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Literature Review: Pedagogical Content Knowledge as Specialized Knowledge for Teaching

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Abstract: During the last two decades, many researchers have attempted to understand pedagogical content knowledge (PCK). Now it is time to think about how to apply the theoretical aspects of PCK to practice. In an attempt to address this issue, it is indispensable to review the existing literature on teachers' knowledge bases and PCK. Therefore, the purposes of this paper are to look at how the concept of PCK has been developed and extended over the past two decades as well as to provide a shared understanding of PCK for the practical use of this concept in teacher education programs. The paper begins with a discussion of various models of teachers' knowledge as conceptualized by several renowned researchers, moves on to a review of existing research focusing on the knowledge of science teachers, then examines the literature on PCK as a critical part of teachers' professional knowledge, and finally concludes with an integrated operational definition of PCK that can be employed into designing teacher education programs.

Key words: teacher knowledge, pedagogical content knowledge, teacher education

I. Introduction

Considering teachers as core agents in active reform, the underlying assumption is that teachers possess a body of specialized knowledge that is acquired through both teaching experience and training events, just as such knowledge is acquired in other professions, such as architecture, medicine, and law. On the basis of this specialized knowledge that distinguishes teachers from other professionals, teachers can reason and make pedagogical decisions that will ultimately enhance their students' understanding of science. What does a teacher need to know in order to teach science? The answer depends largely on the identity of the respondent. Some might suggest that content knowledge is most important, while others indicate that pedagogical knowledge or other factors are more essential to teaching. Another area that has recently gained more attention is pedagogical content knowledge (PCK), which is known as the unique combination of content and pedagogical knowledge that helps teachers transform science content into learning experiences for students. This special knowledge has been discussed as one of the main themes in teacher education during the last two decades. (Davis & Krajcik, 2005).

Standard documents in science education put great emphasis on developing teachers' PCK as the crucial element of any effective reform effort (Bybee & Loucks-Horsley, 2001). The National Science Education Standards [NSES] (NRC, 1996) incorporated PCK as an essential component of professional development for science teachers. In doing so, NSES defined PCK as "special understandings and abilities that integrate teachers' knowledge of science content, curriculum, learning, teaching and students," which allows science teachers to "tailor learning situations to the needs of individuals and groups" (p. 62). Since Shulman (1986a, 1986b, 1987) first introduced PCK as a special knowledge required for teaching, numerous educational researchers have sought to formally describe the PCK of teachers. In recent years, the research in this domain has significantly promoted an understanding of a teacher's knowledge base. As a result, it became evident that the knowledge a teacher holds is complex and not just comprised of content and pedagogy.

Despite its ambiguity and complexity, it is clear that this unique knowledge for science teaching represents a class of knowledge that is central to the

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work of science teachers and that would not typically be held by scientists or by teachers who know little about science subject matter. With this said, a retrospective approach is indispensable to look at the evolutionary features of this concept in order to clarify the domain and categories of this knowledge, and then to find and provide promising ways of enhancing the acquisition and development of the knowledge (PCK). Therefore, the purpose of this study is twofold. One goal is to look at how the concept of PCK has been developed and evolved over the past two decades. The other goal is to provide a shared understanding of PCK for the application of this concept into practice.

The paper begins with an exploration of various models of teachers' knowledge bases as conceptualized by several renowned researchers from generic to subject-specific approach. This investigation was a necessary process to understand how PCK is placed as a factor that influences teaching practice. The paper then moves to review the literature on PCK, a critical part of teachers' professional knowledge, focusing on its definition, a variety of conceptualizations and two models of PCK development. Finally, the paper concludes with a concise synthesis of what is known about PCK, and how to bridge it to actual practice.

II. Generic Approach: Teachers' Knowledge Base

Before discussing the various models of teachers' knowledge bases proposed by researchers, it is necessary first to define "teachers' knowledge bases". Adopting the definition of Wilson, Shulman, and Richert (1987), the term "teacher's knowledge base" signifies "the body of understanding, knowledge, skills, and dispositions that a teacher needs to perform effectively in a given teaching situation" (p. 106); e.g., teaching middle school science to a class of sixth graders in an urban school, or teaching chemistry to a class of high school seniors in an elite private school. While most researchers agree that the development and conveying of knowledge is essential to teaching, many of them also highlight that beliefs influence how a teacher performs in the classroom (Tobin *et al,* 1994, Veal, 2004). There has been debate over the definitions of beliefs and knowledge and the relationship between them. As many researchers point out, a teacher's knowledge base is intertwined with his/her belief system, and it is hard to think of each construct separate from each other. (Gess-Newsome, 1999; Kagan, 1990). However, it is necessary to clarify that the purpose of this paper is not to draw a line between knowledge and belief, but to better understand a teacher's knowledge base required for teaching. The attempt to understand the complexity of teachers' knowledge bases has generated a variety of conceptual models; thus, this paper starts with a discussion of the seminal studies in this area from the past two decades.

