Examining Pedagogical Content Knowledge

Edited by
Julie Gess-Newsome
and
Norman G. Lederman

Published in cooperation with the Association for the Education of Teachers in Science

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From its emergence over two decades ago, the construct of pedagogical content knowledge (PCK) has significantly impacted preservice and inservice teacher education, educational policy, and educational research. PCK has served to re-focus educators' attention on the important role of subject matter in educational practice and away from the more generic approach to teacher education that dominated the field prior to 1975.

This ambitious text is the first of its kind to summarize the theory, research, and practice related to pedagogical content knowledge. The audience is provided with a functional understanding of the basic tenets of the construct as well as its applications to research on science teacher education and the development of science teacher education programs. The authors are prominent educators representing a variety of subject matter areas and K-12 grade levels. Although the focus of the text is science education, it should provide valuable reading for any individuals with interests in professional teacher education.

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Examining Pedagogical Content Knowledge

The Construct and its Implications for Science Education

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The ambitious task of putting together a volume such as this is daunting at best. Although it may not be obvious, the completion of chapter contributions by the authors is far from completion of the project. The individual chapters must then be put together into the text you are now holding. This task involves the creation of subject indices, author indices, table of contents, and extensive copy editing, not to mention general formatting of the text into a coherent whole. As you might imagine, this is a thankless task. We would like to acknowledge the significant contributions and extensive efforts of Mary K. Gfeller, Renée S. Schwartz, and Shiang-Yao Liu, members of the Academy for Excellence in Science and Mathematics Education at Oregon State University, in helping us bring this text to fruition. We are permanently indebted to these individuals for freely volunteering their valuable time to this project.

FOREWORD

The summer of 1983 was quite hot, particularly in Texas. I had been invited to give a lecture at a national research conference on the study of teaching held in Austin at the University of Texas. I purposely chose as my topic the ambiguous title "The Missing Paradigm in Research on Teaching." To my delight, the title had apparently stimulated serious discussions among the participants in anticipation of my lecture. What, they wondered, did Shulman have in mind as "the missing paradigm?" Speculations abounded. Many predicted that I would identify "teacher cognition," the central theme of Michigan State's Institute for Research on Teaching (IRT) which I had directed, as the missing paradigm. Others nominated "context." Still others speculated that it would be "teacher personality." Although I didn't take a formal poll, it appeared that not a single member of the audience anticipated the aspect of teaching and its investigation that I declared missing. Indeed, even as I approached my concluding remarks at the end of a full hour's lecture (I am not, alas, known for my economies of expression), most were shocked when I declared that the missing paradigm was the study of subject-matter content and its interaction with pedagogy.

Perhaps it should not have surprised me, since the centrality of content had eluded me as well for many of the preceding years. I had criticized the reigning program of process-product research for many reasons in the past, primarily its relentless attention to teacher behavior rather than teacher thinking as the focus of "process," and its reliance on standardized achievement tests as the sole indicators of "product." But the more cognitive approaches to the study of teaching, which I had so enthusiastically supported, had treated teachers as generically in their thoughts as Nate Gage or Tom Good had treated them in their actions.

There was an interesting irony in my blindness as well. A major influence on my studies of teachers' thinking had been the research I had conducted from 1968 through the mid-1970s on the reasoning processes of physicians. Perhaps the most salient finding from our studies of medical reasoning (see Elstein, Shulman, & Sprafka, 1978) had been the *domain-specificity* of clinical problem solving. That is, contrary to prevailing medical lore that assumed a general trait of diagnostic acumen in which some physicians were generally better diagnosticians than others, we had demonstrated that diagnostic competence was domain specific rather than general. Nevertheless, although our experience in studying the reasoning and decision processes of physicians was a major influence on the development of new approaches to the study of teaching, we transplanted the emphasis on cognition, but not the insights regarding domain-specificity. Thus, for example, when we studied teacher planning in the IRT, we did so generically.

The ideas that became "pedagogical content knowledge" (or PCK as it was fondly dubbed) first saw the light of print in two key papers. The first, "Those who

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understand: Knowledge growth in teaching," was my April, 1985 Presidential Address to the *American Educational Research Association* and was published about one year later in *Educational Researcher*. The second, "Knowledge and teaching: Foundations of the new reform," was published about a year later in the *Harvard Education Review*. A good deal had happened between the winter of 1985 and the winter of 1987. The earlier paper was one of my first reports of our research on the development of secondary-school teacher knowledge. With support from the Spencer Foundation, we were longitudinally studying the interaction of content knowledge and pedagogical development among a cohort of prospective teachers of science, mathematics, social studies and English at Stanford. During the next two years, I was drawn heavily into directing the research on the assessment of teaching in support of the incipient *National Board for Professional Teaching Standards*. This latter project, supported by the Carnegie Corporation of New York, built directly on the theoretical foundations we had erected in the Teacher Knowledge project (which continued concurrently through 1987).

Our notions of PCK had some interesting consequences for those subsequent initiatives. For example, the National Board opted for a structure that designates domains of certification by content areas as well as developmental levels of students (leading to more than 30 National Board assessments). The Board's view of "what accomplished teachers know and are able to do" is predicated on the age and domain-specificity of pedagogical content knowledge. Moreover, the structure of the Board's teaching portfolios, which include unit design, documentation of teaching, analysis of student work, and substantial reflective analysis of practice, rest heavily on the conception of "pedagogical reasoning and action" that is offered in "Knowledge and teaching."

Other scholars have added substantially to our understanding of the interaction of content and pedagogy. For example, the work of Pamela Grossman and Susan Stodolsky demonstrated how orientations toward content in high school departments of mathematics and English can have a pervasive impact on the faculty members' orientation toward the reform of schools and of teaching. This emphasis on "content as context" has been a productive line of work. It also built on Stodolsky's earlier research on the role of content differences in elementary school pedagogy, persuasively presented in Stodolsky's aptly titled "The subject matters."

Similarly, the contributions of Gaea Leinhardt to the pedagogies of mathematics and of history have helped us to understand the distinctive characteristics of both the discourse and the pedagogies of those fields. Leinhardt and her colleagues have also helped us see that subject-matter domains may well be narrower than their disciplines. Deborah Ball and Hyman Bass are making important inroads to understanding the subtleties of pedagogical content knowledge in the discourse of elementary mathematics classrooms.

An unexpected development was the interest in PCK from the world of higher education. The field of teaching in higher education had been limited by the features of a generic or technical view of teaching. Generic student evaluation forms of teaching, and the more general strategies of teaching improvement characterized by many university centers for teaching and learning had contributed to the view that the quality of teaching had nothing to do with the quality of scholarship in a discipline. Nevertheless, a rhetoric abounded that claimed that teaching and research were closely connected. But how could they be when teaching was seen as generic while research was clearly discipline or domain specific? The concept of pedagogical content knowledge was therefore welcomed in higher education circles because it buttressed the claim that teaching, like research, was domain specific. This implied that teaching as "the transformation of understanding" rested on depth, quality and flexibility of content knowledge and on the capacity to generate powerful representations and reflections on that knowledge. Subsequent projects on the peer review of teaching in colleges and universities, that I pursued in collaboration with Pat Hutchings and Russ Edgerton of the American Association for Higher Education, rested on much of our work on teacher assessment, and grew out of those ideas about PCK.

The Teacher Knowledge and Teacher Assessment projects were blessed with a remarkable group of graduate student scholars who contributed immeasurably to its successes, and who have generally extended the work and corrected its earlier limitations through their own subsequent independent efforts. They included some of the authors who contributed to this volume, such as Jill Baxter and Bill Carlsen, as well as Pam Grossman, Sigrun Gudmundsdottir, Maher Hashweh, Liping Ma, Miriam Gamoran Sherin, Gary Sykes, Suzanne Wilson, and Sam Wineburg, among many others.

A few months ago, a new PhD now embarked on his professorial career approached me at the American Educational Research Association meetings. He was interested in pedagogical content knowledge, the topic of his recent dissertation, and wondered if anyone was working on "it" any more. I assured him that, while I wasn't certain how many people continued to use the phrase, there was every indication that concern with discipline and interdiscipline-specific pedagogies of substance remained both significant and necessary. I am no more sanguine now than I was fifteen years ago that generic conceptions of teaching are sufficient. I am also far less insistent that general conceptions of pedagogy are illusory (see Greta Dershimer's chapter in this volume for a cogent argument in this direction). If we are going to make significant advances to our understanding of the pedagogy of both pre-collegiate and post-secondary education, however, I believe we need to nurture a "scholarship of teaching" that is built upon those same concepts from which we developed our work on pedagogical content knowledge.

