being gifted means to them, so they do feel safe to express their emotion in my class. I've tried to build that kind of environment and rapport with them over time. (Lucy, Interview #2)

Lucy's statement offers evidence that it is the teacher who sets the environment which encourages or destroys interests, develops or neglects abilities, fosters or suppresses creativity, and facilitates or aggravates achievement.

Overall, the teachers generated a variety of instructional strategies as a result of perceiving gifted students' special educational needs. The data in this study showed that they had clear conceptions about gifted students' cognitive and affective characteristics and were willing to change practices to be more responsive to the students' particular needs, abilities, and attitudes. Consequently, they integrated their subject matter knowledge, knowledge of instructional strategies, and knowledge of students in order to adjust their practice to gifted students. Through this procedure, their PCK was expanded. In addition, the teachers were going through the NBC process, and one of the major National Board standards is that teachers should respond effectively to individual differences in abilities, interests, and prior knowledge. This standard seemed to lead them to be more attentive to the variability in their students and to change their

practices according to individual students' variability. This impact of the NBC process appeared to ultimately facilitate the development of PCK. This assertion is discussed in the next section in a great detail.

Roles of the National Board Certification Process in PCK development The whole process, I feel, forces you to be a better teacher. If you really read [the standards] and try to think about the things they are asking for, it forces you therefore to think about how you are relaying information in the classroom. It just forces us to examine our teaching practices and how we can improve them. I think I teach differently now than before the process. (Susan, Interview #3)

The salient implication revealed in Susan's statement is that the NBC process not only validates what teachers have already accomplished, but also improves their teaching. If the process itself influences the teaching practices of candidate teachers for NBC, then the next inquiry will be *how* the process influences *what* aspects of the teachers' teaching. In this regard, this study examined how the NBC process influences teachers' PCK development.

I found that the NBC process, especially the Portfolio Creation Process (PCP), affected five aspects of the candidate teachers' instructional practices. These aspects included (a) reflection on teaching practices, (b) implementation of new and/or innovative teaching strategies, (c) inquiry-oriented instruction, (d) assessment of students' learning, and (e) understanding of students. In the following section, I argue how changes in these five areas related to NBC were reflected in the components of PCK.

#### **Reflection on Teaching Practices**

One of the five core propositions of the National Board Standards is that "Teachers think systematically about their practice and learn from experience" (NBPTS, 2004). This proposition

emphasizes the importance of a teacher's reflection in becoming an accomplished teacher. Parallel to this, candidate teachers for NBC are asked to write reflections for each entry of their portfolios. In this regard, it is not surprising that while the teachers were going through the process, they became more reflective. Susan emphasized the impact of the process on her reflective attitude:

The National Board process forces you to do extensive reflecting and putting it down on paper. You're asked to basically think about your everyday teaching outside of the box. There's a lot of reflection involved, which we don't normally do because of lack of time. (Susan, Interview #3)

This statement revealed that the NBC process required a great deal of teacher reflection. There was evidence, however, that the process influenced not only the amount of reflection, but also the content of reflection. As the teachers went through the process, they reflected more on students' achievement, because the National Board standards place emphasis on it. Amy's statement below gives a representative example of this feature:

I think of students as individuals more focusing on their achievement in science like what kinds of difficulties a student has in learning this unit, why this student dislikes science, how this student's science fair project is going, how I can help them to succeed in science learning. (Amy, Interview #3)

Susan confirmed Amy's assertion,

When you have a standard set out before you, you always look to see if you meet that standard. And then you reflect on what I am doing really [and whether it is] making a difference in their learning. I think every teacher reflects to some degree. National Board forces you to reflect less on what the kids are doing and more on what you're doing to help the students become more successful in the classroom.

The focus moves toward students' achievement. (Susan, Interview #3)

This shift in focus toward students' achievement led the teachers to become more goaloriented and to engage in purposeful planning. These changes are nicely exemplified in the two excerpts below:

I think what National Board has done has made me more purposeful, made me focus on what are my goals for this lesson? Not just, "Hey, let's have an awesome day of science!" You know, what are the specific goals that they need to walk away with today, which is good. (Lucy, Interview #3)

I become more focused on what the learning goals are, how I am able to achieve them effectively, not to just fill up time with stuff....What are the QCC [Georgia state standards] or the national standards or the (name of county standards), whatever level you want to say the learning goals are and make sure that they're being addressed. I'm learning to think about more and more what the goals are. It really makes you become more focused and more planned about that particular focus. (Jane, Interview #3)

In addition to the focus on students' achievement, the teachers grew to reflect more "why" questions through the process, as Amy said:

I think about the whys more. I think about why am I doing this? Or "Oh, that's why I did that." I've become more reflective. I've always been reflective, but it has made me think about whys more than I did. (Amy, Interview #3)

As the teachers sought answers to "why" questions, they became more analytical about their instruction, acquiring the habit of questioning themselves about their instructional decisions. This assertion is supported by Susan's description:

I always think [about] what I want the kids to have as goals and targets, and why I want [that]. Now I can articulate much better why I want [that]. I could tell an administrator at any point in time why I think something is important instead of saying, "Well, we have to teach it, it's in our curriculum." That is not my answer anymore. It is why I spend a lot more time saying why. Why didn't the kids get this? Why did they? Why do I need them to know this? (Susan, Interview #3)

In summary, the NBC process gave the candidate teachers opportunities to be more reflective and analytical about their practices, focusing on students' achievement and the reasons for their actions. Particularly, the National Board standards emphasizing reflection and the refection sections of the portfolios drove them to become better reflective practitioners. In addition, videotaping of their own practices stimulated their analytical reflection on teaching. The candidate teachers had to videotape their teaching and analyze the contents of these tapes in detail for their portfolios. When they observed themselves teaching on the videotape, they started recognizing things that they had not noticed before.

Amy videotaped her honors class for the entry 2, "Active Scientific Inquiry," and CP class for entry 3, "Whole Class Discussions about Science." When she watched her CP class videotaped, she sensed that the discussion was not going well. She, then, took a closer look at what was going on in the classroom and recognized that she had different expectations between CP and honors students. She explained,

It [watching the CP class on the videotape] made me realize that the difference between my honors and my CP is I don't expect my CP students to discuss as well as I do my honors. In my honors class, students can interact. No one gets their feelings hurt. But in my CP class, I'm worried someone will get up to punch someone else out, you know, sometimes they like to brag about doing bad. Being smart is not necessarily a good thing. (Amy, Post-interview #4)

This account implies that she did not provide enough opportunities for CP students to learn how to discuss, because she did not expect they could discuss well for various reasons. After recognizing it, Amy decided to work on making the CP students become better participants in discussion rather than to videotape her honors class for the whole group discussion entry. She explained,

My first instinct was, "Well, I'm going to go back to honors. I know I can get them to do a good discussion." But my next thing was, "No, I'm going to make my CP become better discussers," which I haven't tried before. I'm going to consciously try to have them do little activities where they learn to interact without getting feelings hurt. I'm going to consciously give them a hard time until we have a class that when someone says something smart, the other class members are like, "Oh, that's cool." I'm going to try to get CP kids to interact more and learn how to discuss things. (Amy, Post-interview #4)

She ended up videotaping a discussion section in her CP class for the entry 3, when the deadline for submitting her portfolio to the National Board was approaching. She reflected on the discussion in the following way:

Discussion about the identity of the six substances is an excellent way to help students develop their problem solving skills by letting their peers challenge their assertions and letting me guide them to draw well founded conclusions. In addition, I was able to monitor each student's participation and progress in listening, respecting, and responding to every student's ideas. (Amy, Written reflection)

Amy's story represents the power of reflection in improving teaching. If Amy had not gone through the NBC process, she might not have realized how her low expectations for the CP students' discussion skills limited her effectiveness, and her CP students might not have learned how to discuss as much as they did. In order to enhance the students' discussion skills, she had to develop lessons and instructional strategies, which made additions to her repertoire of teaching CP chemistry. Through this process, her PCK was expanded. In that reflection plays a critical role in teachers' PCK improvement, it is expected that the NBC process positively affects participating teachers' PCK through facilitation of analytical reflection on their teaching. *Implementation of New and/or Innovative Teaching Strategies* 

It is easily assumed that candidate teachers use the lessons or activities that they are already familiar with and good at for their portfolio entries. However, the three candidate teachers also employed new activities or instructional strategies that they had not previously implemented. For instance, Amy and Lucy developed the statue unit for their National Board portfolios based on the labs they learned at a conference. In the interview conducted after the statue lab, Amy answered the question of whether she had done the lab before in this way:

No. I've done a lot of inquiry labs before. But I haven't done this one. This one is one I learned at a chemistry education conference a couple of years ago. I thought it is great!...I wanted to do it last year, but we've never been able to figure out how to get in. National Board sped up doing it. It might not have happened this year....So it sped up my being able to do this because it forced my hand a little bit. (Amy, Post-interview #2)

This passage insinuates that the process itself catalyzed the implementation of innovative activities, labs, or instructional strategies. Once teachers get involved in the process, they attempt to meet the National Board standards for teaching performance throughout the entire process. They try to figure out the best way to prove that they are accomplished teachers based on what they have done. If they realize that there is a gap between what they have done and the standards and they find something better than what they have done to address the standards, then they are likely to employ it. This point is nicely described in Lucy's declaration below:

National Boards actually allows you to look at yourself and analyze your strengths and weaknesses, and actually change something, actually have the opportunity to say, "Well now I've thought about doing this for years. I'm really going to go through and do this because I think this will be effective, or no I've been doing this for years and I thought all along it was accomplishing the goals." (Lucy, Interview #3)

Susan attested to Lucy's assertion reflecting on her past experience with the process. She said, I think that certainly as you are going through the process and you're trying to figure out what would be best, what instructional activities I normally do-would mesh with this, would meet what they are looking for here. And if I've got a hole here, how should I fill this? Then, if you've kind of had things in the back of your mind "It would be nice if I did this" and then when you are in this process, you say, "Well, this is time. I will take the time to give this a whirl." (Susan, Interview #3)

Besides the standards, creation of portfolio entries and videotaping promoted the teachers' pursuit of developing new instructional strategies. Lucy started having students write journals to scaffold their learning with the thought that it would be included in her entry 4, "Documented Accomplishment: Contributions to Student Learning," as she recounted below:

This year, to help students achieve and master material, I've been having some kids who just are so lost keep a journal...I think the journaling, I was a little more motivated to do because of National Boards because I thought, "Oh, maybe I can document that." (Lucy, Post-interview #4)

In her written reflection, she recorded how the journaling helped one student with Obsessive Compulsive Disorder to get on track: "I keep in weekly contact with Sharon's mother. I require Sharon to journal about her homework time and get weekly teacher and parent signatures. At first Sharon resented this, but now sees it as a tool to keep her on track" (Lucy, Written reflection).