In a case study of an English teacher, Elbaz (1983) used the term "practical knowledge" to refer to all kinds of knowledge integrated by the individual teacher in terms of personal values and beliefs oriented to her practical situation. In that study, Elbaz focused on the action- and decision-oriented nature of the teacher's situation, construing that teacher's knowledge as a function. Elbaz identified five categories of teachers' knowledge through five in-depth interviews in the study. The categories were: (1) knowledge of self, (2) knowledge of the milieu of teaching, (3) knowledge of subject matter, (4) knowledge of curriculum development, and finally (5) knowledge of instruction (i.e., of students and of the teaching-learning process).

"Knowledge of self" as a teacher encompasses three facets, including knowledge of self as a resource, knowledge of self in relation to others, and knowledge of self as an individual. The "knowledge of the milieu of teaching" represents a teacher's understanding of how social settings interact with his or her actions with regard to the classroom atmosphere, relations with teachers and administrators, and the political milieu.

According to Elbaz (1983), "knowledge of subject matter" serves as the medium within which knowledge of milieu is shaped and knowledge of self is expressed. However, this area of knowledge is difficult to define because of "the constant and inevitable overlap between the subject matter itself, the actual skills being taught, and the view of learning which

guides teaching" (p. 58). This statement includes implicitly the concept of PCK within the knowledge area of subject matter.

Elbaz (1983) views these three areas of knowledge – knowledge of self, of milieu, and of subject matter – as static knowledge. Unlike these knowledge areas, "knowledge of curriculum development" and "knowledge of instruction" develop relative to teaching experience. The "knowledge of curriculum development" represents the teachers' ability to identify a problem, determine students' needs, organize and develop materials, and evaluate students' learning. Finally, "knowledge of instruction" refers to a teacher's understanding of learning theory, students, the teaching process, beliefs about teaching, and the organization of instruction. While Elbaz's study has stimulated further research on teacher's knowledge bases, it has been criticized for its truncated conceptualization of teacher knowledge, emphasizing the practical knowledge that teachers use while disregarding any theoretical knowledge background (Wilson, Shulman, & Richert, 1987.)

In a comparative study of expert and novice mathematics teachers, Leinhardt and Smith (1985) examined the knowledge required for teaching. Leinhardt and Smith argued that teaching draws upon two bodies of knowledge: knowledge of lesson structure and knowledge of subject matter. In their definition (1985), "knowledge of lesson structure" refers to "the skills needed to plan and run a lesson smoothly, to pass easily from one segment to another, and to explain material clearly" (p. 247). On the other hand, "subject matter knowledge" is topic specific. This area of knowledge involves, for elementary school mathematics teachers, "knowledge of the concepts, algorithmic operations, the connections among different algorithmic procedures, the subset of the number system being drawn upon, the understanding of classes of student errors, and curriculum presentation" (p. 247). For Leinhardt and Smith, complete systems of subject matter knowledge for teaching include "multiple representations, understanding of basic arithmetic principles such as the identity function, and multiple linkages across concepts that are used in any one aspect of arithmetic" (p. 269).

The concept of PCK is included implicitly in the category of subject matter knowledge. Although neither Elbaz's (1983) nor Leinhardt and Smith's (1985) work explicitly identified the concept of PCK as an individual category within teachers' knowledge bases, both studies served as stepping stones for the recognition of and subsequent attempts to articulate the concept of PCK.

Researchers at Stanford University (Shulman, 1986b, 1987; Wilson, Shulman, & Richert, 1987) proposed a more comprehensive model of the professional knowledge base for teaching. According to the findings of the study, teachers draw upon many types of knowledge when making decisions in instructional planning and practice. Teachers use (1) knowledge of subject matter, (2) knowledge of curriculum, (3) knowledge of learners, (4) knowledge of educational aims, (5) knowledge of other content, (6) pedagogical content knowledge, and (7) general pedagogical knowledge. Elaborating upon the concept of teachers' knowledge bases, these researchers called special attention to pedagogical content knowledge because this unique knowledge of a teacher – a blending of pedagogy and content – represents "an understanding of how particular topics, problems, or issues are organized, represented, and adapted to the diverse interests and abilities of learners, and presented for instruction" (Shulman, 1987, p. 8).