Every educational idea is inherently incomplete and probably seriously flawed. An idea is useful to the extent that it can stimulate the thinking and scholarship of others. I trust that our work on pedagogical content knowledge may meet those standards of utility. I hope that those who use these ideas now and in the future will give more attention than I did to the connections between teachers' knowledge and the ultimate consequences for students' learning and development. My current work attends more seriously to those relationships. I am grateful to the editors and authors of this volume for the critical care with which they have approached these ideas, and the combination of respect and skepticism with which they have been treated. I look forward to a continued interest in the pedagogies of substance that will connect the very best scholarship on learning and teaching from the elementary grades through graduate school.

Lee S. Shulman
Carnegie Foundation for the Advancement of Teaching

SECTION I

INTRODUCTION

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 university programs were uncovered. Additional research ultimately linked variations in preservice teachers' conceptions to the organization and implementation of different models of teacher preparation. Interestingly, some of the implications for practice derived from this line of research are represented as programmatic innovations in Chapter 11, this volume.

Why do teachers teach science in the way they do? This question acts as a focal point for Tobin and McRobbie as they conduct a social and cultural examination of classroom life. Chapter 9 describes the types of PCK teachers need to promote student learning and how such knowledge (or lack thereof) reveals itself in the discourse community and power relations established in the classroom. Two contrasting fictional composite cases are used to illustrate subject matter knowledge transformation. One case illustrates a transmission model of subject matter knowledge, characterized by limited student participation and an uneven distribution of power in the classroom. The second case depicts a teacher who acts as a mediator of content understanding, where prediction, experimentation and student explanation dominate classroom discourse. The contrast in cases results in a powerful example of the intersection of knowledge and beliefs as they impact classroom practice and the learning opportunities available to students. Tobin and McRobbie's chapter concludes section two and prompts the reexamination of the differentiated or integrated role of various forms of knowledge and belief on teaching.

Impacts of PCK on the Development of Science Teacher Education Programs

As the construct of PCK was developed, refined, and examined in the research literature, it also acted as a stimulus for the development and evaluation of teacher preparation programs. The final section of this volume considers various views of PCK as they play out in three university teacher preparation programs. Program evaluations reveal the influence of program configurations on the evolving knowledge of preservice teachers as well as that of the public school and university faculty with whom they worked.

The elementary science teacher preparation program described by Zembal-Saul, Starr and Krajcik (Chapter 10) used components of PCK as guideposts for program design, course assignments, and field-based activities. A key program feature was the coordination of course offerings, assignments, and field placements across science content, science methods, and general education courses. Specific assignments and program structures that acted to integrate subject matter knowledge, general pedagogical knowledge, and knowledge of context to form PCK during the junior year of a 2 year program were identified and described. Program impacts on PCK were not specifically examined, but preservice teacher learning was analyzed through three assessments: the form of science content representation used in teaching, attention to the needs of learners, and the quality of classroom implementation. While the preservice teachers made progress in developing accurate content representations, shifted from teacher to student-centered instruction, and improved in management skills, they continued to have difficulty in linking student prior

knowledge to instruction and responding appropriately to students while teaching. The authors concluded that integrated courses and assignments assisted in the synthesis of knowledge gained from various programmatic sources, but acknowledge that limited transfer occurred between the science content courses and science teaching.

Niess and Scholz (Chapter 11) describe a secondary science and mathematics teacher preparation program that used six of Shulman's knowledge domains and defined teacher effectiveness as the ability to transform content in a manner accessible to learners. The Master of Arts in Teaching cohort program employed a 12 month sequence of integrated course work across three main areas: professional core courses, subject matter teaching specialty, and field experiences. As in Chapter 10, program evaluation results indicated that the preservice teachers had consistent difficulty merging subject matter or education courses that were not integrated by design. As a result, the preservice teachers advocated the retention of separate views of subject matter and pedagogy as opposed to the integrated knowledge base predicted by the PCK model.

The secondary science teacher preparation program described by Mason (Chapter 12) was also founded on an integrated model of content and pedagogy. Based on the premise that content majors need to construct a comprehensive view of their discipline for teaching and that students often believe that generic teaching strategies, when taught in isolation, are equally effectiveness in all situations, the TRIAD program was developed around a collaborative/cooperative instructional team dedicated to developing PCK in preservice teachers. A high school science teacher, a science content professor, and a science education professor were responsible for planning and implementing three courses during the certification program. The courses allowed for the examination of the theoretical underpinnings of content and its translation into teaching, provided linkages between content and pedagogy, and offered a model of interdisciplinary teaching. While the program participants all agreed that PCK acted as a realistic and logical framework for teacher preparation, the university faculty's increased appreciation for the content and pedagogical expertise held by their colleagues was perhaps the most important outcome.

In all three programs, the importance of the purposeful integration of subject matter and pedagogy is underscored. While specific tools such as portfolios, lesson plans, and field placements were anticipated to be effective in assisting in the integration of knowledge bases, few preservice teachers were able to accomplish this transformation. The implications for separate or synthesized knowledge bases will be explored in the final section of this chapter.

CONCEPTIONS AND IMPLICATIONS OF MODELS OF TEACHER KNOWLEDGE

PCK and its related knowledge domains represent an effort to develop a model, or theory, of teacher cognition. Attributes of a sound model presented at the beginning of this chapter included knowledge organization, integration of previously anomalous data, the suggestion of explanations, stimulation of research, and prediction of new knowledge. Researchers value one model over another based upon these attributes as well as the model's coherence and consistency with observations. Using these criteria as a framework, an analysis of the merits and implications of models of teacher knowledge are explored in the remainder of this chapter.

PCK has many of the characteristics of a good model. It has revitalized the study of teacher knowledge, provided a new analytical frame for organizing and collecting data on teacher cognition, highlighted the importance of subject matter knowledge and its transformation for teaching, incorporated findings across related constructs, and provided for a more integrated vision of teacher knowledge and classroom practice. In addition, PCK is an intuitively appealing construct, one that has been actively incorporated into the vocabulary of many teachers and researchers alike.

There are, however, two elements of a good model where the construct of PCK bears careful scrutiny: in its degree of precision and in its heuristic power. Precision can be judged by the discriminating value of the constructs included in the model, the relationship among constructs, and the match of this organization to the research data. Although PCK creates a home for the "unique" knowledge held by teachers (Shulman, 1987, p. 8), identifying instances of PCK is not an easy task. Within this volume, most authors agree that the PCK construct has fuzzy boundaries, demanding unusual and ephemeral clarity on the part of the researcher to assign knowledge to PCK or one of its related constructs. This difficulty of knowledge categorization can be seen as inherent in using any construct or it may be an indication of a serious lack of precision in the model. Is PCK with its related domains a more precise model, explaining better the teacher cognition data than other models? Or, could the knowledge divisions as offered in PCK be overly refined? Could three integrated categories of teacher knowledge -- subject matter, pedagogy and context -- offer a more precise and powerful organization?

The heuristic power of a model may be judged by its potential for supplying explanations for data similarities, the acknowledgment of gaps in the knowledge base, and the prediction of the nature of missing knowledge. PCK has certainly stimulated research, but in what way has it predicted or helped reveal new knowledge? Indeed, few studies of teacher knowledge claim to identify specific elements of PCK. Most researchers still choose to separate their investigations along pedagogical or subject matter knowledge lines. Why? Perhaps researchers are unfamiliar with the model or resistant to it, not wanting to abandon traditional models and research divisions. Or perhaps PCK has low heuristic value.

To forward this examination, it is helpful to create a continuum of models of teacher knowledge. At one extreme, PCK does not exist and teacher knowledge can be most readily explained by the intersection of three constructs: subject matter, pedagogy and context. Teaching, then, is the act of integrating knowledge across these three domains. For convenience, I will call this the Integrative model. At the other extreme, PCK is the synthesis of all knowledge needed in order to be an effective teacher. In this case, PCK is the transformation of subject matter, pedagogical, and contextual knowledge into a unique form -- the *only* form of knowledge that impacts teaching practice. I will call this the Transformative model.

