JULIE GESS-NEWSOME

1. PEDAGOGICAL CONTENT KNOWLEDGE: AN INTRODUCTION AND ORIENTATION

THE NATURE AND HISTORY OF PEDAGOGICAL CONTENT KNOWLEDGE

Human beings are inherently complex. We have history, background experiences, emotions, knowledge and goals. We make assumptions, recognize tradition, make sense of information, invoke beliefs, and take action. In some cases we recognize and can articulate the basis for our actions, in others we cannot, seeming to act on instinct.

To make sense of the teaching process and to understand the influence of teachers' knowledge on instruction, it is necessary to reduce the conceptual and contextual complexity of teaching: "scholars must necessarily narrow their scope, focus their view, and formulate a question far less complex than the form in which the world presents itself in practice" (Shulman 1986, p. 6). Knowledge, beliefs, attitudes and values, as well as a myriad of constructs are now used to help reduce, yet still communicate, this complexity. Unfortunately, such terms tend to be unclear and used inconsistently by researchers (Alexander, Schallert, & Hare, 1991).

The attempt to understand and reduce the complexity of teaching to enable its study has generated a variety of metaphors and models. Models of cognition are created from data interpretations, are proposed as conceptual tools to identify and discriminate among hypothesized constructs, and represent inferred relationships among constructs. For researchers, a fundamental task is to select, modify, or create a conceptual model from which to work. Good models, like good theories, organize knowledge in new ways, integrate previously disparate findings, suggest explanations, stimulate research, and reveal new relationships.

In 1986, a new model and set of hypothetical domains of teacher knowledge were offered by Lee Shulman. In reaction to the proliferation of generic educational research, Shulman argued that the study of "teachers' cognitive understanding of subject matter content and the relationships between such understanding and the instruction teachers provide for students" (1986a, p. 25) may be the "missing program" in educational research. He went on to differentiate and call for the study of three types of content understandings and their impact on classroom practice: subject matter knowledge, pedagogical knowledge, and curricular knowledge. Later model refinements renamed the constructs as subject matter knowledge, curricular knowledge, and pedagogical content knowledge (Shulman, 1986b). Of these, pedagogical content knowledge, the "subject matter *for teaching*" (1986b, p. 9, emphasis in original), has prompted considerable interest in both the arenas of research and practice. Shulman described pedagogical content knowledge (PCK) as

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"the most useful forms of [content] representation..., the most powerful analogies, illustrations, examples, explanations, and demonstrations -- in a word, the ways of representing and formulating the subject that makes it comprehensible for others" (1986b, p 9).

Additional articles by Shulman and his colleagues provide 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. PCK was defined as:

> that special amalgam of content and pedagogy that is uniquely the providence of teachers, their own special form of professional understanding....Pedagogical content knowledge...identifies the distinctive bodies of knowledge for teaching. It represents the blending of content and pedagogy into an understanding of how particular topics, problems, or issues are organized, represented, and adapted to diverse interests and abilities of learners, and presented for instruction. 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)

Later work by Shulman and colleagues 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, Shulman, & Richert, 1987). The most comprehensive delineation of the knowledge bases for teaching and their interrelationships is found in Grossman (1990), where she defines "four general areas of teacher knowledge...as the cornerstones of the emerging work on professional knowledge for teaching: general pedagogical knowledge, subject matter knowledge, pedagogical content knowledge, and knowledge of context" (p. 5). Of the four knowledge bases, PCK was anticipated as having the greatest impact on teachers' classroom actions.

In the 13 years since the publication of the *Third Handbook of Research on Teaching*, research into teachers' understandings of subject matter knowledge within disciplines has proliferated. PCK is now a commonly accepted construct in the educational lexicon. Books and chapters have been dedicated to the exploration of teachers' knowledge of subject matter in general (see Ball & McDiarmid, 1990; Brophy, 1991), and in specific disciplines (see Grossman, 1990). In addition, PCK has been used as a major organizing construct in reviews of the literature on teachers' knowledge (see Borko & Putnam, 1995).

With a focus on science education, this book represents the first systematic attempt to synthesize the research on PCK and the model from which it was derived and trace its implications for research and practice. Specifically, this book addresses the following questions: What are current conceptions of PCK? What research exists to support PCK and the related constructs of teacher subject matter knowledge and pedagogical knowledge? How have researchers used both PCK and related constructs to develop lines of research on teacher thinking and learning? And, how

have visions of PCK been applied to teacher preparation program development and evaluation?

ORGANIZATION

Pedagogical Content Knowledge: The Construct and its Implications for Science Education is organized into three major sections: the literature, emerging lines of research in science teacher education, and the impacts of PCK on the development of science teacher education programs. Each section and its chapters are described below.

The Literature

Using subject matter knowledge, pedagogical knowledge, and PCK as primary divisions in the knowledge base for teaching, the first four chapters provide an overview of the research literature that exists within the field of science education and other disciplines. While science education remains a focus, research from mathematics, English, social studies, and reading are included where appropriate.

PCK is commonly believed to be a transformation of at least two constituent knowledge domains: general pedagogical knowledge and subject matter knowledge. Morine-Dershimer and Kent (Chapter 2) open the literature review section with a careful examination of pedagogical knowledge and the presentation of their own model of its derivative components. They posit that the most important aspect of generic knowledge that impacts teaching is context-specific pedagogical knowledge. This knowledge is created through reflection, active processing and the integration of its two contributing components: general pedagogical knowledge and personal pedagogical knowledge. General pedagogical knowledge, gleaned from the research and scholarly literature on classroom organization and management, instructional models and strategies, and classroom communication and discourse, and typically presented in teacher preparation programs, is ultimately combined with personal pedagogical knowledge, which includes personal beliefs and perceptions about teaching. A critical and integrating aspect of pedagogical knowledge is teaching experience, where the subtleties of applying general pedagogical knowledge to classroom situations are learned. The result, context-specific pedagogical knowledge, assists in teacher decision making and contributes most directly to PCK.

In an examination of subject matter knowledge, Gess-Newsome (Chapter 3) concentrates on the instructional implications of secondary teachers' knowledge and beliefs. Synthesizing the literature in science, mathematics, social studies, and English, she suggests five overlapping categories of subject matter research: conceptual knowledge, subject matter structure, nature of the discipline, content-specific teaching orientations, and contextual influences on curricular implementation. Derived from an analysis of the research literature in science and other disciplines rather than from a philosophical position, these categories represent a

departure from the now traditional view of subject matter as falling into the three categories of content, syntactic and substantive structures (Grossman, 1990). Using teacher development as an analytical frame, three critical junctures in the preparation and development of teachers are identified: university content preparation, content-specific methods courses, and the induction period of teaching. Specific strategies and methods to increase the subject matter knowledge of teachers are described, as well as a consideration of theoretical issues surrounding subject matter knowledge research.

Both Chapters 2 and 3 use Shulman's model as a point of departure for further articulation of knowledge ascribed to each domain. The same is true for the review of PCK found in Chapter 4. Magnusson, Krajcik, and Borko argue 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 that is iteratively fueled by its component parts: subject matter knowledge, pedagogical knowledge, and knowledge of context. Five aspects of PCK are identified and described: science curriculum, student understandings of specific science topics, assessment, instructional strategies for teaching science, and orientations toward science teaching. The value of PCK as a unique and identifiable construct is explored and a model of PCK development is forwarded.