Grossman (1990) reviewed different definitions of "teachers' knowledge bases" with various components, and incorporated them into four general areas of teacher knowledge (see Fig. 1). These general areas can be seen as the cornerstones of the emerging work on professional knowledge for teaching: (1) general pedagogical knowledge; (2) subject matter knowledge; (3) pedagogical content knowledge; and (4) knowledge of context. In Grossman's (1990) model, "general pedagogical knowledge" includes knowledge and beliefs concerning learning and learners; knowledge of general principles of instruction; knowledge and skills related to classroom management; and knowledge and beliefs about the aims and purposes of education. "Subject matter knowledge" is comprised of two elements: the content of the subject area and the knowledge of the structures of a subject. Gross-

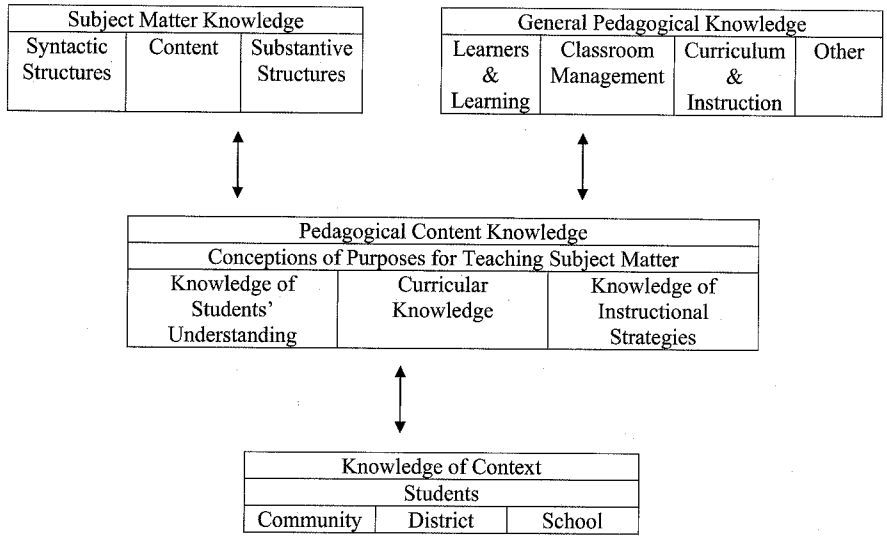

Fig. 1 *Grossman's model of teacher knowledge (1990)*

man adopted Schwab's (1964) notion to elaborate the latter knowledge into "syntactic" and "substantive" structures. According to Schwab, the substantive structure includes the concepts, ideas, understandings, principles, and propositions that characterize the discipline. This structure influences the disciplinary perspectives of a researcher and the research questions he or she pursues. The syntactical structure refers to the methods researchers use to achieve their goals. Grossman agreed that subject matter knowledge heavily influences what and how teachers teach, and is thus strongly related to teachers' PCK.

Defining PCK as knowledge that is specific to teaching a particular subject matter, Grossman asserted that teachers must draw upon that knowledge to formulate "appropriate and provocative representations of the content to be learned" (p. 8). In Grossman's model, PCK is placed in the central part, depending upon three other areas of knowledge – subject matter knowledge, general pedagogical knowledge, and knowledge of context. Lastly, "knowledge of context" is considered as one of the essential components of teachers' knowledge, allowing teachers to adapt to specific students and the demands of school districts.

In summary, researchers have reached a consensus on describing teachers' knowledge bases – including content knowledge, understanding pedagogy and knowledge of context – explicitly or implicitly identifying PCK as the essential portion of teachers' knowledge bases.

Ⅲ. Subject-specific Approach: Science Teachers' Knowledge Base

Since certain aspects of teachers' knowledge are discipline-dependent, it is necessary to specifically review the efforts to articulate the knowledge bases of science teachers. This section focuses on models of teachers' knowledge bases within the field of science education.

With a focus on the training of biology teachers, Tamir (1988, 1991) attempted to reorganize and extend the categories suggested by Shulman's group into a general framework that can be used as a foundation for teacher education. The six categories within this framework are: (1) general liberal education; (2) personal performance; (3) subject matter knowledge; (4) general pedagogical knowledge; (5) subject matter specific pedagogical knowledge; and (6) foundations of the teaching profession. Tamir argued that the term "subject matter knowledge" is more reasonable than the term "content knowledge" because subject matter knowledge accurately includes the content of a subject *per se*, as well as the structure and processes of a given subject. In Tamir's conceptualization of teachers' knowledge bases, the notion of subject matter specific pedagogical knowledge is equivalent to that of PCK. The study suggested that three of those categories – subject matter knowledge, general pedagogical knowledge, and sub-

ject matter specific knowledge—could be substantively addressed in pre-service teacher education. Tamir (1988) was the only researcher who addressed the need for some distinction of *knowledge* (knowing that) from *skills* (knowing how) under each category in the framework of teachers' knowledge.