In order to complete entry 3, candidate teachers have to submit a 20 minute unedited videotape of whole class discussion. Jane confessed the 20 minutes time limit forced her to come up with the strategies to effectively facilitate intensive and in-depth discussion: "When you have to get something in 20 minutes, you kind of have to think about time management a lot more, which I think is a good thing. Time management has forced me to be more efficient and get to the point. I need to use different strategies to lead discussion in depth." (Jane, Post-interview #4)

Lucy's and Jane's cases reveal that the NBC process triggered the expansion of their knowledge base of instructional strategies, which they believed benefited their students. Given that knowledge of instructional strategies is a major component of PCK, the NBC process was related to the teachers' PCK development.

### Inquiry-Oriented Instruction

The National Board standards for the Adolescence and Young Adulthood science certification stress inquiry-based learning (NBPTS, 2004). The portfolio for the certification includes the requirement for creation of an inquiry teaching based entry. In this entry, candidate teachers are required to include three discrete segments of science inquiry documented by video recording. The segments are interacting with students to begin; interacting as the students collect data; engaging the students in analyzing, interpreting, and synthesizing. Hence, it is reasonable to expect that the NBC process may foster the teachers' inquiry-oriented instruction. This expectation was supported by Jane's claim below:

I am trying to try a lot more inquiry labs. There's a big portfolio in science where you have to demonstrate an inquiry lab. So I am thinking twice about lab exercises that I do on a weekly basis. Instead of making it more of a cookbook lab, I've been trying to make it more of an inquiry process. (Jane, Interview #3)

The National Board's emphasis on inquiry made Lucy be more aware of the importance of inquiry, and further inspired her to transform her AP class into more inquiry-oriented lesson. In the interview conducted before an AP class, Lucy said,

In AP, you do tend to teach toward a test. I mean you're teaching really to prepare them for the test and college. But a problem is that you do have to teach thinking. So I have to think about kind of venture into inquiry with AP...NBC forced me to really think about it." (Lucy, Pre-interview, #5) In the middle of that interview, Lucy suddenly came up with an idea to convert a lecture into an inquiry lab. She described her idea with great animation for 10 minutes:

I haven't really been able to wrap my brain around how to make an inquiry.... well, this next thing that I'm going to do is colligative properties...Oh! I'm real excited about this and it's good, because I'm running out of time and I've got to fit a lot of stuff in one, so I'm going to teach it through a lab. I'm going to tell them what sections to read in their book. And then I'm going to give them an unknown powder of ionic compounds...I'm going to let them identify it and give me like three proofs...And, they'll try and get the metal out. If they do that, then I'll say, "Okay, you get a brownie point for the day," and I'll give them a pure metal....I might try and think of something, some kind of murder mystery or some purpose for them to identify the chemical....I'm so excited because I don't know why I just didn't think about it that way...That's way better inquiry. I think I'll talk in my NBC reflection, I'll talk about the other lab and how it allowed me to kind of venture into inquiry with AP, you know, I'm going to try and get that in before Christmas. Because I need to teach that concept and I think it'll be a good way to do it. (Lucy, Pre-interview #5)

Lucy ended up creating the crime unit and decided to videotape the lab for her entry 2. Before the crime lab, she confirmed,

I felt more empowered to do it. Would I have come up with this inquiry unit if it had not been for National Board? Maybe I wouldn't have been as motivated. I've been wanting to and I think National Board just gave me the kick in the butt to actually make me do it. (Lucy, Pre-interview #7) After teaching the unit, in her reflection, she wrote,

True inquiry means there is more than one way to solve a problem. Having freedom in lab to design their own experiments and being able to articulate their thoughts was especially important for this group of students since they make connections and are very creative in their solutions. (Lucy, Written reflection)

Lucy's story allows us to grasp how the NBC process encourages candidate teachers to shift toward more inquiry-based labs. Inquiry-oriented instruction is one of the major subjectspecific strategies for teaching science that is a component of PCK. In this regard, the teachers' improved understanding of inquiry-oriented instruction stimulated by the NBC process contributed to the development of their PCK.

# Assessment of Students' Learning

The process affected the teachers' assessment of students' learning in multiple ways. While the teachers went through the process, they came to be more aware of the importance of diagnostic assessment in tailoring instruction to meet individual students' needs. Jane pointed it out as follows:

One of the biggest things I have learned from going through that [NBC] is that I was not using student progress in the class enough to address lessons that were going to be coming up. I was busy and a lot of times I didn't have a chance to really look at what my assessment told me. So I think I really learned to use that student assessment as a diagnostic more to tailor my lesson plans. My weak area was not using student performance as a diagnostic tool for other lessons. And I think National Boards helped to point that out. (Jane, Interview #3)

As implied in this statement, the teachers came to perceive assessment as part of the teaching process which served to improve students' learning rather than as strictly evaluation. This perceptual change was often realized in their teaching. Jane used reflective paragraphs to assess students' difficulties and misconceptions and to further adjust her instruction to their understanding levels:

I stopped class several times this year and had students write reflective paragraphs to assess where they had misunderstandings...what trouble they have. Then I use this information to tailor my lesson to correct the misconception and provide more help to students who were struggling. (Jane, Interview #3)

Amy came to use more probing questions to gauge where her students are:

To assess student learning, I try to ask more probing questions during class discussions and also while monitoring small group interactions. The information gleaned from these interactions direct further instruction and enables me to gauge whether remediation or further exploration is needed. (Amy, Written reflection) Lucy and Jane also used assessment to discover the progress of students who had not mastered material, and provide extra help for them. Lucy illustrated it in this way:

By carefully examining students' assessment grades, I was able to distinguish between students who had mastered all the learning goals and those who had not. I held help sessions after school to re-teach stoichiometry to those who needed more help. Students had to attend help sessions until they demonstrated mastery of stoichiometry on a short quiz. This strategy put lower achievers on par with their classmates. (Lucy, Post-interview #10) The three excerpts above suggest that the teachers came to perceive assessment as an aid to improve their instruction and ultimately to enhance students' learning.

As the focus of the assessment shifted toward improving students' understanding, teachers were led to employ strategies for facilitating the diagnostic role of assessment such as the use of rubrics, oral and written feedback, or graphic organizers. Jane described how her approaches to assessment changed through the NBC process:

Before, I could see myself giving an assignment to a student and then grading it. And now, just through the practices I chose to do for the portfolio, I now give them a rubric on how I will grade it and what I will be looking for as an evidence of their learning. Once you focus on students' learning, you feel like "I have to do this." So I find myself using more rubrics and graphic organizers and teaching tools to help them learn or give them guides for the lesson. (Jane, Interview #3) Amy summarized the strategies she employed to make assessment supportive for improving students' understanding in her reflection:

I communicated my criteria to students using lab goals, rubrics, pretests, oral and written feedback, and review sheets. Students used feedback to determine how close they were to achieving goals. In test reviews and post lab discussions, I emphasized solutions to problems that demonstrated core understanding of overall goals. (Amy, Written reflection)

From those two statements above, it appeared that the teachers implemented multiple assessment methods with the primary goal of increasing students' understanding.

The National Board's standards emphasize teachers' commitment to students' learning and their responsibility for managing and monitoring students' learning. Under this overarching

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standard, "Assessing for Results" is one of the standards that candidate teachers need to meet for entries 1, 2, and 3. Particularly, for entry 1, "Teaching a Major Idea over Time," they are required to analyze students' work samples in terms of the changes in individual students' understanding. In addition, they have to provide a rationale for the assessment they employ. Taken together, it seems natural that the teachers came to view assessment as a tool to help students understand the subject matter better while going through the process.

The teachers also came to employ more diverse types of assessment while going through the process. If teachers believe that assessment serves as a means to enhance students' learning, then they try to employ assessment tools that can tell them exactly where individual students' understanding is. However, there is no single instrument to accurately measure every student's learning. In this regard, the teachers are likely to use more types of assessment to obtain more correct information about their students' learning. Lucy encapsulated this view as the following way:

One of the biggest things I have changed is different assessment tools than just typical tests. I think, the traditional paper pencil tests, if that's all you're using, it does get frustrating, because you don't always see the results and they're very one dimensional. So if I know the kids who aren't going to do [the] test well, and you know somewhere they have some understanding of the content and those types of things over time get very frustrating. So I try to use a lot more diverse tools. (Lucy, Interview #3)

Improved awareness of the difference in students' learning styles also influenced the teachers' use of various assessment methods. For the portfolio entries, they had to profile their students. In order to obtain a better understanding of the students' learning styles, the candidate

teachers administered "the multiple intelligence test." As a result, they came to perceive a range of the students' learning styles, so that they attempted to accommodate their assessment methods as well as their teaching styles to the students' learning styles. Amy reported,

Most of my students have a kinesthetic learning style. So, I have been doing a lot more projects, and a lot of lab assessment. And, I've strived to design different kinds of assessment to accommodate many learning styles. I've done some portfolio kind of things and cartoons. In my CP classes, they had to build a model set. (Amy, Interview #3)

By and large, the NBC process promoted the teachers' use of diagnostic assessment to meet students' needs. In addition, they clarified what evidence they had to look for to ensure students had achieved the goals of the lesson, and what methods were appropriate to assess that learning. This analysis points toward a conclusion that also validates the expanded model of PCK that will be presented in the final chapter. To that end, the teacher knowledge, which is labeled as "assessment of science learning" within the larger model of PCK, contains two elements which encapsulate aspects of science learning for assessment and methods of assessing science learning. Both of these elements are clearly visible within this analysis as is their relationship to the larger concept called "Assessment of Science Learning." Thus, the conclusion was reached that these teachers exhibited all of the characteristics of assessment related to the model and that assessment is a major component of PCK. But the NBC process, by pushing teachers to consider assessment within a larger and more holistic view of teaching, fostered the teachers' PCK development.