The distinctions between these two models are subtle -- the integration of knowledge versus the transformation of knowledge. An analogy from chemistry may help make the distinction. When two materials are mixed together, they can form a mixture or a compound. In a mixture, the original elements remain chemically distinct, though their visual impact may imply a total integration. Regardless of the level of apparent combination, the parent ingredients in a mixture can be separated through relatively unsophisticated, physical means. In contrast, compounds are created by the addition or release of energy. Parent ingredients can no longer be easily separated and their initial properties can no longer be detected. A compound is a new substance, distinct from its original ingredients, with chemical and physical properties that distinguish it from all other materials.

When looking at models of teacher knowledge, the Integrative model is similar to that described for a mixture. Elements of knowledge from subject matter, pedagogical and context domains are called upon and melded in classroom practice. Upon reflection, the parent domains can be found in the justifications for planned and interactive classroom decisions. The Transformative model implies that these initial knowledge bases are inextricably combined into a new form of knowledge, PCK, in which the parent domain may be discovered only through complicated analysis. The resulting amalgam is more interesting and powerful than its constituent parts.

Whether teaching knowledge is a compound or a mixture, Transformative or Integrative, has implications for research and practice in terms of the identification and development of knowledge domains, the definition of teaching expertise, and the merits and dangers of each position. A schematic of these two models of teacher knowledge is presented in Figure 1 and an overview of positions within these models are presented in Table I. Articulation and implications of these models are considered in the remainder of this chapter. The reader is reminded that neither of these models are representative of the views of authors in this volume, but have been created as a means for more closely examining the PCK model and its surrounding constructs.

Knowledge Domains and Teacher Expertise

In the Integrative model, PCK does not exist as a domain of knowledge. Teaching depends upon the presentation of content to students in some context using an appropriate form of instruction. The task of the teacher is to selectively draw upon the independent knowledge bases of subject matter, pedagogy, and context and integrate them as needed to create effective learning opportunities. An expert teacher, then, is one who has well-organized individual knowledge bases that are easily accessed and can be flexibly drawn upon during the act of teaching. A teacher can provide justification for instructional actions from the individual knowledge bases as well as add to and refine the domains as a result of teaching. When observing an expert teacher, the movement from one knowledge base to the next will be seamless, giving the appearance of a single knowledge base for teaching.

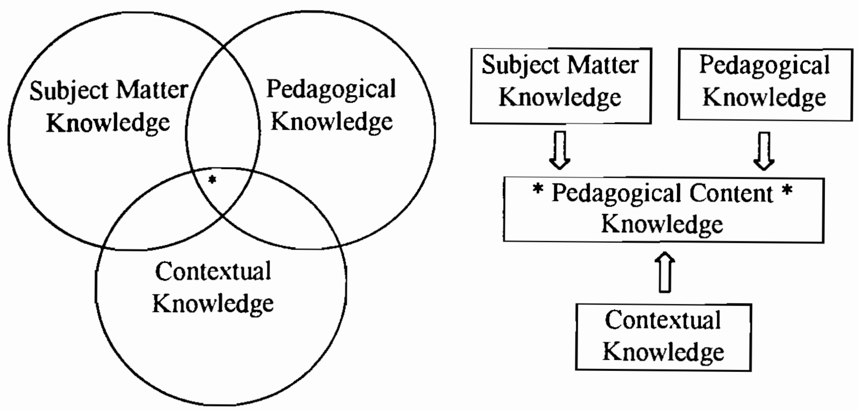

Figure 1. Two models of teacher knowledge
* = knowledge needed for classroom teaching

There is support in the literature for the Integrative model. Despite overt attempts to integrate subject matter and pedagogical knowledge in preservice preparation programs, teachers often state that they maintain separate knowledge bases for the two.

The Integrative model also closely follows traditional patterns of preservice teacher preparation with temporal and spatial separation of subject matter, pedagogical, and contextual issues. A potential danger in this model is that teachers may never see the importance of knowledge integration and continue to emphasize the importance of content over pedagogy, resulting in transmission modes of teaching with little regard for content structure, classroom audience, or contextual factors.

The Transformative model recognizes the value of a synthesized knowledge base for teaching. PCK that helps students understand specific concepts is the only knowledge used in classroom instruction. While knowledge bases containing subject matter, pedagogy, and context exist, they are latent resources in and of themselves and are only useful when transformed into PCK. Teachers can justify their instructional decisions within the domain of PCK; the teasing apart of teaching knowledge into its related forms is best left to researchers and theoreticians. An expert teacher, then, has well formed PCK for all the topics commonly taught. All teaching knowledge is contextually bound, potentially making transfer or drawing generalizations across teaching episodes difficult. The danger in this position is that it ignores context as it objectifies teaching knowledge, potentially implying that correct teaching practices exist for given topics to specific audiences. The classroom becomes the primary location of teacher knowledge, calling into question the value of decontextualized declarative and procedural knowledge and teacher preparation as it currently exists.

TABLE I
Overview of Integrative and Transformative models of teacher cognition

	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 separately 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?

The authors in this volume position themselves between these two extremes. The most common position is to recognize both the foundational knowledge bases of subject matter, pedagogy, and context *and* their reciprocal and nurturing relationship with PCK. New knowledge gained through preparation programs and teaching experience increases the organization and depth of both PCK and the foundational knowledge domains, though changes in one knowledge base will not necessarily result in changes in the others. PCK then is a unique domain that does not totally subsume all other knowledge, allowing for distinctions within and across domains. Inevitably, these mid-point positions are less theoretically powerful or precise than either of the two extremes, allowing some teaching episodes and teacher understandings to be recognized as PCK and others as not. As a result, PCK becomes difficult to distinguish and is therefore less influential than it might otherwise be with teachers and researchers. The theoretical defensibility of this mid-position is further complicated by the fact that expert teaching in both models may appear virtually the same, though differentially interpreted. To perhaps overstate a point, all authors in this book recognize the need for teachers to rethink their content understandings prior to teaching. In addition, all authors recognize the important role played by both campus and field-based settings in the education of preservice and inservice teachers. The question is, is the result of this thinking and teaching experience a new form of knowledge, a temporary integration of other knowledge domains, or both? The answer to this question has important implications for the preparation of teachers and the forms of research conducted on teacher cognition.

Implications for Teacher Preparation

To prepare teachers using the Integrative model, deep and flexibly organized understandings in the areas of subject matter, pedagogy and context are required, as well as the tools necessary to integrate the knowledge bases when attending to issues of classroom practice. While the implementation of the Integrative model would resemble many current teacher preparation programs, research on the program effectiveness has not produced the desired results. Few preservice teachers hold well organized knowledge structures nor can they effectively integrated knowledge across domains. Several explanations account for these results and are supported in the research literature: (1) Students leave university settings with poor content understandings. The system of preparing content specialists (often deemed necessary for various careers) versus generalists (a model more appropriate for teaching careers) may be partially responsible. Inappropriate course structuring or pedagogical implementation throughout the university also may be to blame. (2) Students leave university settings with poor understandings of context issues as they relate to teaching. In part, limited field experiences while taking education courses that cover issues such as multi-cultural education, educational psychology, and political/historical/economic issues related to schools may be responsible. Disjunctures between course content and the incoming beliefs and perceived needs of teachers may play an additional role. (3) Students leave teacher preparation programs with few tools to integrate subject matter, pedagogy and contextual issues. It is difficult to determine if this is a result of preparation programs, the developmental progressions in dealing with the realities of teaching, limited pedagogical knowledge, or the sheer difficulty of integrating knowledge across several domains while attending to the immediacy of classroom complexity. Research reinforces the notion that students are frequently unwilling or unable to attend to issues of content and pedagogy until basic classroom management skills are mastered. The advantage of the Integrative model is that knowledge domains can be developed independently and then integrated. In addition, once integrated, the knowledge used to teach a specific lesson can be deconstructed into its parent domain, potentially deepening and/or reorganizing knowledge in that domain.