The degree of overlap in construct articulation in the first three chapters requires mention. On the surface, both Chapters 2 and 4 include subcategories of instructional models and strategies, while Chapters 3 and 4 include teaching orientations. A careful analysis reveals a more substantial degree of overlapping of ideas and highlights the fuzzy borders between knowledge domains. This overlap demonstrates the difficulty of producing adequate definitions of complex concepts and of establishing clear, discrete, and manageable categories that avail themselves to examination. It also raises questions about this model of teacher knowledge itself. And, while the authors in this book recognize that assigning knowledge to categories is more easily accomplished in theory than practice, knowledge categorization itself has implications. Carlsen (Chapter 5) explores this issue when he claims that many researchers employ structuralist views of teacher knowledge -- where a knowledge domain is recognized and characterized in relation to other forms of knowledge and described independently from the individual. Carslen challenges such views by contrasting them with views from a post-structural framework -- where knowledge is historically and politically situated, idiosyncratic, and embedded in a community as opposed to an individual. Within the post-structural framework, Carlsen examines the theoretical, political and historical background of PCK as it relates to the movement to professionalize teaching. While cautioning about the over reliance on structural models, Carlsen offers his own explication of the knowledge bases for teaching by adding subcategories that reflect recent developments in educational research, science education reform, and socio-cultural perspectives. Separately or juxtaposed, the chapters in this section offer contemporary views of PCK, expanding the conception from how it was originally proposed and providing evidence that a reexamination of the PCK model is perhaps warranted.

Emerging Lines of Research in Science Education

While arguments about the composition of and relationships among teachers' knowledge domains will continue, individuals and research teams have drawn upon the concept of PCK to design and conduct extensive research. The chapters in this section focus specifically on the use of PCK in science teacher education research and teaching. The section opens with an analysis of issues related to the assessment of PCK and concludes with descriptions of research conducted at the elementary and secondary levels.

Baxter and Lederman (Chapter 6) present a review of methods and techniques used for studying PCK and its related domain, subject matter knowledge. While acknowledging the difficulties of accessing teacher cognition, they identify three assessment categories: convergent and inferential measures; concept mapping, card sorts and pictorial representations; and multi-method evaluations with triangulation. Critiques of the assessments include incoming assumptions inherent in the measures, the accuracy of long term memory representation, the clarity or ambiguity of data analysis, and the strength of the assessment versus the intensity of labor in data collection and analysis. In addition to providing data for research, the authors observed that some assessments are useful as teacher development tools through their stimulation of thinking, reflection, and articulation of beliefs and knowledge. Implications of this review of PCK assessments has implications for the literature reported in the first section of this volume. Do all studies of PCK produce equally useful data? Can quantitative measures of PCK ever be effectively developed and interpreted? Baxter and Lederman conclude that, to be useful, measures of PCK must ultimately examine the interaction and consistency across teacher knowledge, belief and reasoned action.

Smith (Chapter 7) takes us on a personal and professional journey as a teacher and researcher of elementary science instruction. In her chapter, Smith explores teacher knowledge development and instructional strategies used to teach children content related to light and shadows. Four separate and interactive aspects of PCK are used in her analysis: illustrative content examples, curriculum and materials, children's naive ideas, and teaching strategies. Through the presentation of her own development as a teacher, researcher, and facilitator of teacher development, Smith reveals the critical dependence of PCK on accurate content understanding, the usefulness of PCK for teachers as they meet the challenges of teaching and changing their practice, and the recursive and reinforcing aspects of learning about content, teaching, and the teaching of content.

In Chapter 8, Lederman and Gess-Newsome trace their development as researchers in the examination of subject matter knowledge as it impacts teaching practice. Early studies revealed a mismatch between the superficial and fragmented subject matter knowledge held by beginning biology teachers and the deep and well-organized knowledge they needed for teaching. From the studies that followed, issues related to the development of subject matter knowledge, the ability of preservice teachers to implement instructional beliefs while struggling with classroom management, and the types of content understandings developed from

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2. THE COMPLEX NATURE AND SOURCES OF TEACHERS' PEDAGOGICAL KNOWLEDGE[1]

SETTING THE STAGE

The concept of pedagogical knowledge has been given short shrift in most discussions of Shulman's (1987) model of teacher knowledge. Shulman himself seems to limit the parameters of pedagogical knowledge in presenting his initial set of categories of teacher knowledge, describing the category only as:

> general pedagogical knowledge, with special reference to those broad principles and strategies of classroom management and organization that appear to transcend subject matter (p. 8).

This limited view of pedagogical knowledge may have been a side effect of Shulman's concern for reinstating content as a critical facet of teacher knowledge, and a contextual feature too much ignored in classroom research at the time. One of the important effects of Shulman's introduction of the concept of pedagogical content knowledge was to restore some balance in the attention given to content vs. pedagogy in research on teaching.[2] Now that that goal has been accomplished, it is time to acknowledge the true complexity of pedagogical knowledge, and to identify the varieties of sources that contribute to that knowledge. A carefully detailed reading of Shulman's full essay (1987) reveals his acknowledgement of several aspects of pedagogical knowledge in addition to the initially identified principles of classroom management and organization. More recent research and scholarship provides further material to flesh out this important category of teacher knowledge.

The conception of pedagogical knowledge to be explicated in this chapter can be summarized briefly in two graphic displays. Figure 1 shows our interpretation of the place of pedagogical knowledge in relation to the full set of categories of teacher knowledge identified by Shulman (1987). Three points are important to note here. First, we contend that knowledge of educational ends and purposes is inseparable from knowledge about evaluation and assessment procedures. Second, we hold that curriculum knowledge is fed by both content knowledge and knowledge of goals/assessment procedures, while pedagogical knowledge is fed by both knowledge of learners/learning and knowledge of goals/assessment procedures. Third, in our display only the category of knowledge of general educational contexts is further delineated to the sub-category of knowledge of specific contexts, but each of the other categories contributing to pedagogical content knowledge can be so delineated, i.e., knowledge of specific content, specific curriculum, specific goals/assessment procedures, specific pedagogy, and specific learners.

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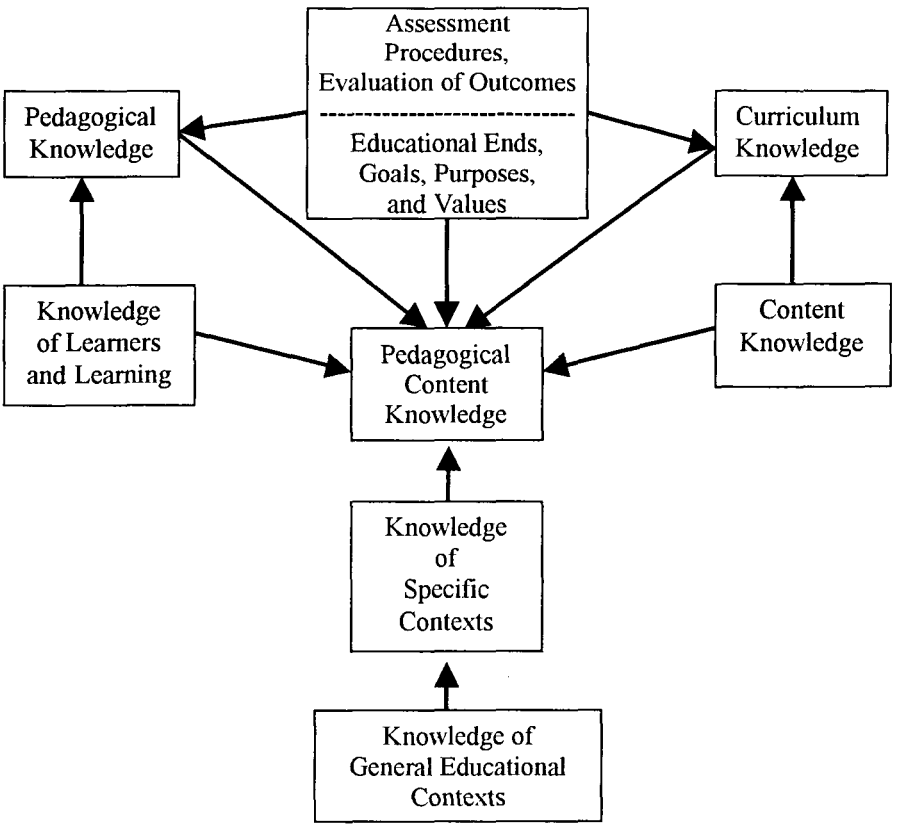