# Understanding of Students

*David's story.* Lucy was teaching a tenth grade gifted chemistry course. At that time, Lucy was pursuing the National Board Certification. One day, she administered a survey to the students in which she asked them about who works after school, what subjects are their favorites, who speaks another language at home, etc, because she had to profile her students for her portfolios for NBC. While Lucy was reviewing the survey, one of her students, David, caught her attention. David answered that his favorite subjects were physics and mathematics, and he wanted to be either a computer software designer or a physicist. Lucy was surprised, because David was one of her weakest students. He did not seem to pay attention in her class. To Lucy, "He wasn't the sharpest tack in the box." Thus, when she read his answer, she thought, "Well, there's a big discrepancy with how he is performing." Lucy began paying more attention to David.

A few days later, Lucy videotaped the class. As a component of her portfolio, she had to include a videotape of her teaching with a detailed analysis of instruction in her portfolios. While reviewing the class videotape, she noticed that David doodled a lot during the class. She thought, "Oh, great, how am I am going to explain that he is off task?" She rewound the videotape and took a closer look at the scenes in which David was doodling. The time he was doodling struck Lucy: The first time was when he was talking about how to convert area to volume and the other time was when he was talking about how he interpreted the shape of the statue to be an arch, not a triangle. "Well, that's a math and a physics question. And that's when that kid was doodling. That's so cool." Lucy thought, "His learning style may be more visual, because he is writing down."
Next day, Lucy asked David about his learning style. Surprisingly, he said, "No, I'm very verbal. I get distracted visually. If I'm trying to learn something, I can hear it but I need not to look. So, I occupy my eyes with doodling, because that's less distracting than seeing all the things going on in the room." By her own admission, she would have never interpreted the events that way. This conversation stimulated them to build rapport with each other. Later that week, David came to her and said,

"I just started my medicine for ADHD, it's really helping. I am happier."

"I guess that would be really frustrating if you're trying to pay attention and all of the sudden you find your mind is somewhere else."

"Yeah, it was kind of frustrating because it wasn't always that I didn't want to pay attention."

After this conversation, Lucy made a note not only for National Board, but for herself, "I want to call his parents."

Lucy was motivated to know more about David, so she looked in his folder. She found that he had been suspended when he was in ninth grade. She visited an administrator and asked what happened. David was suspended because he had brought alcohol to school and sold it there. "I'd like for his parents to get a good report on him," Lucy thought. She visited David's home after phone calls, and she talked about what best serves him with his mother. She provided individualized support to him. As a result, he did better on his assignments, finished his science project early for extra credit, and took more responsibility.

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Lucy cried when she recounted this story.

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David's story depicts how the NBC process provided the catalyst for a candidate teacher to take a closer look at individual students, and further how the teacher's improved understanding of the students was translated into her practice to improve the students' learning. In an interview, Lucy reflected on David's story in this way:

I hope that would have happened normally. I hope it's just not externally motivated by National Board. But I wouldn't have known that he got paneled [suspended]. I never would have gone and looked in his folder...I don't know that I would have ever sought out that information. I think that there are definitely some things that I've got from the process. (Lucy, Interview #3)

*Increased awareness of individual students' differences in understanding.* Through the NBC process, the teachers became more alert to individual differences in their prior knowledge, achievement levels, interests, learning styles, etc. Lucy put this point in the following way:

There are several things I've learned so far. To make sure you're focusing on the worries of everyone in the classroom! The same three people maybe can answer every question, and therefore you think everything you're teaching is the right way. But, not to overlook everyone in the classroom! To realize that everybody in the classroom once again is not going to get the same material the same way! In being able to adjust to within even one classroom, be aware that everyone is not on the same level, just adjust some things that you're doing to better help everyone learn something. (Lucy, Interview #3)

Lucy's statement stresses that teachers should tailor their instruction to individual students' different levels of understanding, so every student can reach appropriate learning goals. In a

similar vein, Susan highlighted how the NBC process led her to take into consideration individual students' differences in her planning and teaching, stating,

I think some of the questions we were forced [by NBC] to answer and do some research on--it was like identifying strengths and weaknesses in children and planning your instruction towards them and then building upon what they learned. We had to do it more in depth than I had done before I went through the process....I looked up different student scores on each thing and saw where they were and where they were in my classroom, where they were before and where I could take them. (Susan, Interview #3)

The teachers' better understanding of students' differences seemed to be fostered through the portfolio creation process. For entries 1, 2, and 3, the candidate teachers wrote about their instructional contexts in which they were required to describe their students in detail. In addition, they had to analyze their teaching in terms of students' learning. Particularly, in the entry 1, they were asked to profile two students' conceptual understanding over time in depth. Without deep understanding of individual students' misconceptions, ability levels, learning difficulties, interests, and learning styles, the analysis of instruction and students' work samples would have been superficial. In this regard, those requirements pushed them to pay more attention to individual students. This aspect is well demonstrated in Lucy's description below:

The students I profiled, I definitely know their style a lot and at a much deeper level than I would have. And it really made me think, well, "Am I changing my other students?" because I really did get to know what they were doing and their style and little things. And it made me wish I had smaller classes and more time to really do that for every student. It was almost like every student deserves this kind of attention. (Lucy, Interview #3)

Taken together, the process influenced the teachers' better understanding of students, especially, in terms of students' understanding of science concepts.

*Impact of better understanding by students on teaching practices*. The teachers' understanding of students was translated into their practices in several ways including varying instructional modes, careful grouping, and tailoring their instruction to individual students. First, the teachers varied the types of instruction to accommodate different students' learning styles and ability levels. The following two excerpts provide evidence for this assertion:

I am trying to vary the mode at which I teach to accommodate different learning styles, not always doing lecture or lab, but trying to incorporate other strategies. I'm kind of trying to give them a different twist for visual learners, arrange it around, or spatially on the board. I started with the auditory learners, you know, so anytime I have something that's difficult I think is going to be hard for them to do, I try and do it many different ways. (Jane, Interview #3)

As a part of my National Board work, I administered a multiple intelligence test and I found that most of my students like learning by doing. And, there's a big portfolio in science where you have to demonstrate an inquiry lab. So through [the] process, I've been trying to make my class more of an inquiry process. Also, I've been trying to differentiate the degree of its openness. Because there are some kids who need it real open ended like gifted kids. And then there's other kids where you need to give them a little bit of guidance or it's so open ended that 135

they're frustrated and they're not getting anywhere. So I've got to learn that balance. (Amy, Interview #3)

One of the National Board standards underscores the idea that in order for teachers to be committed to students' learning, they need to recognize individual students' differences in abilities, interests, learning styles, and prior knowledge, and adjust their practice accordingly (NBPTS, 2004). Also, some part of the guidelines for the portfolios is grounded in the multiple intelligence theory (NBPTS, 2005). Hence, teachers became attentive to students' different learning styles, abilities, and multiple intelligence.

Second, in grouping students, the teachers took into consideration students' learning styles, interests, personal background, and personality as well as their achievement levels to maximize every student's learning. Lucy's report below reveals how deep her understanding of each student was:

Because of individual learning needs, I grouped students in the way that each was able to participate actively. I grouped Sherry (is diagnosed with Obsessive-Compulsive Disorder) with Collin and Ben who listen very well and are considerate of others' ideas. (Ben helped an OCD student in my class last year.) Jane, Sharon and Cindy are all shy and I did not want their purposeful thinking to be rushed by a stronger personality or intimidated by a boy. Joshua and Ann were grouped since they often let others do the work and thinking for them. Sam and Mika are quick, and I did not want them to give ideas away to others who could learn through discovery or to be frustrated with the slower pace of their classmates. Tom and John are both strong students who process verbally. Charlie can talk confidently about things, but does not always think things through, while Scott thinks better when forced to such as when working with Charlie. (Lucy,

Written reflection)

Last, the understanding of individual students enabled the teachers to offer individually tailored instruction. The individualized instruction was especially helpful for the students who brought special needs to the classroom. Lucy reported how she modified her instruction for a student who was bipolar:

Jamie is bipolar and brilliant. His mother and I talk weekly about his progress and his medication. He gets concepts very quickly and does not pay attention when I am providing second explanations or additional practice for other students. After talking with his mother about how I can help him, I have him work through upcoming labs as soon as I've presented a topic so that he immediately has to apply class information in a tangible way. I am lucky that my classroom houses both student desks and lab stations so that I can monitor Jamie while teaching. (Lucy, Written reflection)

This description reveals that Lucy developed an instructional strategy appropriate for Jamie's need through communication with his mother. Frequent communication with parents was another strategy employed by this teacher to gain a better understanding of the students. And through this avenue as well, there were impacts on the student's learning. Along this line, the National Board standards accentuate active interaction with parents. In fact, candidate teachers are asked to document how they make connections with parents and how the connections affect students' learning in their portfolios. Due to this requirement, the candidate teachers attempted to communicate more with parents through multiple avenues such as emails, phone calls, notes, etc. Amy put it in this way: I've always sent out progress reports to parents. But this year I'm sending out notes on them like what are we studying in class, what could they help their child with studying. And I've gotten back some positive response on that, like "Thanks, it's so nice to know what you're doing so I can ask them about it." I'm really glad I did that and I wouldn't have done that if it hadn't been for National Board.

(Amy, Interview #3)

Amy's account indicates that interaction between a teacher and parents encouraged the parents to more significantly engage in their child's learning.

In conclusion, through the portfolio creation process, the teachers became more informed of individual students' differences in prior knowledge, learning difficulties, abilities, learning styles, and interests. Moreover, they took into consideration those differences in teaching practice. Knowledge of students' understanding is one of the significant factors that promote PCK development. In this respect, the NBC process was highly related to the teachers' PCK growth.