The Transformative model offers a solution to the dilemmas highlighted in the Integrative model. If knowledge is taught in a purposefully integrated manner and in

a form that resembles best practice in the schools, students should more quickly develop the skills and knowledge needed to be effective teachers. Fostering integrated knowledge, recognized as a difficult if not impossible task, is removed. Support for the Transformative model is found in preservice teacher requests for immediately applicable solutions to observed teaching problems. Unfortunately, taken to its logical extreme, following the Transformative model would result in reducing teacher preparation to the presentation of a "bags of tricks," externally derived, highly effective curricular packages that represent PCK and result in student learning within a specific context. There are three potential problems with this scenario. First, it assumes that "best practice" can be identified and implemented with equal success in various teaching situations. The variability and subtleties of context highlight the difficulty of this task. Second, it assumes that teachers will take identified episodes of best practice and implement them appropriately and skillfully. Experience with teacher-proof curricula in the 1960s demonstrated the folly of such an idea. Third, in this most extreme form, teacher preparation programs based on the Transformative model would de-professionalize teaching. Expert teaching would become the possession of externally validated best practice and would ignore the development of teacher decision making skills: mimicking practice that resembles PCK is not the same as possessing PCK. Teacher decision making, personal growth, and creativity would become victims of attempts to provide teachers with knowledge of best practice in all teaching areas.

The dilemma is, how do we best prepare teachers for the complex task of teaching? Regardless of the model used, integration of knowledge bases is key, as is informed decision making, exposure to examples of teaching excellence, and multiple, supported and reflective teaching experiences. Unfortunately, simply integrating course content and field assignments in and of itself are insufficient interventions to provide students with integrated teaching knowledge.

Implications for Research

In order to support the Integrative model, research into the mechanisms for facilitating transfer and integration across knowledge domains, both in theory and in practice, need to be identified and implemented. Support for the model could be found in teaching episodes fostering more highly developed knowledge bases in subject matter, pedagogy, and context, and a wisdom of practice that helps unravel the mysteries of the most effective blend of knowledge use in specific situations. The Transformative model would demand the identification of outstanding examples of PCK in action. Best practice would be defined by student learning through teaching practices supported by other external goals, such as those found in science education reform documents. Research into the best methods of developing PCK in teachers, teaching the appropriate selection of PCK based on context examination, and the establishment of a well-organized PCK base would be needed. In either model, the following questions need to be explored: What are the relative advantages and disadvantages of generic and content-specific teacher preparation programs? What program configurations lead to the desired goals of teacher understanding and practice? How is knowledge integration best achieved? How does the student learning in the public schools relate to the knowledge held by teachers? How does student learning relate to various forms of teacher education?

CONCLUSION

It should be noted that the authors in this volume represent neither of the continuum extremes presented in the previous section. However, each author started with Shulman's model and, based on their interpretation, shaped the model in unique ways that fit their perceptions of the data on teacher cognition. Hopefully this book will enhance the reader's understanding of PCK through an analysis of both historic and current conceptions, an overview of the research literature, and a presentation of the practical implications derived from this model. Does the construct of PCK help or constrain our pursuit of excellence in teacher preparation? The answer to this question is left to the reader. An anticipated result of such contemplation will lead to individual and community exploration, development, and evaluation of alternative models used to study teacher cognition. As with PCK, future models will need to address the following questions: What knowledge do teachers need to possess in order to be effective? What model of teacher knowledge best explains the data that exists and stimulates future attempts to reconcile, synthesize, and expand our knowledge?

Regardless of future evaluation, the explication of PCK as a construct and a model has reintroduced the importance of content knowledge into the teaching equation, promoted renewed vigor in the subject-specific teaching areas such as science education, and highlighted the need for integration of the various domains of knowledge in research, teaching, and teacher preparation. Using these criteria, PCK has proven to be an especially fruitful model.

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SECTION II

THE LITERATURE

GRETA MORINE-DERSHIMER AND TODD KENT

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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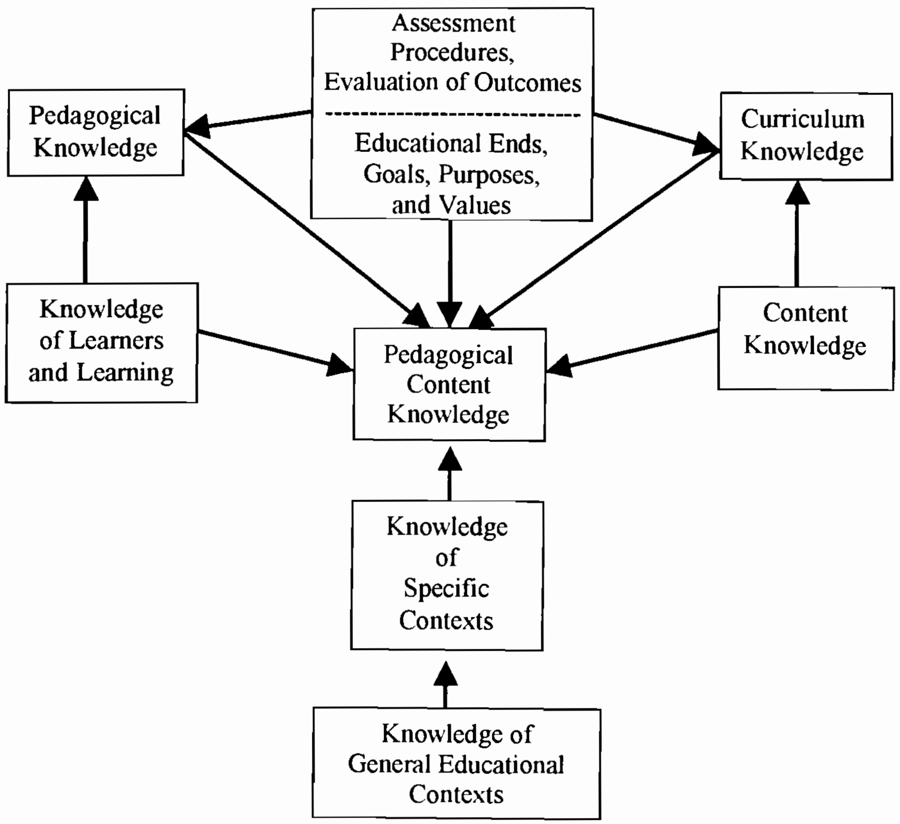

Figure 1. Categories Contributing to Pedagogical Content Knowledge

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

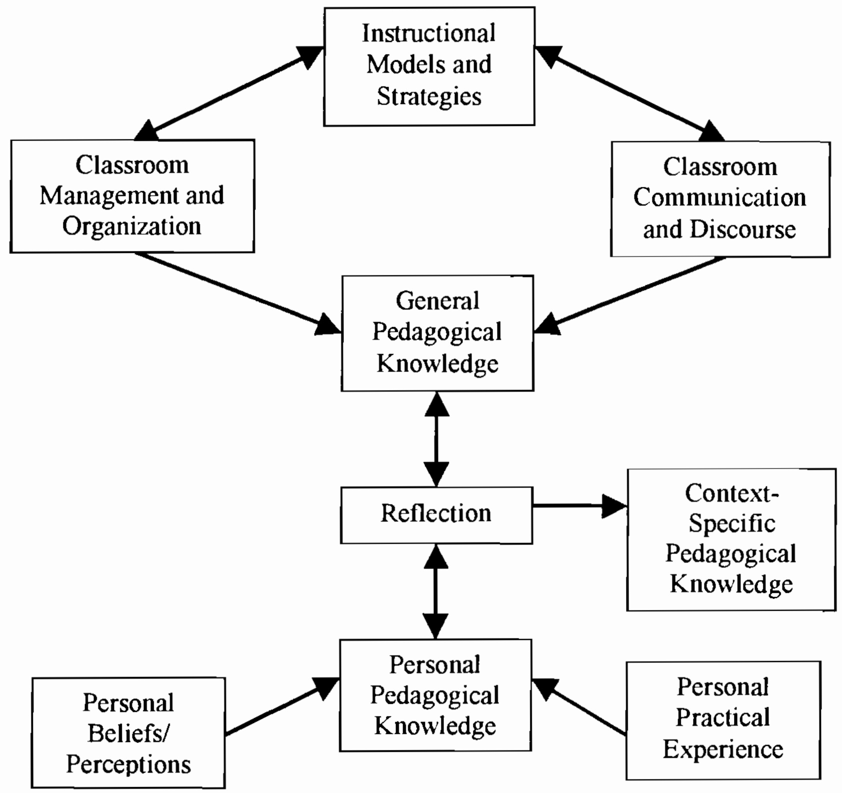

Figure 2. Facets of Pedagogical Knowledge

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 organization 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 skillful in using a range of specific management techniques, and knowledgeable about the circumstances in which a given technique might best be used to promote student learning.