Figure 1. Categories Contributing to Pedagogical Content Knowledge

Figure 2 shows our conception of the various facets of pedagogical knowledge that have been informed by recent research on teaching. Studies in the three major areas contributing to general pedagogical knowledge (classroom organization and management, instructional models and strategies, and classroom communication and discourse) have been attentive to educational goals/evaluation and learners as critical contextual features of pedagogical practice, confirming the relationship depicted in Figure 1. Of particular importance here is the interplay between general pedagogical knowledge, which is derived from the research and scholarly literature, and personal pedagogical knowledge, which is fueled by personal beliefs and personal practical experience. The process of reflection promotes the interplay between general and personal pedagogical knowledge such that perceptions formed

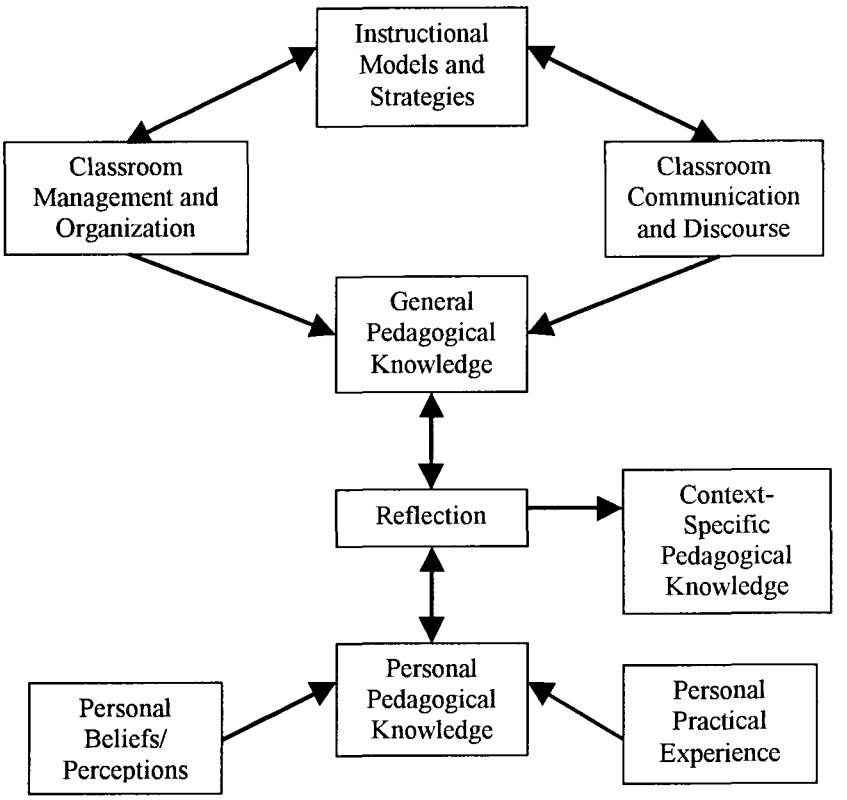

Figure 2. Facets of Pedagogical Knowledge

by personal beliefs and experiences are broadened and made more objective, while conceptions and principles of pedagogy explicated by research are exemplified and contextualized. What results from this process is the context-specific pedagogical knowledge that helps to guide teachers' decisions and actions.

This conceptualization of pedagogical knowledge will serve to organize the content of this chapter. We first discuss the research bases for general pedagogical knowledge in relation to classroom organization and management, instructional models and strategies, and classroom communication and discourse. Next, we consider research on the sources of personal pedagogical knowledge. Finally, we suggest possible implications of this research for science teaching, science teacher education, and future research related to science teaching and teacher education.

RESEARCH CONTRIBUTIONS TO GENERAL PEDAGOGICAL KNOWLEDGE

Classroom Organization and Management

Knowledge about classroom organization and management is well grounded in research on teaching. Process-product studies have repeatedly established consistent relationships between certain teacher behaviors and measurements of student achievement. Many of these relationships contribute to a type of general pedagogical knowledge that can transfer across grade levels and content areas. This knowledge forms a basis for the professional knowledge that beginning teachers acquire through teacher education programs. However, any application of this knowledge must take into account the different contextual factors that might affect the meanings of teacher behavior. In addition, the relationships linking teacher behavior, student achievement, and contextual factors are complex and may be non-linear or may interact with individual student differences (Rosenshine, 1971). Teacher educators promoting acquisition of such knowledge must guard against simplification and insulation from context in order to preserve the integrity and meaning of the observed relationships (Brophy, 1997).

The available knowledge base. Brophy and Good (1986; see also Brophy, 1997) have clearly demonstrated the link between student achievement and teacher behavior through a thorough review and synthesis of process-product research. Their findings have helped form a foundation for continued research that has expanded the understanding of the complexities of behavior-outcome relationships. Their review identifies a number of important relationships between teacher behavior and student achievement. Students learn best from teachers who spend most of their available time focusing on content, who provide learning activities for their students that are appropriate in their level of difficulty, and who also maintain momentum in the pacing of instruction. Students respond well to active teaching which structures the presented material. Clear presentations, a degree of redundancy, and adequate wait-time for student responses are all factors that promote positive student outcomes.

Brophy and Good acknowledge a tension between teaching behaviors that maximize content coverage and the need to move through instruction in small steps that allow student practice, mastery, and integration of subject matter. Such tensions create the arenas where teachers' pedagogical decisions become most critical.

Brophy and Good summarize their synthesis of research with two generalizations: 1) academic learning is influenced by the amount of time students spend on appropriate academic tasks, and 2) students learn more efficiently when their teachers structure new information, relate it to prior knowledge, monitor performance, and provide adequate feedback. They caution however, that research findings must be qualified by grade level, type of objective, type of student, and other contextual factors. In addition, they advise that different teacher behavior patterns may be functionally equivalent in their impact. Their review ends with an acknowledgment of the complexity of pedagogical knowledge related to classroom organi-

zation and management. Better understanding, they argue, can be achieved through attention to variation in factors like the sequencing of content and activities, and teachers' goals and intentions.

Student achievement is also influenced by teachers' processes of classroom management. Teachers manage classrooms effectively through the ability to address more than one classroom event at a time or by demonstrating "withitness" in identifying and resolving problems in a timely and accurate manner. The influence of effective classroom management has been confirmed in research by Emmer and Evertson (1981). Systems of consequences were shown to be effective in promoting desirable student performance, and the way teachers structured the first part of the school year was revealed as having management consequences throughout the school year (Emmer & Evertson, 1981; Evertson, Emmer, Sanford, & Clements, 1983). Teachers who set clear expectations for behavior, academic work standards, and classroom procedures were better classroom managers. The researchers note, however, that these characteristics are subject to contextual influences including the level of student ability, the degree of student homogeneity, and school level management procedures.

Evertson and Harris (1992), in a more recent review of research on classroom management, have concluded that management practice must move beyond a model of behavior modification to create an environment that supports all aspects of learning (see also Evertson, 1997). The use of extrinsic rewards as a management tool has been shown to have the potential for detrimental effects (Brewer, Dunn, & Olszewski, 1988). Research suggests that the effectiveness of reward systems depends on student characteristics such as the locus of motivational control. Externally motivated students work measurably better with externally motivating teachers, whereas students with a developed internal locus of control perform better with a non-directive teacher.