#### Summary

In this chapter, I examined the nature of PCK that experienced high school teachers possess. The evidence presented here supports the contention that PCK was developed through reflection-in-action and reflection-on-action. Teacher efficacy also appeared to be a critical component of PCK. Students greatly affected PCK development, particularly students' misconceptions played an important role in shaping PCK. With those common characteristics, PCK was idiosyncratic to some extent. I also argued that instructional challenges caused by gifted students' special characteristics influenced teachers' PCK in multiple ways. The NBC process impacted candidate teachers' PCK development through facilitating reflection, encouraging implementation of new instructional strategies, fostering inquiry-oriented instruction, improving assessment of students, and increasing understanding of students. In the next chapter, I explicate the major findings and provide implications for science teacher education.

#### CHAPTER V

## DISCUSSION AND IMPLICATIONS

This research study was developed with the assumption that teaching is a highly complex cognitive activity in which the teacher must apply knowledge from a wide range of sources and knowledge domains. Within this assumption, the idea underlying this study is that PCK is a body of knowledge for teaching that powerfully impacts teaching practices. PCK is developed over time and results from academic learning in pedagogy and subject matter as well as from prolonged experience in classroom settings with students (Cochran, et al., 1993), and as such, it is knowledge unique to the teaching profession. In this regard, central to this study is the belief that the construction and refinement of PCK creates a fundamental means of helping teachers become more professional. Along this line, this study examined the nature of instructional practices of experienced high school science teachers in order to gain a deeper understanding of PCK.

PCK is a type of teacher knowledge which combines pedagogy and subject matter content in a synergy that ultimately transforms the subject matter knowledge into forms that are intellectually available to students. To determine whether the transformation of the subject matter is sufficient for learning, assessment of student accomplishment is required and thus plays a central role through feedback on how teachers should transform subject matter knowledge. In this vein, this study explored how students affected the ways that PCK was organized, developed, and validated. With respect to the relationship between students and teachers' PCK, especially, this study focused on how students' giftedness functions in developing teachers' PCK. This study was initiated as a part of a larger research project that examined the impact of the National Board Certification (NBC) process on participating teachers' teaching practices and students' learning. The conjecture fundamental to the larger project was that NBC is a professional development activity that results in improved students' learning as well as serving as a reward for the teachers who participate. Supposing that teachers reconceptualize teaching through the NBC process, the process must influence the teachers' knowledge for teaching because teaching is a highly cognitive process. In this regard, this study also scrutinized the effects of the NBC process on teachers' PCK.

# The Nature of PCK of Experienced Science Teachers

The data collected from multiple sources validated and refined the characteristics of PCK that were revealed from the literature review. One primary characteristic of PCK arose from the synthetic impact of both knowledge-in-action and knowledge-on-action. On the one hand, the knowledge-in-action aspect enabled teachers to develop PCK through a dynamic process in which its components were spontaneously integrated in response to specific instructional incidents which occurred during the act of teaching. Particularly, this knowledge-in-action aspect allowed teachers to transform an unexpectedly challenging moment into a teachable moment. One the other hand, the knowledge-on-action aspect of PCK arose when a teacher reflected after a class while considering how to resolve the concerns that arose as he or she was dealing with subject matter in the class. Accordingly, the knowledge-on-action and knowledge-on-action of PCK, reflection played a highly significant role.

Each aspect of PCK spurred the other's development and synergistically impacted PCK improvement. This interrelationship between knowledge-in-action and knowledge-on-action

implies that PCK development encompasses knowledge acquisition and knowledge use. It is unlikely that teachers acquire PCK first, and then enact it. Rather, knowledge acquisition and knowledge use are interwoven within the context of instructional practices (Eraut, 1994). In other words, PCK development that is associated with any change in practice occurs within the context of use. Teachers develop PCK through the spiraling relationship among knowledge acquisition, new uses of that knowledge, and reflection on the use that is embedded in their practices. This assertion also supports the idea that teachers do not simply receive knowledge that others create to teach, but produce knowledge for teaching through their own experiences. Although teachers' knowledge can be influenced and improved by receptive learning, the most powerful changes in teachers' knowledge result from experiences in practices. In this regard, teachers are knowledge producers not knowledge receivers.

This study was conceptually grounded in the pentagon model, which represents five components of PCK for science teaching. This model was developed from an extensive examination of the research literature related to PCK. The model, however, changed as a result of this empirical research. Through the "in-depth analysis of explicit PCK" approach, one new affective component of PCK emerged. That component, teacher efficacy, was identifiable when the teachers were teaching a certain subject matter to a special group of students in a particular context. In brief, teacher efficacy was identified as a component of PCK in a data-driven way.

In this study, PCK was conceptually defined as teachers' understanding of and their enactment of how to help a diverse group of students develop understanding of specific subject matter using appropriate instructional strategies, representations, and assessments in a complex and dynamic context. Teacher efficacy was closely related to both dimensions of PCK: understanding and enactment. Increased teacher efficacy had the result of providing

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encouragement for teachers to enact their understanding. When the enactment was successfully performed, it increased their teacher efficacy. The increased teacher efficacy renders the teachers ready to learn new instructional strategies whereby their understanding is expanded (Stein & Wang, 1988). Through this argument, the conclusion is made that teacher efficacy is linked with PCK. As a component of PCK, teacher efficacy specifically shows the context- and domain-specific nature of PCK as a larger construct.

Another salient aspect of the nature of PCK was that PCK was greatly influenced by students in multiple ways. First, students' challenging questions served as a motivator for teachers to deepen and broaden their subject matter knowledge. Increased subject matter knowledge can stimulate PCK development because it is a major reservoir of raw material that is available to be shaped into PCK. Second, oftentimes students' critical thinking stimulated teachers to come up with innovative ideas for reshaping their instructional practices. This indicates that students are a resource for PCK. Last, students' verbal or nonverbal responses and learning outcomes played an important role in shaping PCK. Teachers revamped, modified, or validated their instructional strategies according to students' feedback, enjoyment, and achievement levels, therefore causing construction and reconstruction of PCK.

This feature implies that teachers' capacity to "read" students is essential to their PCK development because students' responses can influence teaching practices only when a teacher is aware of their significance. Stated differently, only when teachers grasp their students' cognitive and affective status with regard to the learning of the subject matter content can they apply pedagogically adjusted procedures to the students in order to facilitate learning. However, since teachers cannot always directly assess students' learning, they should learn to detect the signs of understanding and confusion, of pretended interest and genuine absorption. The teacher's

capability to make these judgments and detect these understandings is grounded in subject matter knowledge and the components of PCK such as knowledge of students' understanding, assessment, curriculum, and orientations to science teaching. Therefore, it is clear that knowledge of students is a key component of PCK.

With respect to knowledge of students, teachers' understanding of students' misconceptions appeared to be another factor that promoted PCK development. In planning and actual teaching, the teachers paid particular attention to students' misconceptions. The teachers' instructional decisions were made primarily in ways that best detected misconceptions and remedied them effectively. Their concern about misconceptions provoked them to develop representations and instructional strategies that would work to rectify misconceptions associated with a specific content area. The new representations and instructional strategies created were included in their repertoire for teaching the content area. In addition, they used assessment either to discover students' misconceptions or to make sure the misconceptions were changed into valid understandings. Consequently, as teachers reacted to misconceptions, they came to improve their PCK. Moreover, it appeared that the teachers' emphasis on students' misconceptions was closely tied to their beliefs about the goals of teaching science to high school students.

The emergence of teacher efficacy and the importance of reflection in PCK led the pentagon model of PCK to evolve into the hexagon model of PCK as shown in Figure 3. In this model, the concept of PCK represents not only teachers' understanding of how to teach subject matter effectively, but also the enactment of their understanding. This figure depicts that PCK for science teaching consists of six components: orientation to teaching science, knowledge of science curriculum, knowledge of assessment of science learning, knowledge of students' understanding, knowledge of instructional strategies for teaching science, and teacher efficacy. The figure also presents the elements that constitute each component. In order to emphasize the importance of students' misconceptions in improving PCK drawn from this study, the misconception element is encircled with an oval.



Figure 3. Hexagon model of pedagogical content knowledge for science teaching.

As has been found in the literature review and in this study, the six components influence one another in an ongoing and context bound way, therefore leading to PCK development. Said differently, the improvement of one component may concurrently stimulate the development of others, and ultimately increase PCK. In order for effective teaching to occur, teachers will integrate all the components in an appropriate way and enact them within a given context. The integration of the components is accomplished through both reflection-in-action and reflectionon-action, which are tied together in a complementary fashion centering on teaching practices.

This model implies that as a teacher develops PCK, the coherence among the components is strengthened and which then reinforces the integration of the components, which in turn facilitates the PCK increase and further changes in practice. For some teachers, however, all the components are in place but the dynamic properties of the hexagonal model may not be functional, due to the lack of coherence between those components. In this regard, if a teacher is unable to integrate the components in a coherent way, improving a single component may not be enough to advance PCK and practices.

However, since PCK development requires a teacher to integrate different components of PCK and a teacher develops one or many of the components in a variety of ways, teachers' PCK is idiosyncratic to some degree. As an illustration, the three chemistry teachers' (i.e., Amy, Lucy, and Jane) PCK differed even when they taught the same unit, the Mendeleev Manor unit. These differences appeared especially from the use of different representations during classroom practices. Their variations in representational repertoires were influenced by their orientations to science teaching, teaching experiences, personal characteristics, and the characteristics of their students. Individual teachers' idiosyncratic PCK seemed to be continuously changing and reconstructing to become a permanent aspect of their PCK.

The findings regarding the idiosyncrasy of different teachers' PCK were summarized in a diagram as shown in Figure 4. In the planning stage, individual teachers, due to their own way of preparing to teach, place themselves somewhere on the continuum of having minimal plans for teaching on one extreme to maximal elaboration of plans for teaching on the other extreme.





Figure 4. Stable and idiosyncratic pedagogical content knowledge.

Planning:

session

Planning to teach

that instructional

the content of

Enactment:

Enactment of the

instructional plan

The potential for similarity among individual teachers' plans is high at this stage. For example, the three chemistry teachers, Amy, Lucy, and Jane, all planned an inquiry-oriented approach and four major experiments (Cu, Zn, Ag, and Pt lab) in the Mendeleev Manor unit, though, the degree to which they elaborated their plans differed dramatically.