Signifying that what good teachers know, do, and feel is largely about teaching, and is situated in everyday classroom life, Barnett and Hudson (2001) suggested a model of exemplary science teachers' knowledge called "pedagogical *context* knowledge." This model included four kinds of knowledge: (1) academic and research knowledge, (2) pedagogical content knowledge, (3) professional knowledge, and (4) classroom knowledge. In this model, "academic and research knowledge" refers to: (a) science content knowledge including concepts, facts, and theories; (b) knowledge about the nature of science—including issues in the history, philosophy, and sociology of science—as well as the relationships among science, technology, society, and environment; and (c) knowledge about how and why students learn. "Professional knowledge" refers to the knowing of teaching, acquired through unconsciously-reflected experience—including the political and sociological knowledge of schooling, as well as the professional knowledge of education. The last category, "classroom knowledge," is the knowledge that teachers have of their own classrooms and students, which is entirely situational and specific to each individual teacher. Using this framework to analyze interviews with science teachers about the ways in which they design and implement science lessons, Barnett and Hudson (2001) asserted that this model of pedagogical context knowledge provides a simple and effective way of examining teachers' views and the knowledge upon which they draw when they teach or talk about their teaching.

Carlsen (1999) reformulated science teachers' knowledge into five general categories: (1) knowledge about the general educational context, including nation, state, community, and schools; (2) knowledge about the specific educational context, including the classroom and students to be taught; (3) general pedagogical knowledge; (4) subject matter knowledge, including syntactic and substantive structures of science, as well as the nature of science and technology; and (5) pedagogical content knowledge. In an attempt to explore teachers' knowledge from post-structural viewpoints, Carlsen (1999) explicated knowledge bases for teaching by adding subcategories reflecting recent developments in educational research and science education reform.

Looking at recent research on science teachers' knowledge, it is clear that most researchers have posited PCK as a crucial part of that knowledge, because it prompts teachers' pedagogical decisions and strategies with regard to presenting subject matter to their students. In the following sections, literature pertaining to PCK—particularly focusing on the definition and nature of PCK—will be reviewed. Following that, different conceptualizations of PCK will be discussed.

IV. Pedagogical Content Knowledge (PCK)

1. Definition of PCK

In an attempt to redress the evaluation of teachers in mid 1980s, Shulman (1986b) denied that the competence of teachers dwells on the teacher's management of the classroom and brought to light the critical features of teaching with the stress on three categories of content knowledge—subject matter content knowledge, pedagogical content knowledge and curricular knowledge. In highlighting the importance of these three knowledge domains, he identified PCK as "the most useful forms of content representation, the most powerful analogies, illustrations, examples, and demonstrations—in a word, the ways of representing and formulating the subject that makes it comprehensible for others" (p. 9). This area of knowledge also includes "an understanding of what makes the learning of specific topics easy or difficult: the conceptions and preconceptions that students of different ages and backgrounds bring with them to the learning of those most frequently taught topics and lessons" (p.9).

Additional articles by Shulman and his colleagues further developed the conceptions of the domain of teacher knowledge and knowledge categories for teaching. PCK was placed by Shulman (1987) as one of seven categories of knowledge base for teaching, equally aligned with content knowledge, general pe-

dagogical knowledge, curricular knowledge, knowledge of learners, knowledge of educational contexts, and knowledge of the philosophical and historical aims of education. PCK was defined as:

> The special amalgam of content and pedagogy that is uniquely the province of teachers, their own special form of professional understanding··· Pedagogical content knowledge··· identifies the distinctive bodies of knowledge for teaching. ···Pedagogical content knowledge is the category most likely to distinguish the understanding of the content specialist from that of the pedagogue (Shulman, 1987, p. 8).

The National Science Education Standards (NSES) put great emphasis on developing the PCK of science teachers. NSES defined PCK as "special understandings and abilities that integrate teachers' knowledge of science content, curriculum, learning, teaching and students," which allows science teachers to "tailor learning situations to the needs of individuals and groups" (NRC, 1996, p. 62).

2. Various Conceptualizations of PCK

Since the introduction of the concept of pedagogical content knowledge (PCK), educational researchers have attempted to describe and understand the PCK of teachers. However, definitions of PCK and attempts to measure it have varied greatly. Table 1 summarizes different conceptualizations of PCK by various researchers.

Elaborating upon an understanding of teachers' knowledge bases, Shulman (1986b, 1987) identified initially two key components of PCK. The first category is knowledge of comprehensive representations of subject matter, which encompasses the ways of representing and formulating the subject in order to make it comprehensible to others. Powerful analogies, illustrations, explanations, and demonstrations fall into this category. The second category is teacher understanding of content-related learning difficulties. Knowing students' preconceptions—and which of those are misconceptions—allow teachers effectively use knowledge of strategies to reorganize the learners'