To summarize, the research on classroom organization and management is consistent in noting general principles of teacher behavior that promote student achievement. Students learn more when new information is structured and related to their prior knowledge and experience, when they are assigned academic tasks at appropriate levels of difficulty, and when they are provided with adequate feedback on their task performance. Students learn more when teachers use time efficiently, implement group and instructional strategies with high levels of involvement, communicate rules and expectations clearly, and prevent problems by introducing a management system at the beginning of the school year and implementing it consistently throughout the year. This research demonstrates that teachers' classroom organization and management procedures have a critical impact on student learning. An understanding of this aspect of classroom life is therefore an essential element of pedagogical knowledge. These general principles, however, should not be adopted by teachers in a simplistic fashion. They must be adapted to fit the particular contexts in which teachers work. For example, the degree of structure, the complexity of the academic task, and the type of feedback provided would all appropriately vary depending on contextual factors such as the age, ability, gender, or cultural background of the students being taught. Thus teachers need to become

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3. SECONDARY TEACHERS' KNOWLEDGE AND BELIEFS ABOUT SUBJECT MATTER AND THEIR IMPACT ON INSTRUCTION

Early in my experiences as a university instructor I had the responsibility for leading a micro-teaching course. As the prospective secondary math and science teachers taught 20 minute lessons to their peers emulating the instructional models they had been taught, I was struck by the wide range of developing presentation skills, lesson creativity, content knowledge, and conceptions of teaching that were revealed in the lessons. Of this group, one student in particular caught my attention. Where other students were satisfied teaching traditional lessons such as the parts of the cell or how to apply the Pythagorean Theorem, Sarah's lessons compared and contrasted wild and domestic animals or evaluated different arrangements of natural areas for the attraction of wildlife. Later that year I asked Sarah about the unique teaching topic choices she had made during the class. A bit defensively she explained:

> You know, I'm a biology major. I took all the required course work for my degree, and did quite well. But no one has ever explained to me what it is that I am expected to *teach* about biology. In micro-teaching, I selected lessons that I had seen in workshops or that other instructors had taught. I wasn't trying to be unique. I just didn't know what else to do.

Sarah's answer has intrigued me since that day. What *do* teachers know about the content that they are expected to teach? What lessons about content instruction do they take away from their personal experiences, time in formal education, and induction into the teaching profession? How do teachers perceive their content and how do these perceptions impact the manner in which they organize and deliver instruction? This chapter will examine the research on the knowledge and beliefs about subject matter held by secondary teachers and how this knowledge impacts classroom practice and student understanding.

HISTORICAL CONCEPTIONS OF SUBJECT MATTER KNOWLEDGE

Research on teachers' content knowledge is not new. The earliest attempts at defining good teaching systematically explored the relationship between teacher knowledge and student achievement. Described as the presage-product era of research, relationships were sought between the number and type of courses that

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teachers took, their grade point averages, their scores on various standardized tests and student learning (Druva & Anderson, 1983; Dunkin & Biddle, 1974). Despite weak correlations, the intuitive belief in the relationship between teacher knowledge and student achievement has persisted. More recent extensions of this research (Ferguson & Womack, 1993; Guyton & Farokhi, 1978) have been undertaken, matching preservice teachers' academic performance to their teaching performance. Grades in the students' major accounted for less that 1% of the variance in teaching performance while grades in education courses seemed to be strong predictors of successful teaching. Despite the contributions made by such research to our understanding of teaching, the narrow operational definition of subject matter knowledge, often limited to factual knowledge, and inadequate measures of this understanding provide potential explanations for the decline of this paradigm (Wilson, Shulman & Rickert, 1987).

Research on subject matter understanding was abandoned during much of the process-product era of research only to reemerge later. Information processing research, and studies inspired by the teacher-as-decision-maker movement, brought renewed interest in the nature and influence of teacher content knowledge. Assuming that teachers' thoughts, decisions, and judgements guided classroom actions, Shavelson and Stern (1981) created a model of pedagogical decision making from the extant research literature. Differences in teachers' beliefs and conceptions about their subject matter were directly linked to teachers' judgements about content and were noted as a primary factor influencing planning. Unique to this research was the systematic examination of teachers' beliefs and their impact on practice as opposed to the simple measurement of subject matter knowledge. Two of the six recommendations from their review call for additional research that focuses on the integration of teachers' subject matter understanding and classroom practice, and an examination of the structure of the subject matter that teachers portray to their students.

In 1986, Shulman refocused the attention of researchers again on the importance of teachers' subject matter understandings. In an attempt to define the knowledge bases held by teachers, three initial areas of expertise were delineated: subject matter knowledge, pedagogical knowledge, and curricular knowledge (1986a, p. 26). The definition of content knowledge was expanded in future articles (Shulman, 1986b, p. 9) subsuming subject matter knowledge and curricular knowledge, and adding the new sub-category–pedagogical content knowledge. In 1987, Shulman identified a minimum of seven knowledge bases needed for teaching: content knowledge, pedagogical knowledge, curricular knowledge, pedagogical content knowledge, knowledge of students, knowledge of context, and knowledge of educational goals. Shulman and his colleagues initiated a rich line of research, reframing the definition of subject matter understanding to include the "nature, form, organization, and content of teacher knowledge" (Grossman, Wilson & Shulman, 1989, pp. 25-26). This broadened definition of subject matter knowledge avoided many of the pitfalls of earlier definitions and reopened the possibility of finding links between the knowledge teachers possess, the instructional actions they employ, and the learning, attitudes, and beliefs of the students they teach.

National reform movements across a number of disciplines have recently pushed issues of content knowledge to the forefront of educational concerns. Where early attempts to define subject matter knowledge were based on easily quantifiable measures, new conceptualizations of the advocated outcomes of schooling were portrayed using a new vocabulary. Goals such as science and mathematical literacy for all students, integrated understandings of the unifying concepts within a discipline, and participation in the discourse that surrounds the creation and evaluation of new knowledge have replaced the more simplistic indicators of knowledge such as GPA, national test scores, and rates of course completion (American Association for the Advancement of Science, 1990; National Council of Teachers of Mathematics, 1989; National Research Council, 1996). These changes in intended student outcomes demanded a change in the knowledge expectations and classroom practices of their teachers. Reciting endless lists of vocabulary terms, applying disconnected and meaningless algorithms, and memorizing the names, dates and places associated with fragmented historical events were no longer considered acceptable instructional practice. To teach as advocated by the reforms, teachers must hold deep and highly structured content knowledge that can be accessed flexibly and efficiently for the purposes of instruction (Sternberg & Horvath, 1995; Talbert, McLaughlin & Rowan, 1993). Such knowledge will be essential in order to teach for understanding and to provide authentic learning opportunities for students (Newmann, 1993; Talbert, McLaughlin & Rowan, 1993). Teachers will need to understand the structure and nature of their discipline, have skill in selecting and translating essential content into meaningful learning activities, maintain fluency in the discourse of the community, and recognize and highlight the applications of the field to the lives of their students.

Conceptions of teachers' subject matter knowledge have increased in complexity and sophistication, and so has the research base that supports our understanding of teachers and teacher education. This chapter will review the literature on secondary teachers' subject matter knowledge and beliefs and its impact on teaching. Though the borders among the constructs used to frame teachers' knowledge are fuzzy and perhaps more clearly defined in research than in practice (see McEwan & Bull, 1991), this chapter is limited to teachers' subject matter knowledge rather than pedagogical or pedagogical content knowledge, which are described more fully in Chapters 1, 2, 4 and 5 (this volume).

SELECTION OF RESEARCH AND ORGANIZATION OF THE REVIEW

Determining the best way to organize the literature surrounding teachers' subject matter understandings is not a simple task. For the purpose of this review, the literature has been organized into five broad but overlapping categories of teacher knowledge: conceptual knowledge, subject matter structure, nature of the discipline, content-specific orientations to teaching, and contextual influences on curricular implementation. In all cases, research seeking to relate teachers' knowledge or beliefs to classroom practice are highlighted.