When teachers put their plans into practice, these enactments ranged from minimal adherence to the instructional plan to strict adherence to the instructional plan. At this stage, potential for commonality in their practices is still high. For instance, Lucy changed the last lab activity, the Pt lab, in the Mendeleev Manor unit from group work into individual work because she took into consideration that her gifted students preferred individualized work, while Amy and Jane implemented that lab for group work as they planned. Nonetheless, the learning goals and content of the lab were almost same in the three teachers' practices.

During the lab, however, as specific events that required teachers' reactions occurred, the teachers' responses to them varied, regardless of whether the events were initiated by the teachers or the students. This claim is supported by the different representational strategies the three teachers employed when they had to answer students' questions, explain subject matter, confront misconceptions, and make points during discussion. Thus, potential for idiosyncrasy is high when teachers encounter specific events, particularly, when incidents they do not expect to happen occur. In this regard, the idiosyncrasy in teaching practices reflects the complexity and unpredictability of teaching. As an individual instructional event can be described as more specific, its complexity and unpredictability become higher, and different teachers' responses to the event become more various. But the knowledge about teaching which results from these "more various" responses to an instructional events is still PCK, even though it may become

much less available for careful description and characterization by either the teacher or by an observer.

## Teachers' Perceptions of Giftedness and PCK

Gifted students' special educational needs caused by their unique characteristics led teachers to modify their instruction to respond appropriately. This response was linked to an increase of knowledge about teaching and thus promoted PCK improvement. This study revealed that teachers encountered a variety of instructional challenges while they were dealing with gifted students within both homogeneously and heterogeneously grouped classrooms. A challenge was that gifted students asked too many and, often, embarrassing questions due to their intellectual curiosity. Gifted students' ability to learn more quickly sometimes caused them to be bored with the pace of the regular curriculum and to lose interest in learning. Their perfectionism and negative attitudes toward routine and busy work oftentimes challenged the teachers.

Furthermore, many gifted students were critical of other students and expressed high expectations toward others as well as to themselves. As a result, teachers had to consider this characteristic in grouping students. Meanwhile, gifted students frequently suffered from emotional issues that resulted from their awareness of being different. Those emotional problems often caused gifted students to underachieve at school. Thus, teachers were required to help gifted students cope with the emotional issues more commonly than with other students. This added to the instructional load of working with gifted students.

Teachers translated their knowledge of gifted students' characteristics and needs into their practices in a variety of ways. Differentiation was a strategy that teachers most commonly employed to provide challenging tasks to gifted students. Teachers differentiated instructional materials and modified assessment to provide qualitatively differentiated learning opportunities to all students according to their abilities. Moreover, they created thematic and problem-based units that created more flexibility for tailoring instruction to individual students' levels of understanding as compared to teaching chapter by chapter in textbooks. Differentiation was also achieved through variation in instruction types, representations, students' products, and assessment.

Another strategy to meet the instructional challenges gifted students brought into the classroom was to use grouping and peer-tutoring appropriately. Although the effects of peer-tutoring on gifted students are still controversial (Robinson, 1997), this study showed that peer tutoring was beneficial to all the students including the gifted students. As an endeavor to meet gifted students' needs, the teachers provided individualized support, employed strategies to manage challenging questions and to deal with their perfectionist traits, while also maintaining a psychologically safe classroom environment.

All of these strategies were most effective when they were grounded in knowledge of students, subject matter, and instructional strategies. For example, the findings of this study suggest that if teachers had learned differentiation as an instructional approach, but they had had a weak knowledge base of subject matter and their students' understanding, they would not have differentiated their instructional materials or created thematic units to accommodate different students' ability levels. Therefore, the instructional approaches the teachers demonstrated, and which were assumed to be representative of their PCK, resulted from the integration of subject matter knowledge, knowledge of students, and knowledge of instructional strategies. Accordingly, PCK seemed to be a significant body of knowledge that enabled teachers to meet the different needs of individual students.

Roles of the National Board Certification Process in PCK development

From this study, it was revealed that the NBC process, especially the portfolio creation process, had impacts on PCK development through facilitating reflection through the requirement of descriptive narrative regarding instruction, enhancing the implementation of innovative teaching strategies and inquiry-oriented instruction, improving assessment, and increasing knowledge of students. One of the salient effects of the process was that teachers came to be more reflective and analytical about their own practices. They reflected more frequently on their practices and the focus of their reflection shifted toward students' achievement. Moreover, they came to ask more "why" questions. They saw beyond the surface of teaching strategies, answering the questions, "Why does it work?" or "Why does it not work?" They also sought the reasons for their actions and decisions, asking "Why do I do this?" According to Shulman (1986), a professional is capable of not only practicing an understanding of his or her craft, but also communicating the reasons for professional decisions and actions to others. In this sense, the process itself seemed to help teachers to be more professional.

The improved reflective attitudes were directly stimulated by the great emphasis the National Board standards place on reflection. For example, teachers are required to videotape their classroom teaching and reflect upon it. Through creating portfolios, teachers reflected on what they were doing, assessed the results of their practice, and explored new possibilities for teaching. In other words, as teachers reflected on their teaching to answer the "why" questions while working on portfolios, they came to recognize their deficiencies and internalized the need for change. In consequence, they developed PCK and ultimately changed their practices.

Another positive influence of the process was that teachers came to implement more new instructional strategies while creating their portfolios. While pursuing NBC, teachers tried to

include in their portfolios activities or instructional strategies that would meet the National Board standards. This desire highly motivated them to put into practice previously untried instructional strategies that they believed would be effective. In short, the process served as an incentive for the teachers to try out new activities and strategies, as implied in Susan's and Lucy's metaphors of "give it a whirl" and "give me the kick in the butt." In addition, since the highly structured National Board portfolios have sometimes asked some teachers to engage in practices that were very different than their ordinary approaches, it stimulated the use of new instructional approaches.

With respect to instructional strategies, the teachers got to use more inquiry-oriented approaches because of the big inquiry section in the portfolio. Hence, they became more skilled in creating inquiry-based learning experiences and more knowledgeable about inquiry-oriented instruction, both of which served to increase their PCK.

Assessment of students' learning was the area that the process affected most. Teachers became more aware of the importance of diagnostic assessment in adjusting instruction to reach all students. The National Board standards required teachers to connect their teaching with students' understanding. To this end, the teachers had to articulate how their actions, assessment practices, and behavior and task requirements affected student learning outcomes. In this process, they recognized that assessment could be used as a tool for facilitating students' understanding as well as for evaluating learning. Moreover, they provided the students with rubrics, oral and written feedback, or graphic organizers to help them to assess their own learning. In order to consider students' different learning styles and multiple intelligence, they also varied their assessment methods. As their assessment repertoire grew, it seemed to enrich or extend their PCK in that knowledge of assessment is a significant component of PCK.

As illustrated in David's story, the process encouraged teachers to take a closer look at individual students' interests, abilities, learning styles, personalities, family circumstances, and peer relationships. Consequently, they gained a better knowledge of their students, and this knowledge then became a basis for their PCK development. They developed various types of instruction to meet different students' learning styles and ability levels. In grouping students, they considered students' learning styles, interests, personal background, peer relationships, and group dynamics as well as achievement levels to foster every student's learning. Furthermore, their improved understanding of individual students enabled the teachers to offer individually tailored instruction.

On the whole, while going through the NBC process, teachers became more insightful about their instructional practice; took more time for reflection and self-evaluation; more closely monitored their instruction to make sure that worthwhile content was being taught to all students; more effectively adapted pedagogical procedures to meet the specific needs and abilities of their students at particular moments in time; and more fully accepted responsibility for guiding student learning. By the standards of NBC, by other ideals published in the literature of education, and by the teachers' own informal admissions, all of these adaptations moved this group of teachers forward toward being more effective in the classroom. Truly, those features encompass what effective teachers are supposed to be.

In conclusion, it is clear that the NBC process acted as a catalyst in improving teaching. The teachers might have become more reflective, more responsive to individual students' differences, more aware of diagnostic assessment, and more effective in their use of innovative strategies through further teaching experiences even without going through NBC. However, involvement in NBC accelerated the process of the teachers becoming better teachers. In this regard, the NBC process was highly related to teachers' knowledge development and improvement of practice.

## Implications for Teacher Education

Based on the findings and discussion, I suggest several implications for future science teacher education. First, PCK appears to be an essential body of knowledge for effective science teaching. The development of PCK was shown by this research to be fundamentally embedded in teaching practices. In addition, reflection was a major vehicle to facilitate PCK development. In this regard, pre-service teachers should have enough school-based field experience such as student teaching, practicum, and classroom observation *in combination with reflection*.

Through such experiences, though the PCK which develops for them may not be as sophisticated PCK as experienced teachers have, these novice teachers can construct a certain level of PCK. That body of PCK will then enable them to reduce the time required for planning, collecting resources, teaching, reflecting, and reteaching specific topics and also enable them to conduct these activities with increased effectiveness and fluency when they get into schools as beginning teachers. The significance of offering reflective experience as professionals in preservice teacher education has been supported by much research (e.g., Bryan & Abell, 1999).

Moreover, in order to facilitate pre-service teachers' PCK development, mentor teachers and university supervisors should provide subject-specific mentoring during field experiences. Without that kind of mentoring, PCK development will be acquired more slowly through trial and errors, reteaching efforts, and gradual successes (see Wilson et al., 1987). For in-service teachers' PCK development, professional development programs need to focus on a particular subject matter and the ways in which that subject matter is translated in teaching. To this end, case study learning approaches in which teachers analyze and reflect on the given cases or video analysis of teaching practices can be recommended. In those activities, sufficient attention should be paid to reflection on what works, what does not work, and why.

Second, knowledge of students was essential to the teachers' own PCK development. This implies that only when teachers understand their students' cognitive and affective status can they optimally apply pedagogically adjusted procedures to the students in order to facilitate their students' learning. In this regard, both pre-and in-service teacher education programs should provide opportunities for teachers to examine or analyze students' understanding, reasoning types, learning styles, motivation, characteristics, and interests.