Factors influencing teachers' knowledge use. While the context for practice influences the knowledge about classroom organization and management that is most relevant for teachers to use, other factors may influence individual teachers' ability to use the knowledge that is generally available. These factors include the degree of teachers' awareness of student cognitions, the complexity of teachers' knowledge structures, and the extent of teachers' practical experience.

Some interesting work by Peterson (Peterson, 1988; Peterson & Swing, 1982) has demonstrated the importance of teacher awareness of both general and content-specific cognitive processes of students. These processes include a student's ability to judge his or her own understanding, to monitor and diagnose that understanding, and to use specific cognitive strategies during classroom learning and instruction. In Peterson's study, students who were able to explain their difficulties in understanding content and procedures being taught performed better than students who could not provide detailed explanations of what or why they had trouble understanding. Students who reported greater numbers of specific cognitive strategies in coping with difficulties they experienced in carrying out instructional tasks showed better achievement than students who reported more global and general strategies. Specific cognitive strategies included such actions as checking answers, reworking problems, or rereading directions. Peterson suggests that teachers are generally unaware of these differences in student cognitions, and recommends that they encourage students to talk together about the strategies they use, as a way of both assessing student thinking and expanding opportunity to learn.

Another factor of influence is the complexity of teachers' knowledge structures. In a study by Winitzky (1992), beginning teachers were given lists of 20 classroom management terms and asked to group the items that best fitted together. The teachers also participated in a reflective interview. The interview data collected were compared for teachers with highly structured groupings of management terms and teachers with low-structured groupings. The results indicated that the intricacy of knowledge structures of these beginning teachers was associated with their ability to reflect upon classroom practice. This finding underscores the importance of developing teacher education methods that help to develop more complex knowledge structures related to classroom organization and management.

Other research has shown that novice and experienced teachers differ in the quality and level of their perceptions, monitoring, and understanding of classroom events. In one study (Sabers, Cushing, & Berliner, 1991), teachers of varying levels of experience were shown three different television sets which simultaneously played different views of the same science lesson. The teachers were asked to monitor all three video screens and then describe the instructional and management techniques they observed. The results indicated that expert teachers were more skilled at monitoring and interpreting the multiple classroom events than novice teachers. These researchers concluded that classroom experience plays a significant

role in teachers' comprehension and interpretation of classroom organization and management.

To summarize, in addition to learning general principles of classroom organization and management, beginning teachers must develop the ability to understand and use these principles in particular classroom and school contexts. The research suggests that novice teachers' awareness of student cognitions as well as their interpretations of classroom management events may be expanded and deepened as they gain experience in classroom settings. Thus, practical experience emerges as an essential ingredient for developing an understanding of the subtleties involved in the application of this type of pedagogical knowledge to real classroom situations.

Instructional Models and Strategies

Elmore (1992) notes that past research on effective teaching has focused on the measurement of student outcomes by readily available standardized tests. He argues that current research defines learning as the development of understanding and the ability to perform complex cognitive tasks that require the active management of different types of knowledge around concrete problems. In order for teachers to use the results of research, he contends that the organizational structures of schools which form the context for practice must shift to accommodate changes in teaching that promote student understanding. He identifies student grouping, division of teacher responsibility, time allocations, and assessment as four prominent structural areas interfering with the transformation of research findings into teaching practice. Most schools approach these areas in a relatively straightforward way that does not reflect the findings of current research. Schools generally group students by age; they assign one teacher to each group of students; they break the day into roughly one-hour blocks; a different subject is allocated to each block; and student progress is routinely assessed by standardized tests organized by subject. Elmore asserts that this pattern is so ingrained in the structure of American schools, that most teachers, as well as administrators and parents, do not realize that alternatives exist.

Despite the apparent constraints imposed by the organizational structure of schools, instruction can take many alternative forms, and teacher knowledge about the possible alternatives and their appropriate uses is a critical aspect of general pedagogical knowledge. Instructional models are inherently related to the general educational purpose to be achieved, thus alternative models can be differentiated in terms of alternative ends. Two productive approaches to such a differentiation can be seen in the work of Joyce (Joyce & Weil, 1986; Joyce, Weil & Showers, 1992) and Rosenshine (1993).

Differentiation by learning capability goals. Joyce and Weil (1986; also Joyce, Weil & Showers, 1992) provide a comprehensive array of alternative instructional procedures associated with varied instructional goals, all geared toward increasing students' capabilities for future learning. The models of teaching they have developed are based on theory and research in psychology (e.g., personality theory, cognitive and social development, cognitive psychology, social psychology) as well as research on instruction. In a continuing line of research Joyce and his colleagues have demonstrated that prospective and experienced teachers can learn alternative models (Joyce, Peck & Brown, 1981), that peer coaching improves the probability that models once learned will be implemented in the classroom (Joyce & Showers, 1981), and that models systematically implemented can improve student learning (Joyce & Showers, 1988).

Joyce and Weil's models of teaching are organized into four families, according to the principal goals or learning capabilities addressed. Models in the Social Family focus on developing capabilities for cooperative and productive interaction in the learning community. Models in the Information-Processing Family focus on improving capabilities for acquiring and organizing information, identifying and solving problems, and forming and conveying concepts and generalizations. Models in the Personal Family focus on developing capabilities for understanding oneself and taking personal responsibility for growth and learning. Models in the Behavioral Systems Family focus on developing capabilities for self-correction or modification of behavior based on feedback.

Joyce and Weil's models of teaching provide prospective and experienced teachers with greatly increased flexibility in adapting instructional procedures to varied instructional goals. Most of the models can be used in a wide variety of subject areas, and with a wide variety of students (range of ages, range of academic abilities). Many require the teacher to reorganize content materials found in typical textbooks, or to provide students with varied additional materials. Thus a thorough understanding of the content to be taught, as well as the goals to be achieved, is essential for the effective use of this approach.

Differentiation of academic tasks. Rosenshine (1993) presents a useful model for comparing and contrasting two alternative sets of instructional procedures generated by research and learning. One set of procedures derives from research on teacher effects (e.g., Brophy & Good, 1986; Gage & Needels, 1989) and is commonly referred to as "direct instruction." The second set derives from research on the teaching of cognitive strategies (e.g., Palincsar & Brown, 1984) and is generally called "expert scaffolding." Rosenshine places these two sets of procedures along a continuum of academic tasks that varies from well-structured tasks to less-structured tasks; and suggests that direct instruction is most appropriate for teaching well-structured tasks, while expert scaffolding procedures are most appropriate for teaching less-structured tasks.

1) Direct instruction. The teacher effects research has demonstrated that when effective teachers teach well-structured tasks such as arithmetic computation, their instructional procedures incorporate a series of basic functions that include: materials presented in small steps; high levels of active practice by all students; guided student practice; feedback and correctives; and independent practice (Rosenshine & Stevens, 1986). The instructional procedures associated with direct instruction are generally well-known, but not always carefully followed. The most common misuse involves omitting the guided practice function (Rosenshine, 1993), a critical function for the success of this instructional model.

2) Expert scaffolding. Less-structured tasks cannot be taught directly, because not all the steps leading to successful completion can be specified. Researchers have been successful in improving learning of less-structured tasks by teaching cognitive strategies that serve as guides to task completion. Reading comprehension is one example of a less-structured task. Cognitive strategies to help students construct meaning from text include: generating questions while reading; and summarizing paragraphs and passages.

Cognitive strategies can be taught by use of scaffolds (e.g., Palincsar & Brown, 1984). Like the scaffolds on construction jobs, instructional scaffolds are temporary supports that minimize the difficulty of the task so that the student can accomplish the work. Scaffolding techniques include: modeling procedures, including thinking aloud; giving students hints and expert models (e.g., examples of good questions or summaries); and encouraging students to provide hints, models, and prompts for each other (reciprocal teaching). Most of these techniques are designed to encourage student self-regulation and self-evaluation during task performance. Scaffolds are gradually withdrawn as students internalize the prompts or procedures, and become more independent in their use of the cognitive strategies.