Elementary and secondary teachers are different. In a review of the characteristics of teacher candidates as they enter their first methods course, Brookhart and Freeman (1992) found that both groups held high levels of confidence in their general teaching abilities and valued the nurturing and interpersonal aspects of the teachers' role more than the academic aspects. They differed in their general orientation to teaching, with elementary candidates being more child-centered and secondary candidates more subject-centered. Prospective secondary teachers, having taken more concentrated content-specific course work, held fewer reservations about their subject matter knowledge than their elementary counterparts.

Since elementary and secondary teachers have a different relationship with the content they teach established by their university preparation and their expectations for teaching, this chapter will only focus on the knowledge and beliefs of the secondary teacher. As a content specialist, secondary teachers are the most likely individuals to hold the complex knowledge needed to implement the goals outlined by the national reforms. Since teacher knowledge changes with time and experience, the literature reviewed in each section will progress from novice to the more experienced teacher in order to reveal potential developmental trends across a teacher's career continuum. Finally, in keeping with the organization of the book and the content expertise of the author, this review will focus primarily on studies that have been conducted in the area of science, but will be informed by the research that exists in other disciplines, primarily mathematics, English, and social studies. The chapter concludes with a discussion of the sources of teacher subject matter knowledge and beliefs across a career and the concomitant impact of content-specific knowledge and beliefs on classroom practice. Implications for teacher education research and practice close the chapter.

TEACHERS' KNOWLEDGE OF AND BELIEFS ABOUT SUBJECT MATTER: A CATEGORICAL OVERVIEW

Defining, characterizing, and categorizing teachers' knowledge of subject matter and distinguishing it from closely intertwined beliefs and attitudes has been the topic of numerous articles. Yet, there is no agreement about the definitions of knowledge and beliefs, their relationships, or their relative influence on teaching (Alexander & Dochy, 1995). For example, in a review of a line of research on the knowledge of mathematics teachers, Peterson, Fennema and Carpenter (1991) noted:

> We were struck both by the influences of teachers' knowledge on their thinking about instruction, learning, and assessment, as well as by the pervasive influence of teachers' beliefs about students' knowledge; by the way in which teachers' thinking was influenced both by their beliefs and by their knowledge; and by the interconnections that seem to exist between knowledge and beliefs in the teachers' minds. (pp. 60-61)

They follow with the question, "Where does knowledge end and belief begin?" That such a distinction is difficult to make has implications for any categorization of the knowledge bases held by teachers.

Knowledge is most often described as evidential, dynamic, emotionally-neutral, internally structured, and develops with age and experience (Alexander, Schallert & Hare, 1991; Gagne & Glasser, 1987; Hiebert & Carpenter, 1992). Conceptual knowledge, or knowledge that is rich in relationships, is used in problem solving situations (Post & Cramer, 1989). The amount, organization and accessibility of conceptual knowledge has been shown to distinguish experts from novices (Eraut, 1994; Shuell, 1986). Beliefs, in contrast, are described as both evidential and non-evidential, static, emotionally-bound, organized into systems, and develop episodically (Nespor, 1987; Pajares, 1992). Beliefs have both affective and evaluative functions, acting as information filters and impacting how knowledge is used, organized and retrieved. Beliefs are also powerful predictors of behavior, in some cases reinforcing actions that are consistent with beliefs and in other cases allowing for belief compartmentalization, allowing for inconsistent behaviors to occur in different contexts.

Though the semblance of a simple dichotomy is portrayed by the above use of contrasting terms, the lines between teacher knowledge and beliefs become easily blurred when one looks at classroom practice (Bullough & Baughman, 1997; Grossman, 1990). This creates a conundrum since making distinctions between aspects of teacher's knowledge and beliefs is heuristically convenient for the study of teaching, though flawed in the potential misrepresentation of the dynamic interplay between the constructs that we wish to describe (Carlsen, 1991a). For the purposes of this review, no specific attempts will be made to categorically distinguish between knowledge and beliefs, using instead categories based on the structure of the discipline or the implementation of teacher knowledge and beliefs into classroom practice. Operational definitions of the five categories used in this review are presented below.

Conceptual Knowledge

For the purposes of this review, *conceptual knowledge* is defined as the facts, concepts, principles, and procedures that are typically taught in secondary school classrooms. This knowledge is assumed to be interconnected in nature, impacted by related beliefs, socially constructed, and personally integrated, distinguishing it from knowledge that is strictly declarative in nature (Alexander et al., 1991). This distinction is important since early attempts at establishing relationships between teacher declarative knowledge and teaching were unsuccessful, and richly integrated conceptual knowledge matches most closely the types of student outcomes advocated in the national school reforms. Finally, the rich connections of conceptual knowledge allows for its use in problem solving situations. Since teaching is clearly an ill-structured problem solving context, the organization of and access to stored conceptual knowledge plays a vital role in the reaction of teachers to teaching

SHIRLEY MAGNUSSON, JOSEPH KRAJCIK AND HILDA BORKO

4. NATURE, SOURCES, AND DEVELOPMENT OF PEDAGOGICAL CONTENT KNOWLEDGE FOR SCIENCE TEACHING

INTRODUCTION

"What shall I do with my students to help them understand this science concept? What materials are there to help me? What are my students likely to already know and what will be difficult for them? How best shall I evaluate what my students have learned?" These questions are common for every teacher, and central to describing the knowledge that distinguishes a teacher from a subject matter specialist. In this paper, we argue that such knowledge is described by the concept known as pedagogical content knowledge, and that this concept is critical to understanding effective science teaching. We describe pedagogical content knowledge as the *transformation* of several types of knowledge for teaching (including subject matter knowledge), and that as such it represents a unique domain of teacher knowledge. This chapter presents our conceptualization of pedagogical content knowledge and illustrates how this concept applies to understanding science education from the perspective of the teacher, the science teacher educator, and the science education researcher.

THEORETICAL FOUNDATIONS

Planning and teaching any subject is a highly complex cognitive activity in which the teacher must apply knowledge from multiple domains (Resnick, 1987; Leinhardt & Greeno, 1986; Wilson, Shulman, & Richert, 1988). Teachers with differentiated and integrated knowledge will have greater ability than those whose knowledge is limited and fragmented, to plan and enact lessons that help students develop deep and integrated understandings. Effective science teachers know how to best design and guide learning experiences, under particular conditions and constraints, to help diverse groups of students develop scientific knowledge and an understanding of the scientific enterprise.

These statements about the role of knowledge in teaching is supported by a body of research documenting that science teachers' knowledge and beliefs have a profound effect on all aspects of their teaching (e.g., Carlsen, 1991a, 1993; Dobey & Schafer, 1984; Hashweh, 1987; Nespor, 1987; Smith & Neale, 1991), as well as on how and what their students learn (Bellamy, 1990; Magnusson, 1991). Some of this research was framed by conceptualizations developed by Shulman and his

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colleagues of the diverse knowledge domains that teachers use when planning and teaching (Grossman, 1990; Shulman 1986, 1987; Wilson, Shulman & Richert, 1988). A major contribution of this formulation of the knowledge base for teaching was its acknowledgment of the importance of subject-specific knowledge in effective teaching. A revolutionary feature of this work was the identification of a type of knowledge that was viewed as unique to the profession of teachers: pedagogical content knowledge.[1] Pedagogical content knowledge is a teacher's understanding of how to help students understand specific subject matter. It includes knowledge of how particular subject matter topics, problems, and issues can be organized, represented, and adapted to the diverse interests and abilities of learners, and then presented for instruction. We argue that pedagogical content knowledge, also known as content-specific or subject-specific pedagogical knowledge (e.g., McDiarmid, Ball, & Anderson, 1989), 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.