With respect to knowledge of students, teachers' better understanding of students' misconceptions especially affected their PCK growth. In other words, when teachers grasped students' misconceptions and the ways in which students reasoned, they were able to restructure their subject matter knowledge into a form that enabled productive communication with their students whereby their PCK became richer and fuller. Research has suggested that students' errors and misconceptions are more easily recognized when a teacher has a richer understanding of the content topics and concepts (Hashweh, 1987; Van Driel et al., 1998). Thus, a thorough understanding of subject matter is a prerequisite for PCK development (Van Driel et al., 1998).

In this regard, pre-service teacher education needs to place more emphasis on the sufficient subject matter preparation. Jane confirmed this suggestion:

What are the things that are really good for them to know? What are some good educational strategies to help them learn, to keep them excited, to make subject matter understandable to them? So I feel like the college education programs need to be more specialized for the content area so that we don't walk out thinking, "How am I going to teach them this?" (Jane, Interview #3) For science teachers with subject matter knowledge deficiencies, it is suggested that teacher professional development programs should offer opportunities that are specifically tailored for science teachers rather than for science majors in which subject matter is not taught independent of pedagogy.

Third, individual teachers developed the components of PCK in different ways and integrated them through various means to foster students' learning. This implies that there is no single definite way to impart PCK to a teacher. In addition, PCK is context-specific, so that there is no right PCK for a topic that can transfer across all teaching contexts. In this regard, teacher education has to foster teachers' capability to develop each component of PCK, integrate the components in an adequate way, and apply them to the right students at the right time in the right contexts rather than to present pedagogy as a "bag of magical tricks." Also, the hexagon model stressed the importance of coherence and integration among the six components of PCK for effective teaching. Hence, teacher educators need to be aware of the interrelatedness among the components, even when they focus on the development of one component. In that teacher efficacy appeared to be a critical component of PCK, teacher educators also should take into consideration teachers' affective domains as well as their cognitive domains in building teacher education programs.

Fourth, this study revealed that teachers tailored their instruction to meet the needs of gifted students and to respond to their unique characteristics. The instructional strategies the teachers implemented were not content-free skills or strategies. Rather, they applied specially adapted pedagogical procedures for their specific learning goals or objectives through an amalgamation of subject matter knowledge and pedagogical knowledge. This finding suggests that courses that are used to fulfill the requirements for certifications to teach gifted and students

focus on how to transform subject matter knowledge, and how to relate the transformation to gifted and other students instead of teaching simply a set of general teaching methods that can be applied to any content area.

Fifth, the National Board portfolio creation process appeared to improve teachers' reflection and further practices. Parallel to this finding, research has asserted that creation of teaching portfolios encouraged student teachers and teachers to think more deeply about their teaching and about subject matter content, to become more conscious of the theories and assumptions that guide their practices, and to develop a greater desire to engage in collaborative dialogues about teaching (Zeichner & Wray, 2001). This implies that creating teaching portfolios contributes to the growth of teachers, which will also contribute to a cumulative improvement of the teaching profession. In this regard, teaching portfolios can be used as a vehicle to stimulate teachers' reflection and analysis of practices in teacher education programs. In that videotaping of teaching inspired teachers to be reflective and analytic about their work, it is also suggested that videotaping teaching practices be used for either assessment or development purposes in pre- and in-service teacher education.

Last and foremost, the NBC process impacted both PCK and teaching practices. For those teachers who participate, the NBC was a learning process as well as a means to recognition or reward for their teaching accomplishments. Therefore, it is recommended that all agencies and stakeholders encourage teachers to get involved in NBC. As has been shown by research, both intrinsic and extrinsic motivating factors inspired teachers to engage in NBC (Oliver & Peker, 2004). Those motivators included financial incentives, colleagues' encouragement, and the desire to improve teaching, meet personal challenges, and secure prestige/recognition. In this regard, strategies to provide extrinsic motivation and to facilitate intrinsic motivation need to be adopted.

## Implications for Future Research

This study ultimately proposed the hexagon model as a conceptualization of PCK for science teaching. This model drew its fundamental structure from the literature of educational research, but was verified and expanded from the data analysis of this project. The hexagon model presents the six major components of PCK and underscores the importance of interrelatedness among the components for effective teaching. In order to strengthen the hexagon model, further research into the relationships among the components needs to be conducted. Conducting this research will contribute to a better understanding of the complexity of teaching and learning.

Furthermore, the hexagon model suggests teacher efficacy as a new component of PCK. Considered as a component of the whole, this affective feature combines with the previous cognitive features to describe a fuller understanding of teachers and teaching. Although teaching is largely conceived of as a cognitive activity, affective aspects must also be recognized as an integral part of teaching because teaching involves humans who always have opinions about and affinities toward life experiences. In consequence, teachers' instructional decisions are inextricably influenced by their affective characteristics. Even though this study is exploratory and limited to simply identifying teacher efficacy as a component of PCK, future studies need to explicate how teacher efficacy is interrelated with the other components and integrated into PCK.

In that reflection facilitated integration across the components of the hexagon model, research into strategies to enhance systematic reflection that promotes PCK development and leads to changes in practice will provide significant insights into teacher preparation and

development. Also, in order to investigate the assumption that PCK is highly related to students' learning, how a teacher's PCK is reflected in students' understanding of science concepts should be more fully examined. Understanding the relationship between a teacher's reflective capacity, PCK, and students' learning will provide a more holistic and clearer picture of how students' learning relates to the knowledge and thinking carried by teachers.

In this study, knowledge of students' misconceptions played a critical role in shaping PCK. This feature was closely associated with the teachers' goals for teaching science to high school students, which emphasized conceptual understanding. Considering that subjects are more central in secondary schools and secondary teachers are more subject-oriented than their counterparts in elementary and middle schools, the nature of elementary and middle school teachers' PCK and its development might be different from the results of this study. Therefore, research on PCK with elementary and middle school teachers is suggested.

From this study, it appeared that the National Board Certification portfolio creation process positively affected teachers' teaching practices in powerful ways. In order to verify the sustainability of the effects of the process, however, longitudinal studies should follow. The longitudinal studies need to examine whether new teaching practices implemented through the process are maintained after the portfolio construction experience or whether habits of reflection and analysis developed through the process continue on well after the initial experience of constructing a portfolio.

#### Summary

In this chapter, I have discussed the findings of this study in three aspects: the nature of PCK experienced science teachers possess, students' giftedness and PCK, and the roles of the NBC process in developing teachers' PCK. Beyond these three aspects, the purpose of this study

was two fold. From a theoretical perspective, this study aimed to obtain a better understanding of the nature of PCK, the relationship between students and PCK, and sources of PCK development. With this purpose in mind, this study investigated how students' giftedness played a role in shaping teachers' PCK in order to understand the relationship between students and teachers' PCK. As to the sources of PCK, this study examined how the NBC process served as a conduit to improve PCK.

From a practical point of view, this study was designed to provide research-based implications for teacher education and research on teaching. In this regard, implications for preand in-service teacher education and future research drawn from this study were also suggested in this chapter.

This research demonstrated a powerful relationship between PCK, National Board Certification, and gifted students. The confluence of these three aspects created a unique edifice of effective teaching. This end product of my research is a culmination of my own personal experience in teaching and education, as well as my desire to impact a larger community of science teaching and learning. My interest in PCK arose as a result of my own teaching experience and reading a few important reports from the research literature. Through a seven year teaching experience, I came to be aware that effective teaching requires a specific body of knowledge beyond subject matter knowledge and pedagogical knowledge, and further, I learned in my master's degree program that this knowledge was called PCK. This interest in PCK led me to devote my efforts to examine how professional development programs help teachers develop PCK. My involvement in a large externally funded research project in the College of Education that examined teachers' experience with NBC convinced me that the NBC process is a powerful professional development opportunity and also provided a community of scholars in which to work.

Further, working with NBC provided a model from which to gain understanding of what it means to be an expert teacher. And it was with expert teachers that I wanted to investigate how the NBC process is related to teachers' PCK. When I was a middle school science teacher, I was selected to teach elementary students who were gifted in science for a nationally funded extracurricular program. Through that experience, I realized that teachers for the gifted need to develop PCK in order to meet gifted students' special needs and further help them to reach their potential. Consequently, I had a desire to explicate teachers' PCK in terms of its relationship with gifted students.

Educational research needs to impact teaching and learning. This impact should happen on a larger scale rather than a smaller one. The three major aspects of this research, PCK, NBC, and gifted learners, come together in a unique way to make this larger impact possible. And in order for this impact to be realized, publication and a new cycle of research will begin.

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## Appendix A

## The Different Orientations to Science Teaching (Magnusson, Krajcik, & Borko, 1999)

Orientation	Goal of Teaching Science	Characteristics of Instruction
Process	Help students develop the "science process skills"	Teacher introduces students to the thinking processes employed by scientists to acquire new knowledge. Students engage in activities to develop thinking process and integrated thinking skills.
Academic Rigor	Represent a particular body of knowledge	Students are challenged with difficult problems and activities. Laboratory work and demonstrations are used to verify science concepts by demonstrating the relationship between particular concepts and phenomena.
Didactic	Transmit the facts of science	The teacher presents information, generally through lecture or discussion, and questions directed to students are to hold them accountable for knowing the facts produced by science.
Conceptual Change	Facilitate the development of scientific knowledge by confronting students with contexts to explain that challenge their naïve conceptions	Students are pressed for their views about the world and consider the adequacy of alternative explanations. The teacher facilitates discussion and debate necessary to establish valid knowledge claims.
Activity- driven	Have students be active with materials; "hands-on" experiences	Students participate in "hand-on" activities used for verification or discovery. The chosen activities may not be conceptually coherent if teachers do not understand the purpose of particular activities and as a consequence omit or inappropriately modify critical aspects of them.
Discovery	Provide opportunities for students on their own to discover targeted science concepts	Student-centered. Students explore the natural world following their own interests and discover patterns of how the world works during their explorations.
Project- based Science	Involve students in investigating solutions to authentic problems	Project-centered. Teacher and student activity centers around a "driving" question that organizes concepts and principles and drives activities within a topic of study. Through investigation, students develop a series of artifacts that reflect their emerging understandings.
Inquiry	Represent science as inquiry	Investigation-centered. The teacher supports students in defining and investigating problems, drawing conclusions, and assessing the validity of knowledge from their conclusions.
Guided Inquiry	Constitute a community of learners whose members share responsibility for understanding the physical world, particularly with respect to using the tools of science	Learning community-centered. The teacher and students participate in defining and investigating problems, determining patterns, inventing and testing explanations, and evaluating the utility and validity of their data and the adequacy of their conclusions. The teacher scaffolds students' efforts to use the material and intellectual tools of science, toward their independent use of them.