3) Overlapping procedures. Rosenshine (1993) notes that most academic tasks fall somewhere in the middle of the task-structure continuum. For this reason, teachers can use techniques from both sets of procedures within a single lesson. Compatibility of the two instructional processes may result from the fact that both stem from studies of effective teacher-led instruction. The possibilities for overlapping procedures enable teachers to increase variation in their instruction.

Common elements. Rosenshine's differentiation of instruction in terms of academic task, and Joyce and Weil's differentiation by types of learning capabilities addressed, have one very important common feature, in that both are grounded in research which indicates the connections between particular instructional processes and particular types of student learning. Thus both approaches affirm the importance of instructional models and strategies as a facet of general pedagogical knowledge. Teacher educators can introduce these instructional systems to prospective and practicing teachers with some confidence in their efficacy.

In addition, both systems promote independent thinking in both students and teachers. Like the scaffolding procedure described by Rosenshine, the overall aim of the models approach to instruction is to increase student independence in use of the learning processes taught. Rosenshine's notion of overlapping procedures, or combining elements of two alternative processes to produce new alternatives, is reiterated in Joyce and Weil's observation that individual models can be used effectively in conjunction with each other. Thus both systems encourage teacher adaptation of basic processes, and advocate expansion of teachers' instructional repertoires.

Most importantly, both of these approaches to differentiation of instruction emphasize the need to consider content and instructional purpose in the selection of instructional strategy. Thus they provide general pedagogical knowledge that can feed into pedagogical content knowledge in particularly productive ways.

Learning communities. Another model for instruction has been developed by Brown and Campione (1990, 1994) and greeted enthusiastically by many teachers and teacher educators. Brown's work on reciprocal teaching (Palincsar & Brown, 1984), where learners worked together to interpret text, led to an interest in establishing learning environments that would foster the interchange of understanding and experience. Brown (1997) has identified seven principles of learning that are critical for the development of learning communities. They are:

1) Much academic learning is active, strategic, self-conscious, self-motivated, and purposeful (qualities also commonly termed metacognition).
2) Classrooms are settings for multiple "zones of proximal development" (Vygotsky, 1978).
3) Individual differences are to be recognized and valued.
4) Active exchange of ideas and experiences fosters internalized dialogue and higher level thinking.
5) Learning and teaching depend on creating, sustaining, and expanding a process of group inquiry.
6) Deep, conceptual content sensitive to students' developmental level is a necessity.
7) Assessment procedures should be authentic, transparent, and aligned with the curriculum.

Brown's principles provide good guidelines for teachers and teacher educators interested in using constructivist approaches to learning. Like the approaches proposed by Joyce and Rosenshine, the instructional process proposed for developing communities of learners emphasizes the relationship between content and instructional purpose. The approach differs from those of Joyce and Rosenshine in placing more emphasis on the importance of a particular type of classroom discourse.

Classroom Discourse

In a review of research on classroom communication, Green (1983) developed a model for understanding the classroom as a communicative environment. The face-to-face interactions in the classroom, whether teacher-student or student-student, are governed by culturally developed rules and expectations. Such rules, for example, govern how people behave when they join in conversations or take turns speaking. The research on classroom discourse suggests that understanding the linguistic characteristics of the teaching-learning process can lead to the creation of more effective learning environments.

Importance of communication patterns. Classrooms consist of multiple levels of communication and multiple contexts for communication. Teachers and students bring individual frames of reference to the classroom environment, and these perspectives shape the ways that individuals construct meaning from classroom interactions. In order to participate effectively, students must understand the implicit rules and expectations governing teaching-learning interactions. The existence of these rules does not mean that interactions are rigid and inflexible. The rules simply describe patterns of interactions. For example, if someone asks a question, the listener is expected to respond in some fashion. A lack of understanding of the rules governing classroom interactions, or differences between home and classroom patterns of communication, can lead to confusion and misinterpretations by both teacher and student. Learning is most effective when instructional patterns of communication are compatible with a student's home patterns.

Student participation and achievement can be influenced by how well students understand and employ the rules and expectations governing classroom interactions. Students spend time and energy learning these rules, and studies have shown that they can identify and distinguish differences between expectations governing informal conversations at home or at play, and those that govern classroom discourse (Morine-Dershimer, 1985). Heath (1982) has noted that minority children sometimes experience difficulty in school because classroom questioning patterns can differ markedly from patterns used at home. She encourages teachers to use discourse analysis techniques to analyze the language in their own homes in order to become more aware of differences between home and classroom patterns of communication.

The achievement of students has been shown to vary with the type of questions used by teachers during language arts instruction (Morine-Dershimer, 1983). Text-based questions that relied heavily on textual material tended not to reflect natural discourse and resulted in low levels of student achievement. Experience-based questions required students to relate lesson content to their own experiences, and reflected a genuine teacher interest or need for the requested information. Such questions resulted in higher levels of achievement. In lessons based on Joyce and Weil's (1992) information-processing models of teaching, teachers asked questions requiring observation and analysis of available data. These data-based types of questions also resulted in higher student achievement.

Teachers who are unaware of cultural differences in communication patterns may misjudge student abilities. For example, Michaels (1984) has reported on a kindergarten teacher's frequent interruptions of stories told in a narrative style used frequently by African-American girls in her class. These stories had a structure that moved through a series of events linked by similarities in actors or activities. This structure contrasted with the thematic structure of stories told by other children in the class, who were allowed to develop their tales without teacher interruption. Michaels further demonstrated that white adults judged the linking narrative style more negatively than the thematic style, while black listeners rated the two styles as equally appropriate.

Students' ability to solicit help from peers can also impact on their opportunities to participate and achieve. In a study of peer-directed reading groups (Wilkinson & Calculator, 1982), students differed markedly in their ability to get classmates to respond to requests for information or assistance. Successful students had a broad repertoire of request forms and persisted in seeking responses to their requests, while unsuccessful students used inexplicit requests and were unlikely to repeat requests for information if they were initially ignored by classmates. A study of student-led groups in junior high math classes (Webb & Culliam, 1983) showed similar individual differences in ability to solicit assistance, and also demonstrated that asking a question which received no response from peers (i.e., being ignored) was detrimental to student achievement.

To summarize, research on classroom communication describes the construction of classroom activities by students and teachers acting on tasks and on each other's messages and behaviors. Thus, classroom curriculum is seen as an evolving process which generates shared meanings constructed from different perspectives. Green (1983) argues that teacher education should work toward developing a conceptual understanding of the teaching-learning process as a linguistic process. Classroom linguistic patterns incorporate both academic tasks and social participation structures which can vary across contexts, by student, by teacher, and by the goal or intent of an activity. Understanding the complexity of classroom interactions can help teachers foster behaviors which clarify the rules and expectations governing these interactions. The research synthesis by Green provides a framework for developing further understanding of classroom discourse as an essential component of pedagogical knowledge.

Communication in science classes. Recent trends in science education emphasize classroom teaching oriented toward hands-on, problem-solving approaches. The traditional role of the teacher must necessarily shift to accommodate these new paradigms, and, consequently, the types of interactions that occur between teacher and student must also change to accommodate the new instructional approaches. In more traditional models of instruction, the teacher's primary role is that of lecturer or discussion leader. Under traditional instruction, students are typically presented with some type of science content, and a laboratory activity or written exercise often follows as assessment or to give students an opportunity to apply what they have learned. When taking a problem-solving approach, however, the teacher's role in the classroom shifts from being a content expert or didactic instructor to that of "metacognitive coach." The primary role of such coaching is to help students internalize processes that encourage the development of scientific reasoning skills. The science teacher, according to Gallagher et al (1995), should frame classroom discussion to encourage students in the following tasks:

> to understand the questions to ask during problem definition, information location, analysis and synthesis, and to sort through potential interpretations and/or resolutions (p.138).

The classroom dialogue begins with a problem, rather than with content-based instruction. Students do acquire content, but do so on a "need-to-know" basis within the context of the problem.