DEFINING PEDAGOGICAL CONTENT KNOWLEDGE

In our view, the defining feature of pedagogical content knowledge is its conceptualization as the result of a *transformation* of knowledge from other domains (Wilson, Shulman, & Richert, 1988). This idea is depicted graphically in Figure 1, which presents a model of the relationships among the domains of teacher knowledge that primarily has been informed by the work of Grossman (1990). The shaded boxes in the figure designate the major domains of knowledge for teaching.[2] The lines that link the domains of knowledge illustrate the relationship between pedagogical content knowledge and the other domains of knowledge for teaching. The terms on the lines and the arrows at the ends of lines describe the nature and direction of each relationship. Arrows at each end of a line indicate a reciprocal relationship between domains. The figure is intended to depict that pedagogical content knowledge is the result of a transformation of knowledge of subject matter, pedagogy, and context, but that the resulting knowledge can spur development of the base knowledge domains in turn. Grossman conceptualized pedagogical content knowledge as consisting of four components (shown in the figure to the sides of the box representing pedagogical content knowledge). Our conceptualization is very similar, with some modification and the addition of one component. We begin our discussion of the concept of pedagogical content knowledge for science teaching by defining and describing these components.

Components of Pedagogical Content Knowledge for Science Teaching

Building upon the work of Grossman (1990) and Tamir (1988), we conceptualize pedagogical content knowledge for science teaching as consisting of five compo-

nents: (a) orientations toward science teaching, (b) knowledge and beliefs about science curriculum, (c) knowledge and beliefs about students' understanding of specific science topics, (d) knowledge and beliefs about assessment in science, and (e) knowledge and beliefs about instructional strategies for teaching science. These components are shown in Figure 2.[3] In this section, we provide conceptual descriptions and illustrative examples to define the specific knowledge that is represented by each component. In addition, we synthesize findings from research that has assessed teachers' pedagogical content knowledge and, where it has been examined, the impact of that knowledge on science teaching and learning.

Orientations Toward Teaching Science

This component of pedagogical content knowledge refers to teachers' knowledge and beliefs about the purposes and goals for teaching science at a particular grade level. Grossman designated this component as consisting of knowledge of the purposes for teaching a subject at a particular grade level or the "overarching conceptions" of teaching a particular subject. Research in science education has referred to this component as "orientations toward science teaching and learning," (Anderson & Smith, 1987),[4] which we prefer to Grossman's term. An orientation represents a general way of viewing or conceptualizing science teaching. The significance of this component is that these knowledge and beliefs serve as a "conceptual map" that guides instructional decisions about issues such as daily objectives, the content of student assignments, the use of textbooks and other curricular materials, and the evaluation of student learning (Borko & Putnam, 1996).

Orientations toward teaching science that have been identified in the literature are shown in Tables I and II.[5] The orientations are generally organized according to the emphasis of the instruction, from purely process or content to those that emphasize both and fit the national standard of being inquiry-based. Each orientation has then been described with respect to two elements that are useful in defining and differentiating them: the goals of teaching science that a teacher with a particular orientation would have (Table I), and the typical characteristics of the instruction that would be conducted by a teacher with a particular orientation (Table II).

A comparison of the characteristics of instruction that follow from particular orientations reveals that some teaching strategies, such as the use of investigations, are characteristic of more than one orientation. This similarity indicates that it is not the use of a particular strategy but the *purpose* of employing it that distinguishes a teacher's orientation to teaching science. For example, teachers with a discovery, conceptual change, or guided inquiry orientation might each choose to have students investigate series and parallel circuits, but their planning and enactment of teaching relative to that goal would differ. The teacher with a "discovery" orientation might begin by giving his students batteries, bulbs, and wires, and proceed by having them follow their own ideas as the students find out what they can make

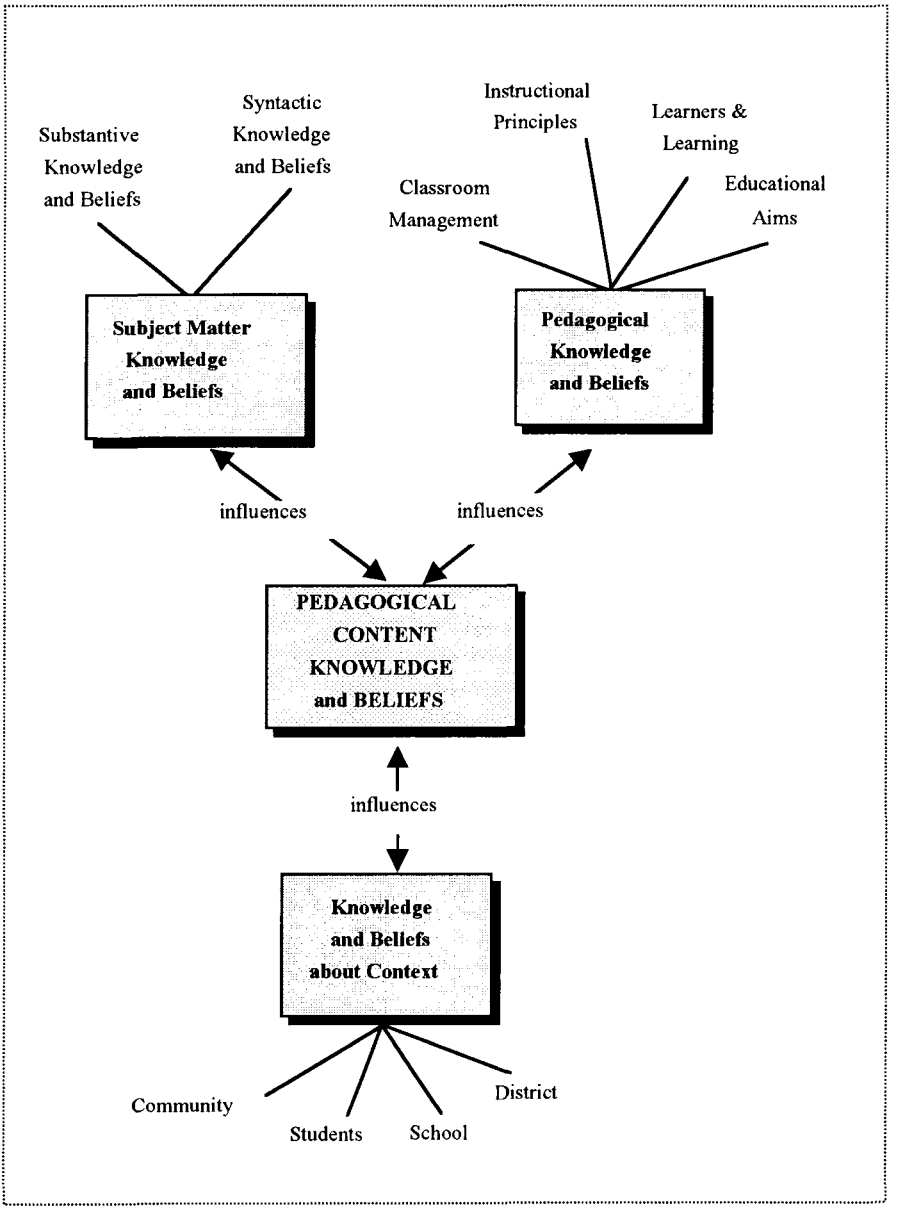

Figure 1. A model of the relationships among the domains of teacher knowledge. [Modified from Grossman (1990)]