# Appendix B

Entry	Standards	Requirements	Specifications	Possible Knowledge Bases	
		Three comples	Three instructional activities (one must show connections to technology)	-Subject matter knowledge -Pedagogical	
	-Understanding students	of student work from each of two students	Related instructional materials	knowledge -Knowledge of context -PCK (orientation to	
1. Teaching a major idea	-Understanding science -Understanding science teaching		Two students responses for each (include written feedback)	science teaching) -PCK (knowledge of student understanding)	
over time	in science		Instructional	- PCK (knowledge of	
	-Assessing for results		Planning	-PCK (knowledge of	
	-Reflecting on teaching and learning	Written commentary	instruction	assessment)	
			Analysis of instruction and student work	-PCK (knowledge of instructional strategies and	
			Reflection	representations)	
		Culminating	Rationale for		
2. Active scientific	-Understanding students -Understanding science -Understanding science teaching -Engaging in science learner -Sustaining the learning environment	One videotape (20 minutes max)	Three discrete segments of science inquiry: interacting with students to begin; interacting as they collect data; engaging them in analyzing, interpreting, and synthesizing.	-PCK (orientation to science teaching) -PCK (knowledge of instructional strategies and representations) -PCK (knowledge of student understanding)	
ınquıry	-Promoting diversity,		Instructional context	- PCK (knowledge of curriculum)	
	-Fostering science	Written	Planning	-Subject matter knowledge	
	Assessing for results	commentary	Videotape analysis	-Pedagogical knowledge -Knowledge of context	
	-Reflecting on teaching and learning		Reflection		

# Entries of the AYA Science Portfolio and Required Knowledge Bases

Entry	Standards	Requirements	Specifications	Possible Knowledge Bases		
3. Whole class discussions about science	-Understanding students -Understanding science -Engaging in science learner -Sustaining the learning environment -Promoting diversity, equity, and fairness	One videotape (20 minutes max, unedited)	A continuous, unedited videotape segment: interacting and discussing with students; showing scientific discourse among students; developing students' reasoning & thinking skills about important scientific ideas	-Subject matter knowledge -Pedagogical knowledge -Knowledge of context -PCK (orientation to science teaching) -PCK (knowledge of student understanding) -PCK (knowledge of instructional		
	-Assessing for results -Reflecting on		Instructional context	strategies and representations)		
	teaching and learning	Written	Planning	curriculum)		
		commentary	Videotape analysis	-PCK (knowledge of assessment)		
			Reflection			
	-Reflecting on	Description and analysis (10 pages max)	Activities or accomplishments significant in the teaching context and what impact they had on student leaning (8 accomplishments max)			
4. Documented accomplishment: contributions to student learning	teaching and learning -Developing collegiality and leadership -Connecting families	Documentation (16 pages max)	Supporting the accomplishments; why are they significant?	-Knowledge of context		
	and the community	A reflective summary (2	Patterns in accomplishments (within the last 5 years)			
		pages max)	What is most effective regard to student learning			

#### Appendix C

#### Interview Questions

#### Interview #1: Backgrounds & Orientations to Science Teaching

- 1. Could you tell me about your background in science and science teaching?
- 2. What do you see as your teaching strengths?
- 3. What areas do you feel are relatively weak in your teaching?
- 4. What is science teaching in your mind?
- 5. Could you describe what your science classes look like? What are the characteristics of your science teaching?
- 6. Could you tell me what you see as the reasons for learning science in high school? What are your goals for your students?
- 7. What do you think makes science difficult for students? How would you help the difficulties students have in learning science? What could make the study of science easier for students?
- 8. Could you tell me about the classes you are teaching this semester? How are the classes organized?
- 9. Could you tell me about the students in your (AP, CP, honors or gifted) classes?

#### Interview #2: Planning for a Class (or a Unit)

- 1. Have you taught this unit before?
- 2. How comfortable are you with the subject matter knowledge within this unit that you are teaching?
- 3. What are your goals for this unit?
- 4. What subject matters or concepts do you expect students would have difficulties with? Why do you think so?
- 5. What kinds of students' misconceptions associated with this unit have you noticed? How would you help them correct the misconceptions?
- 6. What kinds of things do you take into consideration in planning this unit?
- 7. How do you create individual goals or objectives for each topic or class compared to creating for units?

8. How do you plan to assess student learning on this unit? What evidence are you looking for that students have been successful in addressing the goals for the lessons?

#### Interview #3: Retrospective Interview on Teaching a Class (or a Unit)

- 1. Could you tell me about your teaching the unit on \_\_\_\_\_.
  - a. How did the unit go?
  - b. How would you change the unit if you were to teach it again? Why?
- 2. What do you consider the most effective teaching moment was in teaching this unit? (Alternative: What was one of your successes as a teacher during the past week?) Why? How did you achieve? Why did it work? What signaled you that students were learning?
- 3. What do you think the students got out of the unit?
- 4. How did you know that students were learning?
- 5. How would you change the unit if you were to teach gifted class (honors class, CP class, or AP class)? Why?
- 6. With specific examples of representations, strategies, activities, etc used by the teacher during teaching the unit:
  - a. Why did you decide to use this?
  - b. Did you do this activity prior to your involvement with NBC? If so, has your thinking about this changed as a result of participating in the NBC process?
  - c. What evidence did you have that this worked? What counts high levels of accomplishment for this activity? How did you know whether it was effective?

#### Interview #4: Changes Occurred During the NBC PCP

 Have you made any changes in ways to represent science subject matter recently? If so, why?

How the NBC PCP influence the changes?

 Have you made any changes in ways to interact with students recently? If so, why?

How the NBC PCP influence the changes?

3. Have you made any changes in teaching strategies, classroom activities, or classroom management skills recently?

If so, why?

How the NBC PCP influence the changes?

4. Have you made any changes in ways to assess student learning recently? If so, why?

How the NBC PCP influence the changes?

5. Have you experienced your subject matter knowledge is deepen or broaden recently? If so, why?

How the NBC PCP influence the changes?

6. Have you noticed any changes in student performance since your involvement with NBC?

#### **Interview #5: Giftedness of Students**

- What would you characterize gifted students in science classrooms from your experiences? (Cognitive, affective, and social aspects)
- What are instructional challenges you encountered which were caused by unique characteristics of gifted students? How did you handle those challenges?
- 3. How do you take into consideration the characteristics of gifted students in your teaching?

# Appendix D

### Observation and Interview Data Collection Procedure

### Table D1

## Data Collection with Amy

Date	Class	Data Source	Indication
11/2/2004	Honors Chem.	- Observation (Statue unit-statue lab)	- Observation #1
		- Pre-/Post-observation interview	- Pre/Post-interview #1
11/4/2004		- Interview (Background & orientation to science teaching)	- Interview #1
11/9/2004	Honors Chem.	- Observation (Statue unit-post lab for statue lab) - Pre-/Post-observation interview	- Observation #2 - Pre/Post-interview #2
11/16/2004	Honors Chem.	<ul> <li>Observation</li> <li>(Statue unit-assessment)</li> <li>Pre-/Post-observation interview</li> </ul>	<ul><li>Observation #3</li><li>Pre/Post-interview #3</li></ul>
11/18/2004	Honors Chem.	- Observation (Pottery unit-glaze lab) - Pre-/Post-observation interview	<ul> <li>Observation #4</li> <li>Pre/Post-interview #4</li> </ul>
11/19/2004		- Interview (Gifted students)	- Interview #2
11/30/2004	Honors Chem.	- Observation (Chemical reaction unit-bonding activity)	- Observation #5
		- Pre-/Post-observation interview	- Pre/Post-interview #5
12/8/2004		- Interview (Influence of NBC)	- Interview #3
1/18/2005	Honors Chem.	- Observation (Mendeleev Manor unit-copper lab)	- Observation #6
1/21/2005	Honors Chem.	- Observation (Mendeleev Manor unit-zinc lab) - Pre-/Post-observation interview	- Observation #7 - Pre/Post-interview #7
1/27/2005	Honors Chem.	<ul> <li>Observation</li> <li>(Mendeleev Manor unit-gold lab)</li> <li>Pre-/Post-observation interview</li> </ul>	<ul><li>Observation #8</li><li>Pre/Post-interview #8</li></ul>
2/2/2005	Honors Chem.	<ul> <li>Observation</li> <li>(Mendeleev Manor unit-PowerPoint presentation)</li> <li>Pre-/Post-observation interview</li> </ul>	<ul><li>Observation #9</li><li>Pre/Post-interview #9</li></ul>
2/11/2005	CP Chem.	<ul> <li>Observation (Six substances found on planet earth-Part 1)</li> <li>Pre-/Post-observation interview</li> </ul>	- Observation #10 - Pre/Post-interview #10
2/15/2005	CP Chem.	<ul> <li>Observation (Six substances found on planet earth-Part 3)</li> <li>Pre-/Post-observation interview</li> </ul>	- Observation #11 - Pre/Post-interview #11