The Gallagher article provides a description of problem-solving instruction used in a fifth-grade classroom that was part of a federally funded project to develop and explore ways of implementing problem-based learning. On the first day of the instructional unit, students are presented with an ill-structured, messy problem that has no single solution. The role of the teacher is to guide the students in defining the problem and identifying the resources they will need to address the problem:

> The metacognitive coach (classroom teacher) helped the students analyze the problem statement and establish a learning agenda by organizing the discussion around three questions: What do you know? What do you need to know? How can you find out what you need to know? Using these questions, not only was the first outline for learning set up and prioritized, students also identified what human and print resources they had to learn to use in order to define the problem (p.140).

The focus of classroom discourse is less oriented toward communicating what the teacher knows to students and becomes focused more on helping students identify, and learn, what they need to know to address the problem.

In a case study of a teacher making the transition from a traditional, content-dispensing approach to a problem-solving approach, Martens (1992) identified two factors that inhibited such transitions. First, the teacher exhibited a perceived need to retain control of the learning process in order to ensure students were successful in solving the given problem. In one activity in which students built their own telephones, the teacher gave comments to help insure successful results:

> You've got to make sure the tape touches the metal.
>
> I want you to look at the difference between how I wrapped my wire around the nail and how you did yours. I'm not saying anything, but I want you to look at the difference.
>
> You're not following directions. Be careful – you're not going to be successful! (p.153)

The teacher's classroom discourse emphasized the outcome of the activity, rather than coaching the students in the process of asking the right questions to frame a solution to the problem.

The second inhibiting factor was the teacher's tendency to view problem-solving and science instruction as two separate activities. Rather than teaching content through the process of problem-solving, the teacher "supplemented" the problem-solving activities with more traditional, content-based lessons.

One emphasis of the problem-solving model of instruction is to create classroom exchanges that promote the active participation of students in science methodology. This approach is contrasted with the rote learning encouraged by the didactic teacher-student exchanges in many science classrooms. As students encounter new learning experiences, students use previous knowledge and experience to interpret the experiences, and cognitive shifts must take place if past learning does not adequately accommodate or explain the new experiences. This constructivist perspective on science learning acknowledges the influence of past learning and perceptions on the successful acquisition of new learning. In some cases, students may subvert true cognitive shifts with classroom coping strategies, such as waiting for, and then rotely learning, answers given by a teacher (Appleton, 1993).

A study by Lonning (1993) suggests that the student-to-student interactions encouraged by cooperative learning structures help to promote the cognitive shifts described by the constructivist view. Lonning reasons that these types of interactions help students to engage their own perceptions by testing them against other perspectives. The study compared two groups of tenth-grade students in a general science course. Both groups were taught with a conceptual change model of instruction that included an opportunity for peers to interact. The experimental group used cooperative learning to structure the peer interactions, and these structures were based on a model that promoted individual accountability and positive interdependence. The group using cooperative learning structures to guide student-to-student interactions demonstrated higher levels of achievement and higher scores on a verbal interaction scheme that was used as an indicator of conceptual shifts. The Lonning study argues that cooperative learning structures may help raise the level of engagement with the content by encouraging substantive student-to-student interactions. Other research, however, has shown that the potential for classroom interactions to produce positive cognitive shifts may be dampened by other factors, such as inequities in participation levels based upon student gender.

A study by Barba and Cardinale (1991) has demonstrated a relationship between gender and teacher patterns of questioning. An examination of questions asked by secondary science teachers revealed that female students had fewer interactions than males with both male and female science teachers, and were asked lower-level questions more frequently than male students. Lower-level questions were classified according to Bloom's taxonomy and included questions on factual information, comprehension, and the application of knowledge. Higher-level questions demanded analysis, synthesis, and evaluation from the students. While female students were more likely to meet teachers' expectations for classroom conduct, especially in raising their hands to respond to questions, they were also less likely to become "target students" who had four or more interactions with the teacher during one class period.

The work of Barba and Cardinale built upon studies providing evidence that the frequency and type of teacher interaction with students affects both levels of achievement and motivation. The dominance of low-level questioning and lower frequencies of student-teacher interaction for female students provides cues to those students that they are low-ability students (Weinstein, 1983; Weinstein, Marshall, Brattesani, & Middlestadt, 1982). Students who attribute their lack of success to low ability may be less motivated to perform on subsequent tasks (Blumenfeld & Marx, 1997).

A larger study by Jones and Wheatley (1990) examined physical science and chemistry classes and involved more than 1,300 students. This research found that male students participated more in classroom interaction than females in every one of the forty-three categories of interaction investigated in the study. Female students in this study were only half as likely to receive teacher praise as male students.

Female students were also less likely to call out answers. Previous research had indicated that male call-out answers were much more likely to be accepted by the teacher, whereas female students were more likely to be corrected by the teacher for not waiting to be called upon (Sadker and Sadker, 1986). The Jones and Wheatley study concluded that observed gender differences in classroom interactions contributed to male students being generally more confident and outspoken in science classes. The authors conjecture that all students interpret these characteristics as evidence that males are more valued and capable in science, and that these perceptions may contribute to lower enrollment and achievement for girls in science classes.

Another study (Martinez, 1992) demonstrated the existence of gender differences in the level of interest displayed by students concerning science experiments. This research found that middle school girls were more interested in the social aspects of experiments than boys. Girls responded with greater affirmation to such statements as, "This experiment helped us work as a team" and "My partner and I helped each other more than usual." Boys were more interested in gaining control over the experiment and responded more positively than girls to statements such as "I knew exactly what to do during the experiment" and "I felt confident during the experiment." The study also found that girls were more responsive to changes in experiments that were designed to elevate student interest. Such changes included introducing a fantasy element ("Imagine you are a NASA scientist ...") or posing questions requiring discussion or joint answers. Martinez associated the consistency of such interest patterns with the severe underrepresentation of women in science career fields; for example, women account for only 3 percent of physical scientists. This study implies that female attitudes toward laboratory activities might be significantly improved by the modification of curricular and procedural choices. Such actions by teachers might help to achieve a more balanced representation of females in the sciences.

To summarize, understanding different facets of classroom discourse can aid teachers in developing communication patterns that are responsive to the individual differences of students. Classroom activities generate meanings that are influenced by expectations and rules rooted in the different cultures which combine to form classroom environments. Teacher awareness of cultural and gender factors which facilitate or interfere with students' opportunities to participate in classroom interaction can help to promote effective discourse and impact the ability of students to achieve. For these reasons, an understanding of classroom communication and discourse is a critical component of general pedagogical knowledge.

Interaction Among Facets and Categories

As noted in these brief descriptions, there is a research basis for each of the three facets of teachers' general pedagogical knowledge, and each facet provides a crucial component of this knowledge. As Figure 2 (presented earlier) indicates, these three major facets of general pedagogical knowledge are interrelated. Each individual instructional model calls for particular classroom organization and management procedures as well as particular patterns of classroom communication and discourse. Instructional models also provide the most direct link between the categories of pedagogical knowledge and educational goals or assessment procedures (see Figure 1), for different models or strategies promote achievement of different educational goals or outcomes. The facet of classroom communication and discourse provides the most direct link between the categories of pedagogical knowledge and knowledge of learners and learning, for students' individual differences (e.g., cultural background, gender) can alert teachers to patterns of communication that may be most appropriate for promoting participation and learning.

While general pedagogical knowledge is an essential form of teachers' professional knowledge, drawing as it does on classroom research on teaching and learning, it is insufficient. If pedagogical knowledge is to serve as a useful guide for teachers' instructional decisions, it must be supplemented and strengthened by personal pedagogical knowledge.

SOURCES OF PERSONAL PEDAGOGICAL KNOWLEDGE

Researchers and teacher educators agree that teachers' personal pedagogical knowledge is a critical contributor to their instructional behavior and thinking. This personal knowledge has at least two important components -- personal beliefs and perceptions of teaching and learning, and personal practical experience working in classroom settings. Each of these components of personal pedagogical knowledge has been investigated using a variety of techniques.

Prior Beliefs and Perceptions

The personal beliefs and images of teaching and learning that prospective teachers bring with them as they enter professional preparation programs appear to be based primarily on their early experiences as pupils (Calderhead & Robson, 1991; McDaniel, 1991). Several studies indicate that these beliefs and images are difficult to change (e.g., McLaughlin, 1991), but some studies have demonstrated positive changes in perceptions in connection with specific education courses, with teacher candidates reconstructing their initial images of the teacher as information-giver (e.g., Florio-Ruane & Lensmire, 1990). Some reviews of this research tend to take a rather pessimistic view of the possibilities for desirable change in prospective teachers' personal beliefs about teaching during preservice teacher education (e.g., Kagan, 1992; Zeichner & Gore, 1990). Wubbels (1992) and Morine-Dershimer and Corrigan (1997), in contrast, present a generally optimistic approach to the possibilities for change, and recommend a variety of possible procedures to be used.