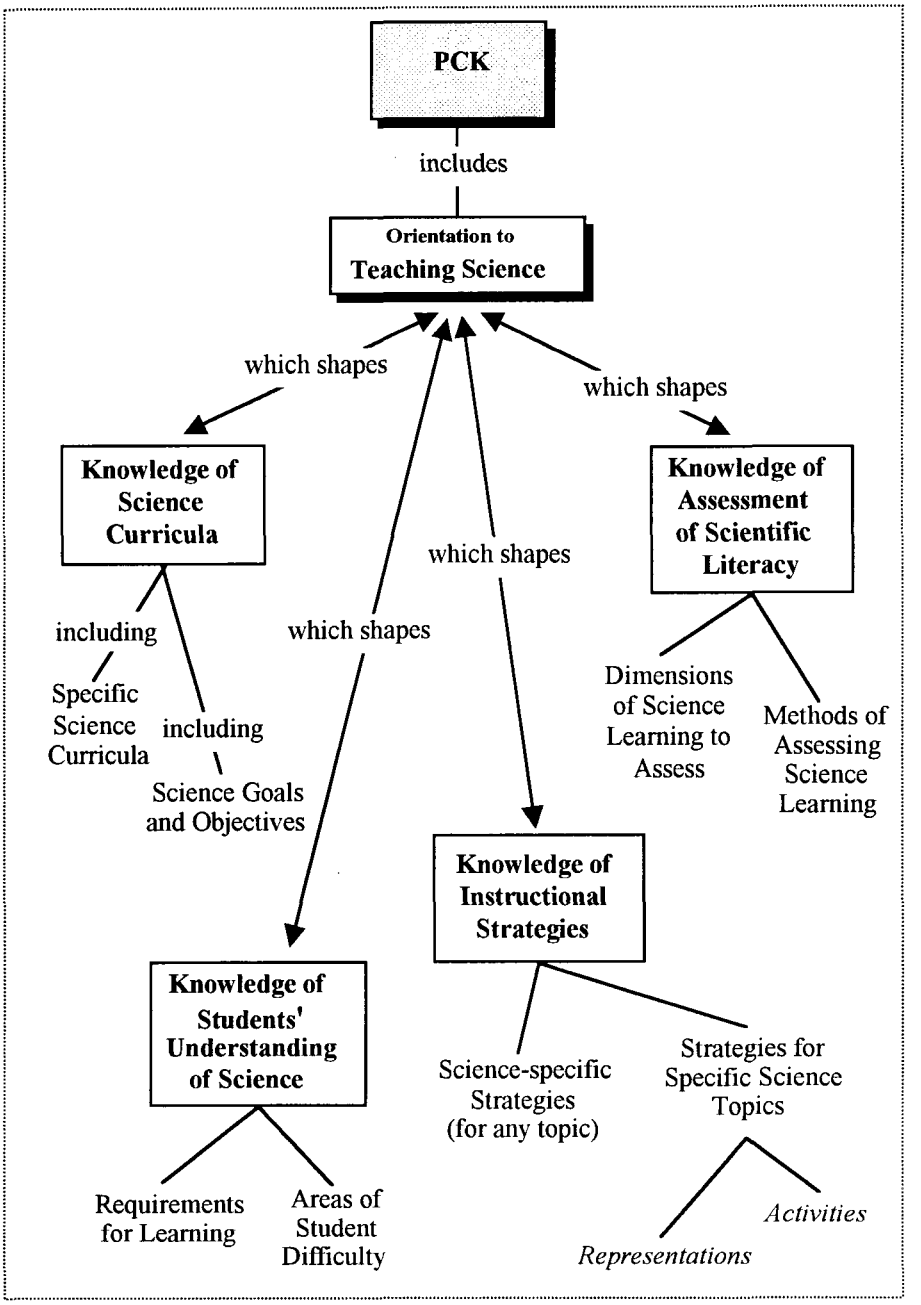

Figure 2. Components of pedagogical content knowledge for science teaching.

WILLIAM S. CARLSEN

5. DOMAINS OF TEACHER KNOWLEDGE

Overview

My goal in this chapter is to examine pedagogical content knowledge (PCK) using structural and poststructural tools. From a structural perspective, PCK can be considered in relation to other types of teacher knowledge, without consideration of historical or political contexts, educational ideologies, or the idiosyncrasies of individual teachers. Such a general approach has many advantages -- it makes sensible the title, "Domains of Teacher Knowledge," for example! -- but it has disadvantages as well. These prompt the second, poststructural perspective -- one that returns the teacher to the center of meaning, that foregrounds historical and political context, and that questions the promise of ideological neutrality.

This chapter provides an overview of pedagogical content knowledge and the more general (for the most part, structural) model of teacher knowledge within which it was created. It also briefly describes the theoretical, political, and historical background of Lee Shulman's original formulation of teacher knowledge, a poststructural move. Finally, I offer some recommendations concerning the use of teacher knowledge domains in contemporary science education. "Pedagogical content knowledge" was invented for two different but related sets of reasons, one set theoretical/empirical in nature, the other political. Some familiarity with these reasons is important for understanding PCK and for using it within the changing landscape of American science education.

A Brief History of Pedagogical Content Knowledge

In the early 1980's, dissatisfaction was growing with the state of American educational research and was already widespread with the status of teaching and school reform in the U.S. (see, e.g., Carnegie Forum on Education and the Economy, 1986; Holmes Group, 1986). In a series of widely read articles, Lee Shulman at Stanford University promoted a paradigm shift in educational research (in part, by "chronicling" it, Shulman, 1986a) and, simultaneously, proposed an approach to educational reform that labeled teaching a profession (Shulman, 1987; Shulman & Sykes, 1986; Shulman, Sykes, & Phillips, 1983). These two goals were complementary in many ways, one being that the view of profession that Shulman proposed was contingent on the existence of a specialized knowledge base of teaching.[1] A paradigm shift in educational research -- or perhaps, more accurately, a shift from overreliance on one predominately psychological paradigm to a multi-

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plicity of paradigms -- would help produce the knowledge base of teaching. By addressing the goal of better research, the political goal of professionalizing teaching could also be addressed. And the cycle would continue: for example, the professionalization of teaching would breathe new life into research, in part by stimulating new perspectives on educational practice via a growing corps of Board-certified teachers and affiliated academic projects.

Most traces of the political dimension of Shulman's work have disappeared from published scholarship on teacher knowledge, leaving pedagogical content knowledge and its conceptual companions dangling in rhetorical space. Some authors have questioned the need for the pedagogical content knowledge construct at all (Carlsen, 1991, April; McEwan & Bull, 1991), generally on epistemological grounds. McEwan and Bull, for example, argued that "all content knowledge, whether held by scholars or teachers, has a pedagogical dimension" (p. 318). Others questioned the "general practice of viewing knowledge as a 'substance'... located in the minds of individuals," and argued for seeing knowledge "as a situated construction of social networks, a textually produced phenomenon rather than an entity with an existence independent of our practices of representation" (Nespor & Barylske, 1991, p. 806).

These objections had little apparent impact on the use of pedagogical content knowledge as a tool in research and teacher education. There is now an interesting literature on science teachers' knowledge, much of it utilizing PCK. There is also evidence, some of it in this book, that, once identified, what we call PCK can be taught to prospective teachers; it might even productively serve as a major organizer for some teacher education curricula. Although PCK may have an epistemologically ambiguous identity, it has certainly proven to be useful.