### Table D2

## Data Collection with Lucy

Date	Class	Data Source	Indication
11/2/2004	Gifted Chem.	- Observation (Statue unit-statue lab) - Pre-/Post-observation interview	- Observation #1
11/4/2004		- Interview (Background & orientation to science teaching)	- Interview #1
11/9/2004	Gifted Chem.	- Observation (Statue unit-post lab for statue lab) - Pre-/Post-observation interview	- Observation #2 - Pre/Post-interview #2
11/16/2004	Gifted Chem.	- Observation (Statue unit-assessment) - Pre-/Post-observation interview	<ul><li>Observation #3</li><li>Pre/Post-interview #3</li></ul>
11/18/2004	Gifted Chem.	<ul><li>Observation</li><li>(Pottery unit-glaze lab)</li><li>Pre-/Post-observation interview</li></ul>	<ul><li>Observation #4</li><li>Pre/Post-interview #4</li></ul>
11/19/2004	AP Chem.	<ul> <li>Interview (Gifted students)</li> <li>Observation (Chemical reaction unit- molecular geometry)</li> <li>Pre-/Post-observation interview</li> </ul>	<ul> <li>Interview #2</li> <li>Observation #5</li> <li>Pre/Post-interview #5</li> </ul>
11/30/2004	Gifted Chem.	- Observation (Chemical reaction unit-bonding activity) - Pre-/Post-observation interview	<ul><li>Observation #6</li><li>Pre/Post-interview #6</li></ul>
12/8/2004	AP Chem.	<ul> <li>Interview (Influence of NBC)</li> <li>Observation (Crime unit-crime lab)</li> <li>Pre-/Post-observation interview</li> </ul>	<ul> <li>Interview #3</li> <li>Observation #7</li> <li>Pre/Post-interview #7</li> </ul>
12/10/2004	AP Chem.	- Observation (Crime unit-post lab for the crime lab) - Pre-/Post-observation interview	- Observation #8 - Pre/Post-interview #8
1/18/2005	Gifted Chem.	- Observation (Mendeleev Manor unit-copper lab) - Pre-/Post-observation interview	<ul><li>Observation #9</li><li>Pre/Post-interview #9</li></ul>
1/21/2005	Gifted Chem.	<ul> <li>Observation</li> <li>(Mendeleev Manor unit-zinc lab)</li> <li>Pre-/Post-observation interview</li> </ul>	<ul><li>Observation #10</li><li>Pre/Post-interview #10</li></ul>
2/2/2005	Gifted Chem.	- Observation (Mendeleev Manor unit-PowerPoint presentation) - Pre-/Post-observation interview	<ul><li>Observation #11</li><li>Pre/Post-interview #11</li></ul>
3/7/2005		- Follow-up interview	- Follow-up interview

### Table D3

### Data Collection with Jane

Date	Class	Data Source	Indication
11/4/2004		- Interview (Background & orientation	- Interview #1
		(o science teaching)	Observation #1
		- Observation	- Observation #1 Pro/Post interview #1
11/11/2004	CP Chem.	(Cheffical reaction unit-atomic	- Pre/Post-Interview #1
		Bra (Post observation interview	
		Observation	Observation #2
		(Chemical reaction unit-chemical	- Observation $\pi 2$ - Pre/Post-interview $\# 2$
11/16/2004	CP Chem.	bonding/computer simulation)	- 110/10st-interview $\pi 2$
		- Pre-/Post-observation interview	
		- Observation	- Observation #3
11/18/2004	CP Chem	(Chemical reaction unit-review)	- Pre/Post-interview #3
11/10/2004	er enem.	- Pre-/Post-observation interview	
12/10/2004		- Interview (Gifted students)	- Interview #2
12/10/2001		- Observation	- Observation #4
12/14/2004	CP Chem	(Chemical equation unit-stoichiometry)	
12/11/2001	er enem	- Pre-/Post-observation interview	- Pre/Post-interview #4
		- Observation	- Observation #5
1/20/2005	Honors Chem.	(Mendeleev Manor unit-copper lab)	
		- Pre-/Post-observation interview	- Pre/Post-interview #5
		- Observation	- Observation #6
1/26/2005	Honors Chem.	(Mendeleev Manor unit-zinc lab)	
		- Pre-/Post-observation interview	- Pre/Post-interview #6
		- Observation	- Observation #7
2/3/2005	5 Honors Chem. (Mendeleev Manor unit-gold lab)		- Pre/Post-interview #7
		- Pre-/Post-observation interview	
		- Observation	- Observation #8
2/8/2005	CP Chem	(Chemical equation-PowerPoint	
2/8/2003	CI Chem.	presentation of zinc lab results)	- Pre/Post-interview #8
		- Pre-/Post-observation interview	
		- Observation	- Observation #9
		(Chemical equation-review of	
2/14/2005	CP Chem.	stoichiometry/Valentine chemistry	
		cards)	
		- Pre-/Post-observation interview	- Pre/Post-interview #9
		- Observation	- Observation #10
2/28/2005	CP Chem.	(The when, why, and what now of	
		petroleum)	
2/7/2007		- Pre-/Post-observation interview	- Pre/Post-interview #10
3/1/2005		- Interview (Influence of NBC)	- Interview #3

### Table D4

### Data Collection with Susan

Date	Class	Data Source	Indication
1/13/2005		- Interview (Background & orientation to science teaching) - Interview (Gifted students)	- Interview #1
1/26/2005	<ul> <li>AP Biology</li> <li>- Observation</li> <li>(Bacteria unit-classification)</li> <li>- Pre-/Post-observation interview</li> </ul>		- Observation #1 - Pre/Post-interview #1
1/27/2004	AP Biology	<ul> <li>Observation (Bacteria unit- classification/student presentation)</li> <li>Pre-/Post-observation interview</li> </ul>	- Observation #2 - Pre/Post-interview #2
2/4/2005	CP Biology	<ul> <li>Observation</li> <li>(Photosynthesis-chromatography lab)</li> <li>Pre-/Post-observation interview</li> <li>Interview (Influence of NBC)</li> </ul>	<ul><li>Observation #3</li><li>Pre/Post-interview #3</li><li>Interview #3</li></ul>

# Appendix E

# PCK Evidence Reporting Table

Date:	Class/ Period:											Te	acher:		
Orientatio	ns		K of Instructional Strategies and Representation						Kof	# of	V. ef	# of	K of		щ _ с
to Teaching Science		Types of Activities	# of Activities	Тур	es of Language Devices	# of Language Devices	# ofTypes of# ofLanguageContentContentDevicesElaborationElaboration		Students	K of students	Curriculum	of K of Curriculum	Assessment		# 01 Assess
Process		Inquiry-		lanation	Metaphors Analogies		-		Miscon-					Diagnostic	
				Exp	Similes		Depth beyond		ceptions		K of		Types		
Academic rigor		Hands-on		Se	Related Similar		the intended goal of text		т.,		vertical curriculum		of assess.	Formative	
				xample	situation Dissimilar		(Topic Knowledge)		difficulty					Summative	
Conceptual change		Demonst- ration		ves E:	situation Stories/		-								
Didactic				Nantati	Biography		-		Motivation/ Interest						
Activity-		Simulation		Mne	Illustration emonic devices		Breadth beyond the intended goal				K of horizontal curriculum		K of assessment methods		
driven		Problem			Recall/factual Qs Attention-		of text (Domain Knowledge)		Need						
Discovery		solving		stioning	focusing Qs Problem posing Qs										
Project-based science		Investiga-		Que	Action Qs Reasoning Os		-		Diversity				K of	students	
Inquiry		tion			Comparison     Fle       Qs     bey	Flexibility beyond the				Curricular saliency		learni impo	ng goals ortant to in a given		
Guided		Etc.		rgument	Logic Induction		viewpoint of text		Background	l			unit		
inquiry				Ā	Deduction										

## Appendix F

## An Example of the In-Depth Analysis of Explicit PCK

Lucy; Gifted chemistry; Statue unit (Students' presentations of their findings and discussion)

			Analysis			Data Sources
	Observation					
Stud presentation presentation that when an a metal, she metal becau must have p nonmetal."" neither prop compound." his lab. In o misconcepti initiated dis conduct elect discussion of S1: I Lucy is an you wate S2: I pola Lucy S3: Lucy S2: I pola Lucy S3: Lucy S2: I pola	Observation, Pre-/post- observation, Written reflection					
nad gotten t	ne point.	What doe	s the teacher	r know?		
Orientation	K of					Interview Observation
to S/T	SC	K of SU	K of As	K of IS/R	Other Components	
0	0	0	0	0	Teacher efficacy	

	Why does the teacher do what she does?	Data Sources
1.	"Through listening carefully to justification of lab designs and data	Pre-/post-
	analysis and careful questioning allowed me to detect and immediately	observation
	correct any misconceptions that students may have developed." (Written $(W = 0.000)$ )	interview,
2	reflection) (K of IS/R)	Written
2.	"From each group, I'll be able to lead the discussion to emphasize one of	reflection
	the lesson's goals of to focus on prior learning of to explore a new idea	
	developed by the students. (Pre-observation interview) My inquiry lab	
	interview) (Teacher office.cv)	
3	"Individual needs and students'	
5.	logic in applying new concepts to old ones. Inquiry allowed me to	
	discover misconceptions quickly and redirect student thinking through	
	questioning ""Inquiry invites students to make connections between new	
	and old concepts and the real world and to develop scientific habits of	
	mind." (Written reflection) (K of IS/R) (Orientation to teaching science)	
4.	"Many misconceptions were exposed I lab, and I wanted to make sure	
	that everyone could benefit from the inquiry process each group had	
	experienced." - Rationale for post-lab - (Written reflection) (K of IS/R)	
5.	Students' common misconceptions:	
	- When an ionic compound contains a metal, it has all those properties	
	of a metal.	
	- Ionic compounds never conducted electricity (K of SU)	
6.	"Discussion fosters higher level thinking and was an engaging way to	
	finalize my unit on chemical reactions and properties. It was a very	
	effective way for me to assess their ability to blend the process goals and	
	content goals that I had identified for this unit. All students were vested	
	in the discussion since they had their own data with which to compare the	
	understanding and allowed mate assess quickly whether the goals of the	
	lesson were being accomplished. Not only did students have to state their	
	arguments but they also had to defend their answers. Discussion	
	enables students to both demonstrate and witness logical scientific	
	thinking Discussion is like a "verbal essay" and I can quickly assess	
	whether students are achieving the learning goals including	
	understanding chemical concepts and making connections to the real	
	world." (Written reflection) (K of IS/R) (K of As)	
7.	One of her learning goals for this class was that "students are able to	
	understand differences in properties of elements and compounds"	
	(Written reflection) (K of SC)	

Abbreviations: Orientation to ST: Orientation to science teaching; K of SC: Knowledge of science curriculum; K of SU: Knowledge of student understanding; K of As: Knowledge of assessment; K of IS/R: Knowledge of instructional strategies and representations