Table 1
Different conceptualizations of PCK

	Knowledge of:							
Scholars	Subject matter	Representations and instructional strategies	Student Learning and conceptions	General Pedagogy	Curriculum and Media	Context	Purposes	Assessment
Shulman (1986b)	a	PCK	PCK	a	a	a	a	b
Tamir (1988)	a	PCK	PCK	a	PCK	b	b	PCK
Grossman (1990)	a	PCK	PCK	a	PCK	a	PCK	b
Marks (1990)	PCK[1)]	PCK	PCK	b	PCK	b	b	b
Cochran, et al. (1993)	PCKg[2)]	b	PCKg	PCKg	b	PCKg	b	b
Fernandez-Balboa & Stiehl (1995)	PCK	PCK	PCK	b	b	PCK	PCK	b
Magnusson, Krajcik, and Borko (1999)	a	PCK	PCK	a	PCK	a	PCK	PCK
Carlsen (1999)	a	PCK	PCK	a	PCK	a	PCK	b
Loughran et al. (2001)	b	PCK	PCK	b	PCK	b	PCK	PCK

a: distinct category in the knowledge base for teaching, b: not discussed explicitly

1) PCK: Pedagogical Content Knowledge a: distinct category in the knowledge base for teaching
2) PCKg: Pedagogical Content Knowing b: not discussed explicitly

understanding.

In an attempt to refine Shulman's work, Grossman (1990) developed an expanded definition of PCK that included four central components: (1) conceptions of purposes for teaching subject matter; (2) knowledge of students' understanding; (3) curricular knowledge; and (4) knowledge of instructional strategies. With this framework, Grossman then examined the influence of teacher education on teachers' knowledge growth, identifying four possible sources of PCK: (1) apprenticeship of observation; (2) subject matter knowledge that influences personal preferences for specific purposes or topics; (3) specific courses during teacher education; and (4) classroom teaching experience. According to Grossman's scheme, teachers rely on their apprenticeships of observation, their disciplinary backgrounds, and professional education in constructing their PCK. Teaching experience also directly affects the development and refinement of that knowledge (1990.)

Marks (1990) also expanded Shulman's notion of PCK through a study that was constructed from interviews with fifth-grade teachers and was designed to present PCK in mathematics. Analysis of the interviews resulted in an extended conceptualization of PCK consisting of four main components: (1) subject matter for instructional purposes; (2) students' understanding of the subject matter; (3) media for instruction in the subject matter (i.e., texts and materials); and (4) instructional processes for the subject matter. Marks asserted that these components are highly interconnected, rather than existing as individual elements. One of the more notable points in his conceptualization of PCK is that he drew attention to the media used as tools and resources for instruction. Another distinct point of his model is that the area of instructional processes is described extensively and consists of three domains: student focus, presentation focus, and media focus. This component is an expanded version of the "knowledge of comprehensive representations of subject matter" as originally identified by Shulman (1987).

Based on an explicit constructivist view of teaching, Cochran, DeRuiter, and King(1993) renamed PCK as "pedagogical content knowing" (PCKg) to acknowledge the dynamic nature of knowledge development. In their model, PCKg is conceptualized more broadly than Shulman's view. PCKg is defined as "a teacher's integral understanding of four components of pedagogy, subject matter content, student characteristics, and the environmental context of learning" (Cochran *et al.,* 1993, p. 266).

Exploring how university professors construct and implement generic PCK across several fields, Fernandez-Balboa and Stiehl (1995) drew distinctions between two types of PCK: "specific" PCK, which is particular to the instruction of a specific subject or content area; and "generic" PCK, which is common to instruction across all subjects or content areas. Based on the data obtained from interviews with ten university professors, they identified five components of effective professors' generic PCK: knowledge about (1) the subject matter, (2) the students, (3) numerous instructional strategies, (4) the teaching context, and (5) one's teaching purposes.

In the area of science education, there have been attempts to conceptualize the PCK of science teachers by Carlsen (1999); Loughran *et al.*(2004); Magnusson, Krajcik and Borko (1999); and Tamir (1988). With an extended framework for reorganizing teachers' knowledge, Tamir (1991) conceptualized PCK under the name "subject matter specific pedagogical knowledge," which is comprised of four components: students, curriculum, instruction, and evaluation. Tamir asserted that PCK is a unique area of knowledge handled by instructors who are pedagogical experts in a particular discipline and work with student teachers preparing to teach in that discipline. He dichotomized each component into two elements: knowledge and skill. While "knowledge" refers to "propositional knowledge (knowing that)," "skill" refers to "procedural knowledge (knowing how)" (p. 100). Focusing on the training of pre-service biology teachers at college, each category of the framework is explained in detail using specific examples related to the discipline of biology. Given that Tamir's work is based on evidence from actual courses in pre-service teacher education, this framework seems to provide a more comprehensive guideline for understanding and developing PCK. Fig. 2 presents Tamir's conceptualization of PCK and examples of each element of subject matter-specific pedagogical knowledge.