Nevertheless, both of PCK's motivators -- the empirical and the political-- should be understood, in part because the terrain of American science education is changing significantly and our conceptions of teacher knowledge should change with it. The view of science teaching that has emerged in recent national science curriculum projects is interdisciplinary, socioculturally and technologically informed, and emphasizes the student's role in sense-making and knowledge construction (American Association for the Advancement of Science, 1993; National Research Council, 1996; National Science Teachers Association, 1993). From such a curricular vantage point, Shulman's descriptions of teacher knowledge and its application already seem dated, in part because they draw very heavily on Schwab's structures of the (traditional) disciplines (Schwab, 1964). For example, in describing content knowledge in his 1986 *Educational Researcher* article, Shulman wrote:

> Teachers must not only be capable of defining for students the accepted truths in a domain. They must also be able to explain why a particular proposition is deemed warranted, why it is worth knowing, and how it relates to other propositions, both within the discipline and without, both in theory and in practice. (Shulman, 1986b, p. 9)

Part of Shulman's motivation in making claims like this was political; by defining content knowledge in disciplinary terms, teachers shown to possess it might

strengthen their claim to the rights, privileges, and responsibilities enjoyed by other disciplinary specialists. This was a strategically bold move. The status of teaching clearly needed to be enhanced if the movement to professionalize teaching were to succeed. By adopting disciplinary specialization (in, for example, biology) as the content standard for teachers, two problems could be addressed simultaneously: "How can we define subject matter knowledge in ways that are useful in research?" and "How can we make teaching a more prestigious and rewarding career choice?"

These two questions are still important, but the conceptions of knowledge that inform them need to be updated. This can be done without a major overhaul of Shulman's original formulation of the domains of teacher knowledge. Nevertheless, we should not be surprised to see that the structural weaknesses of a structural perspective remain. The "domains of teacher knowledge" are best viewed as a heuristic, not an immutable roadmap of any real individual's cognitive structure.

Pedagogical Content Knowledge: A Structural View

Structurally, pedagogical content knowledge is a form of teacher knowledge, distinct from other forms and defined by its relationship to those forms. Figure 1 is one view of the domains of teacher knowledge. The five general domains are (a) Knowledge about the general educational context, (b) Knowledge about the specific educational context, (c) General pedagogical knowledge, (d) Subject matter knowledge, and (e) Pedagogical content knowledge.

Note the following structural features[2] of such a view: (1) There is assumed a correspondence between word-labels, concepts, and (in most flavors of structuralism) real-world referents, a correspondence bound into units called *signs*. "Subject matter knowledge" is simultaneously a term, a concept, and something more or less identifiable in the world, for example through teacher testing. (2) Signs do not exist outside a *system*. "Pedagogical content knowledge" is a sign that exists within a system of other signs, one that here includes other forms of teacher knowledge. (3) The meaning of a sign like "pedagogical content knowledge" is established through its *relationship to and difference from* other signs. Here, PCK is defined as different from, but related to, "general pedagogical knowledge" and "subject matter knowledge."[3] (4) This view of teacher knowledge is static, focusing on a moment in time (what Saussure calls the *synchronic*) and eschewing historical analysis, either of an individual teacher's knowledge or of the general knowledge domains. (5) The structure of teacher knowledge might be described using binary distinctions or *oppositions*, as in knowing/not knowing, cognitive/affective, and subject-centered/learner centered.[4] Finally, (6) with its emphasis on describing and ordering teacher knowledge, the view obtains some *ideological neutrality*. No sides are taken concerning what is worth knowing. For example, a component of pedagogical content knowledge is (Knowledge of) "Students' Common Misconceptions," which implies, but does not articulate, that effective science teaching is a process of inducing conceptual change: certainly a prevalent view in science education, but by no means the only view.

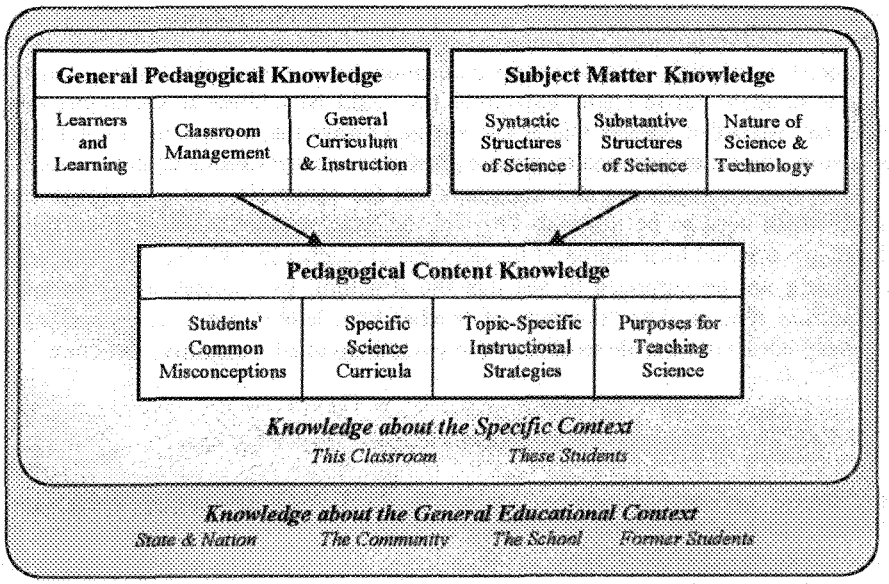

Figure 1. Domains of teacher knowledge

A structuralist approach foregrounds the relationship between forms of teacher knowledge. It supports the consideration of questions like, "How is Biology different from History?" (a structures of the disciplines question), "What substantive structures does a Biology teacher need to understand?" (a teacher education question), and "How might a Biology teacher's knowledge differ from a biologist's?" (a question central to the establishment of teaching as a profession). Much of the appeal of this perspective is that it is reassuring: systematic knowledge is possible; furthermore, that knowledge can be discovered without political disputation. If we assume that pedagogical content knowledge is real, then we can finesse the problem of establishing what veteran teachers *should* know, and instead concentrate on teaching novice teachers what veterans *do* know.

Although Shulman's view of teacher knowledge has structural features, there is little reason to believe that he viewed his model as an immutable template of what teachers should know or do know. In fact, the domains of teacher knowledge differ among the papers he wrote or co-authored. Figure 2 contrasts three that might be considered seminal; some comments on these papers follow.

"Those Who Understand: Knowledge Growth in Teaching" (Shulman, 1986b) was Shulman's 1985 Presidential Address to the American Educational Research Association. The paper's emphasis was on a "missing paradigm" in educational research: subject matter content and teachers' knowledge about that content. Other aspects of teacher knowledge were left to a footnote and another project.[5] Curriculum knowledge, pedagogical content knowledge, and subject matter knowledge

were described as *categories* of the *domain* of "content knowledge." Pedagogical content knowledge was described for the first time in this paper as "the particular form of content knowledge that embodies the aspects of content most germane to its teachability" (Shulman, 1986b, p. 9). It includes "the most regularly taught topics in one's subject area, the most useful forms of representation of those ideas, the most powerful analogies, illustrations, examples, explanations, and demonstrations -- in a word, the ways of representing and formulating the subject that make it comprehensible to others" (p. 9).

Knowledge Category or Domain	Shulman, 1986b	Shulman & Sykes, 1986	Shulman, 1987	Grossman, 1990
Curriculum				
Learners and learning				
Liberal knowledge & skills (general)				
Pedagogy (general)				
Pedagogical content knowledge				
Performance skills				
Philosophy, goals, and objectives				
School contexts				
Subject matter (content)				
Substantive structures of the discipline				
Syntactic structures of the discipline				

Key	
Major category in the model	
Subsidiary category in the model	
Not explicitly referenced in the model	

Figure 2. Domains of Teacher Knowledge: Four Alternatives

"A National Board for Teaching? In Search of a Bold Standard" (Shulman & Sykes, 1986) was a paper commissioned by the Carnegie Forum on Education and the Economy Task Force on Teaching as a Profession. The paper, coauthored with Gary Sykes, analyzed two possible mechanisms for effecting national standards for teachers: a political strategy (which "relies on the constitutionally-based authority of the states to regulate the professions," p. 31) and a market strategy (which "seeks to create demand for teachers at a recognized level of quality," p. 32). Although the authors advocated the latter, they anticipated that a mature standard might well be adopted eventually by states for licensure. Much of the manuscript was an analysis of the political dynamics of standard setting and testing within the teaching