1. Student
   1.a. Knowledge: Specific common conceptions and misconceptions in a given topic
   1.b. Skills: How to diagnose a student conceptual difficulty
2. Curriculum: How to diagnose a student conceptual difficulty in a given topic
   2.a. Knowledge: The pre-requisite concepts needed for understanding photosynthesis
   2.b. Skills: How to design an inquiry oriented laboratory lesson
3. Instruction (Teaching and management)
   3.a. Knowledge: A laboratory lesson consists of three phases: pre-lab discussion, performance, post –laboratory discussion
   3.b. Skills: How to teach students to use a microscope
4. Evaluation
   4.a. Knowledge: The nature and composition of the Practical Tests Assessment Inventory
   4.b. Skills: How to evaluate manipulation laboratory skills

Fig. 2 *Tamir's conceptualization of PCK (1991, p. 264)*

Magnusson, Krajcik and Borko (1999) defined pedagogical content knowledge to be composed of five components. The first component includes orientations toward science teaching that represent the general ways of viewing science teaching. The second component relates to one's knowledge and beliefs about the science curriculum, including goals, objectives, and specific curricular programs and materials. Knowledge and beliefs about the students' understanding of specific science topics is the third component, which includes students' difficulties and misconceptions associated with specific science concepts. The fourth component consists of a teacher's knowledge and beliefs about assessment in science, and the last component refers to the knowledge and instructional strategies for teaching science, including both subject -specific and topic-specific strategies.

Defining PCK as different from, but related to, "general pedagogical knowledge" and "subject matter knowledge," Carlsen (1999) conceptualized PCK with four components: (1) students' common misconceptions, (2) topic-specific instructional strategies, (3) specific science curricula, and (4) purposes for teaching science. Particularly, he emphasized the first two components with special significance to science education. Carlsen also described topic-specific instructional strategies as "knowledge that science teachers draw upon in choosing and using models, orchestrating substantive classroom discourse, and managing laboratory activities" (p.141).

Meanwhile, in the attempt to understand and portray science teachers' PCK with CoRe (Content Representation) and PaP-eRs (Professional and Pedagogical experience Repertoire) approaches, Loughran, Mulhall and Berry (2004) considered five aspects of PCK: (1) approaches to the framing of ideas and effective sequencing; (2) knowledge of students; (3) insightful ways of testing for understanding; (4) knowledge of difficulties and limitations connected with teaching; and (5) knowledge of alternative conceptions. Including these components, Loughran *et al.* (2004) developed the CoRe matrix of eight questions – which include these five components of PCK – to codify teachers' PCK related to a specific content area. This method was suggested as "a way of collecting science teachers' PCK and portraying it in an articulable and documentable form" (p.381).

Although the concept of pedagogical content knowledge is still difficult to pin down theoretically, it is clear that this knowledge for science teaching

represents a class of knowledge that is central to science teachers' work and would not typically be held by scientists or by teachers who know little of science subject matter. Therefore, the extensive definition of PCK that emerges from the foregoing literature review is that PCK encompasses the knowledge and its applications that science teachers incorporate into their pedagogical action. A teacher's PCK facilitates students' better understanding of scientific concepts and encourages students' scientific inquiry by using effective instructional strategies, representations, and assessment tools within diverse teaching situations.

3. Models of PCK Development

Gess-Newsome (1999) presents two models for pedagogical content knowledge development: the integrative and transformative model. The comparative overview of these two models is presented in Table 2. To distinguish between the two models, a "mixture versus compound" analogy was used. In the integrative model, the knowledge domains of subject matter, pedagogy, and context tend to exist as separate entities, like chemical elements in a mixture. On the other hand, PCK in the transformative model is recognized as a synthesized knowledge base for teaching, as in a chemical compound.

For beginning teachers, the integrative model is more appropriate, since beginning teachers tend to rely more heavily on one domain of knowledge rather than drawing simultaneously from all domains, as is the case with an expert teacher (Gess-Newsome, 1999). A variety of conceptualizations of PCK seem to come from these two different viewpoints. With its description of PCK as comprising two primary components – knowledge of (1) students and (2) instructional strategies and representations – Shulman's notion of PCK might be equivalent to that of the integrative model. Meanwhile, as other researchers acknowledged PCK as being essentially a transformative model, they expanded the concept of PCK, adding other components, including knowledge of subject matter, curriculum, purpose, context, and assessment to the original two components. However, since it is hard to draw a distinct line between these two models, it may be useful to place PCK on a continuum of models of teacher knowledge, with the integration model at one end and the transformative model at the other end.

Marks (1990) discussed the development of PCK as an integrative process revolving around the interpretation of subject-matter knowledge and the specification of general pedagogical knowledge. Marks also asserted that it is impossible to distinguish PCK from either subject matter knowledge or general pedagogical knowledge. Also viewing PCK as integrated knowledge, Fernandez-Balboa and Stiehl (1995) suggested that enhancing any of the components would enhance PCK as a whole.

Table 2

Overview of Integrative and Transformative models of teacher knowledge (Gess-Newsome, 1999, p. 13)

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

4. Shared Understanding of PCK

Although conceptualizations of PCK have varied greatly, there is shared understanding of PCK, which is twofold: (1) PCK is the experiential knowledge that is acquired through the classroom experience (Grossman, 1990; NRC, 1996; Baxter & Lederman, 1999; Gess-Newsome, 1999; Magnusson *et al.,* 1999; Van Driel *et al.,* 2001), and (2) PCK is the integrated set of knowledge, including various components, which teachers develop in the context of the teaching situation (Marks, 1990; Ferdandez-Balboa & Stiehl, 1995; Van Driel *et al.,* 1998; Gess-Newsome, 1999; Loughran *et al.,* 2001; 2004).

V. Discussion

There has been considerable debate about the definition and conceptualizations of PCK as Shulman (1987) theorized the seven categories of knowledge without elucidation of these categories. Given the many studies that addressed the complexity of PCK since its introduction (Van Driel, *et al.,* 1998; Loughran *et al.,* 2001; 2004), it is clear that the conception of PCK is still difficult to articulate. However, most research efforts in the area of PCK ratify that PCK is a special construct to describe teacher's cognition, such as beliefs, values and conceptions, and to be the significant force affecting teaching. Although the survey of literature concludes that no consensus of definition has emerged yet, it is apparent that PCK should be activated in teaching practices and this knowledge would not typically be held either by scientists or by teachers who know little science content. Therefore, the operational definition of PCK is likely much broader than "the unique knowledge" required for teaching science. It also encompasses "the use of that knowledge" by teachers in the process of their pedagogical decision -makings and actions.

Although there is prolific research on PCK, and though some consensus exists on some aspects of PCK, there is no universally accepted conceptualization of it to date. In trying to make sense of this complexity, this review work was conducive to identify four components of PCK that are commonly found in various conceptualizations: the knowledge of (1) students' understanding, (2) instructional strategies and representations, (3) curriculum, and (4) purposes. If these four categories, defined in common by researchers in this discipline, are the same ones that science teachers perceive to be their unique professional knowledge domains, both pre-service and in-service teacher education programs should be designed in a manner that integrates these four components.

PCK has been characterized as an experiential knowledge because it is often thought to be d-eveloped through classroom experience (Baxter & Lederman, 1999; Gess-Newsome, 1999; Grossman, 1990; Magnusson, Krajcik, & Borko, 1999; NRC, 1996; Van Driel, Beijaard, & Verloop, 2001). Therefore, it is understood that pre-service or beginning teachers usually have limited or minimal PCK. The PCK of expert science teachers involves an integrated understanding of teaching science through "trial and error in teaching situations, continual thoughtful reflection, interaction with peers, and much repetition of teaching science content" (NRC, 1996, p. 67). In this aspect, collaborative work between experienced teachers and beginning teachers through professional development programs can be an effective way to foster the growth of PCK of beginning teachers. The deeper PCK base in science teaching held by experienced teachers is closely related to interaction in the collaborative work; through the process of interaction, such a knowledge base provides the foundation and context that helps beginning teachers to develop their own expertise (Wang & Odell, 2002).

Pre-service courses can also initiate the development of PCK in science teachers; consequently, teacher educators need to make concerted efforts to build such knowledge. In order to do this, pre-service science teachers need to be made aware of the methods and strategies in science education, and have opportunities to learn about science. Furthermore, this effort should occur during the field experience portion of a teacher education program, as well as at the university. PCK is a "transformative" construct, since content and pedagogy are integrated and transformed into classroom practice (Gess-Newsome, 1999).

The literature review on this topic reveals that

empirical research over a longer period of time is necessary for a better understanding of teachers' PCK. Since many researchers have addressed the experiential nature of PCK, empirical study on how PCK transforms over varying numbers of years of teaching experience is also necessary. A comparative study between beginning teachers and experienced teachers would be appropriate for identifying the differences in their respective PCK conceptualizations. Conducting a longitudinal study focusing on a teacher's development of PCK will also be useful for capturing the evolutionary features of PCK development. The findings of such studies will contribute to generating an effective model of professional development designed to support teachers over the course of their teaching careers.

References

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

Baxter, J.A. and Lederman, N.G., (1999). Assessment and measurement of pedagogical content knowlege. In J. Gess-Newsome and N. G. Lederman (Eds.), *Examining pedagogical content knowledge: PCK and science education* (pp. 147-161). Netherlands: Kluwer Academic Publisher.

Bybee, R. W. & Loucks-Horsley, S. (2001). National Science Education Standards as a catalyst for change: The essential role of professional development. In J. Rhoton & P. Bowers (Eds.), *Issues in science education: Professional development planning and design* (pp. 1-12). Arlington, VA: NSTA.

Carlsen, W. (1999). Domains of teacher knowledge. In J. Gess-Newsome and N. G. Lederman (Eds.), *Examining pedagogical content knowledge: PCK and science education* (pp. 113-144). Netherlands: Kluwer Academic Publisher.

Cochran, K.F., DeRuiter, J.A., King, R.A. (1993). Pedagogical content knowing: an integrative model for teacher preparation. *Journal of Teacher Education,* 44(4), 263-272

Davis, E. A., & Krajcik, J.S. (2005). Designing educative curriculum materials to promote teacher learning. *Educational Researcher,* 34(3), 3-14.

Elbaz, F. (1983). Teacher Thinking: A Study of Practical Knowledge. New York: Nichols Publishing Company.

Fernandez-Balvoa, J. and Stiehl, J. (1995). The generic nature of pedagogical content knowledge among college professors. *Teaching & Teacher Education,* 11(3). 293-306.

Gess-Newsome, J. (1999). Pedagogical content knowledge: an introduction and orientation. In J. Gess-Newsome and N. G. Lederman (Eds.), *Examining pedagogical content knowledge: PCK and science education* (pp.3-pp.17). Netherlands: Kluwer Academic Publisher.

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

Kagan, D.M. (1990). Ways of evaluating teacher cognition: Inferences concerning the Goldilocks Principle. *Review of Educational Research,* 60, 419-469.

Leinhart, G., & Smith, D. (1985). Expertise in mathematics instruction: Subject-matter knowledge. *Journal of Educational Psychology,* 77, 247-271.

Loucks-Horsley, S., Hewson, P., Love, N., and Stiles, K. E. (1998). *Designing professional development for teachers of science and mathematics.* Thousand Oaks, CA: Corwin.

Loughran, J., Milroy, Berry, A., Gunstone, R., & Mulhall, P. (2001). Documenting science teachers' pedagogical content knowledge through PaP-eRs. *Research in Science Education.* 31, 289-307.

Loughran, J., Mulhall, P., & Berry, A. (2004). In search of pedagogical content knowledge in science: developing ways of articulating and documenting professional practice. *Journal of Research in Science Teaching.* 41(4), 370-391.

Magnusson, S., Krajcik, J., & Borko, H. (1999). Nature, sources, and development of pedagogical content knowledge for science teaching. In J. Gess -Newsome and N. G. Lederman (Eds.), *Examining pedagogical content knowledge: PCK and science education* (pp.95-132). Netherlands: Kluwer Academic Publisher.

Marks, R. (1990). Pedagogical content knowledge :From a mathematical case to a modified conception. *Journal of teacher education,* 41(3). 3-11.

National Research Council. (1996). *National Science Education Standards.* Washington, DC: National Academy.

Schwab, J.J. (1964). The structure of disciplines: Meanings and significance. In G.W. Ford & L. Pugno (Eds.), *The structure of knowledge and the curriculum.* Chicago: Rand McNally.

Shulman, L. S. (1986a). Paradigms and research programs in the study of teaching: A contemporary perspective. In M. C. Wittrock (Ed.), *Handbook of research on teaching* (3rd ed., pp. 3-36). New York: Macmillan.

Shulman, L. S. (1986b). Those who understand: Knowledge growth in teaching. *Educational Researcher,* 15(2), 4-14.

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

Tamir, P. (1988). Subject matter and related pedagogical knowledge in teacher education. *Teaching and Teacher Education,* 4(2), 99-110.

Tamir, P. (1991). Professional and personal knowledge of teachers and teacher educators. *Teaching and Teacher Education,* 7(3), 263-268.

Tobin, K., Tippins, D.J. and Gallard, A.J. (1994). Research on instructional strategies for teaching science. In D.L. Gabel (ed.) *Handbook of Research on Science Teaching and Learning.* New York: National Science Teachers Association.

Van Driel, J.H., Verloop, N., & de Vos, W. (1998). Developing science teachers' pedagogical content knowledge. Journal of Research in Science Teaching, 35, 673-695.

Van Driel, J. H., Beijaard, D., and Verloop, N. (2001). Professional development and reform in science education: The role of teachers' practical knowledge. *Journal of Research in Science Teaching,* 38(2), 137-158.

Veal, W.R. (2004). Beliefs and knowledge in chemistry teacher development. International Journal of Science Education, 26(3), 329-351.

Wilson, S. M., Shulman, L.S., & Richert, A.E. (1987). "150 different ways" of knowing: Representations of knowledge in teaching, In. J. Calderhead (Ed.), *Exploring teachers' thinking* (pp. 104-124). London: Cassell.