Metaphors for teaching. A number of teacher educators, including Wubbels (1992) and Morine-Dershimer and Corrigan (1997), have suggested that teacher candidates' preconceptions of teaching may be consciously reconsidered if they are encouraged to analyze their metaphors for teaching and learning. Bullough (1991) studied the personal teaching metaphors of 15 secondary student teachers, and noted that those who had clear, conscious images of themselves as teachers exhibited more growth during their practicum experience. In a later study (Bullough & Stokes, 1993) he worked with 22 secondary teacher candidates over the period of a year, as they generated their own metaphors for teaching, then revisited these metaphors periodically to identify and discuss changes in their thinking associated with their field experiences. Images reported by these students included teacher as guide, coach, parent, artisan, problem fixer, manager, and policewoman. The most prevalent image was teacher as expert, but over time students discovered that "there is much more to teaching than being 'one who knows'" (Bullough & Stokes, 1993, p. 34).

In another report of change in metaphors for teaching (Tobin, 1990) a first-year teacher, Sarah, had major problems with classroom management. Her main metaphor for management was teacher as comedian. When researchers provided Sarah with information about constructivist perspectives of learning, she decided to reconceptualize her role as manager, and shifted to the image of teacher as social director. This shift was accompanied by changes in both teacher and pupil behavior.

In a more indirect approach to the study of metaphoric images, Morine-Dershimer and Reeve (1994) examined the natural use of metaphoric language by 6 prospective teachers describing their observations and decisions during videotape playbacks of their classroom lessons. The lessons were evaluated based on analysis of interactive behavior and pupils' written reactions to the lessons, with pupil engagement as the main criterion for success. The language of those teaching more successful lessons revealed images of pupils as active learners and the teacher as a guide or facilitator: "I try to give them a little space to see what they can do on their own before I jump in;" "He's my fastest student - he has lots of lightbulbs going on - it's fun to kind of catch the lightbulbs with him." The language of those teaching less successful lessons disclosed images of pupils as dependent and the teacher as controller and dispenser of information: "I felt like they would be lost as to my intent;" "I go through the lesson, putting the information on the board a step at a time, so that they will have to keep up with me." These researchers suggested that prospective teachers could analyze their own natural use of metaphoric language in describing teaching, in order to bring tacit beliefs to the level of consciousness, where they might be confronted and re-evaluated.

To summarize, while there are conflicting views about the potential for change in prospective teachers' prior beliefs and images of teaching and learning, there is widespread agreement that these preconceptions can have a strong impact on what teacher candidates learn during their professional preparation. Studies show that there are obvious connections between teachers' images of teaching and their classroom behavior, and demonstrate that changes in images can be associated with changes in behavior of both teacher and pupils. A variety of researchers recommend that teacher educators engage their students in an active examination of their personal images of teaching, and a consideration of possible alternative images.

Personal Practical Experience

A number of studies have traced the changes in novice teachers' knowledge and perceptions occurring during student teaching and the first year of professional practice. Some studies suggest that changes occurring during student teaching tend to involve shifts toward more custodial views of teaching, i.e., emphasizing the need for teacher control of pupil behavior and thinking (e.g., Hoy & Woolfolk, 1990). Most studies take a developmental perspective, and indicate that prospective teachers progress through a series of developmental tasks as they acquire practical classroom experience. Kagan (1992) identifies five components of professional growth in her review of research on learning to teach. These are: an increase in novices' metacognitive awareness of their knowledge and beliefs about teaching and pupils; a reconstruction of their images of teaching and pupils as more practical knowledge of pupils is acquired; a shift from concern with self to concern about pupil learning; the formation of standardized routines for instruction and management; and an increase in problem- solving abilities, with thinking becoming more context specific before it can be generalized across contexts.

On the basis of her review, Kagan concluded that "university courses fail to provide novices with adequate procedural knowledge of classrooms, adequate knowledge of pupils or the extended practice needed to acquire that knowledge, or a realistic view of teaching in its full classroom/school context" (Kagan, 1992, pg. 162). She argued that preservice programs should be providing procedural rather than theoretical knowledge; encouraging student reflection on individual biographical histories rather than moral and ethical dilemmas of practice; and accepting student teachers' obsessions with discipline and classroom control rather than trying to refocus their attention on instructional concerns. According to Kagan, the knowledge of pupils' attitudes, interests, and problems that is essential for professional development can only be acquired through extended classroom experience.

Not all researchers would concur with Kagan's views about the efficacy of extended classroom practice, and few teacher educators would agree with her assessment that college course work is essentially irrelevant for prospective and novice teachers. The views of both groups are supported by Dunkin's (1995) analysis of Kagan's (1992) review, which demonstrates a series of methodological inadequacies that raise serious questions about the validity of her conclusions in this regard. It is true, however, that a continuing problem in the education of teachers has been the issue of how to integrate theoretical knowledge with practical knowledge in order to develop fully functioning professionals. While classroom experience is generally acknowledged to be an important source of practical knowledge, learning primarily from such experience leaves something to be desired, as experiential learning is essentially individual, erratic, and incidental. Several researchers have noted negative effects of student teachers' practicum experiences (e.g., Feiman-Nemser & Buchmann, 1985; Zeichner & Liston, 1987).

Case method approach. One alternative to the potentially haphazard type of learning provided by classroom experience is the case method approach to teacher education (Merseth, 1990; Shulman, 1986). Proponents of this approach suggest

that cases of realistic classroom events which are rich in contextual information, when presented for analysis and discussion by prospective teachers, can serve as proxies for experience. Thus, the particular "experience" can be selected and shared, to promote understanding of critical principles of teaching, and support the integration of theoretical and practical knowledge.

Shulman (1993) sees cases as analogous to the manipulatives widely used to develop young pupils' mathematical knowledge, in that they provide concrete representations of experiences and abstractions. According to Shulman, experience must be represented in some form in order to be understood, and it must be understood if it is to serve as the basis for learning or development. He has identified alternative means of representing experience (see Figure 3), and indicated the ways in which these interact to produce learning. In this view, experience alone cannot lead to professional development, but neither can consideration of a case (narrative account) alone, nor explication of a theoretical principle alone. Learning and development could begin with any one of these three components, but must proceed through the weaving together of the various representations of experience.

To illustrate, a particular classroom event experienced by a prospective teacher might be initially interpreted as an example (or a repudiation) of a principle of management or instruction introduced earlier in an assigned reading or a lecture. The interpretation of the experience could be deepened and enriched by rendering it in narrative form. This could be as a journal entry, or as a story told to peers in a seminar setting, or as a written case, providing an opportunity for reinterpretation and transformation of the experience through successive rewrites. Any narrative rendering of the experience would invite the reactions of readers or listeners, and this could lead to the recounting of other stories or cases. As relationships were noted between the original experience and the stories or cases it prompted others to recall, an even greater depth of understanding might be reached. In an alternative sequence, analysis and discussion of a well-developed case, as an activity in a university course, could prompt a prospective teacher's recall of an initially unexamined classroom experience. Noting the instructional or managerial principles pertinent to the case under discussion, which might be revealed by the comments of peers, could lead to new insights about the prior "real world" experience.

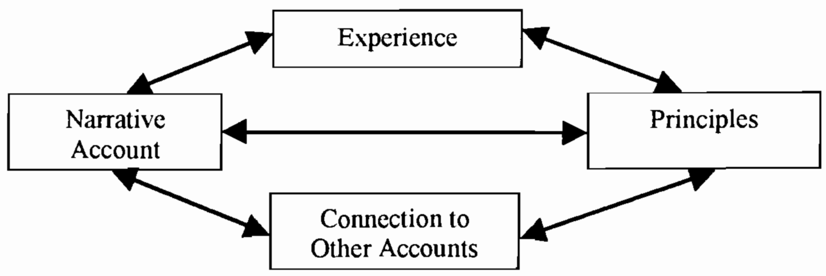

Figure 3. Alternative Representations of Experience

When a case is used as a proxy for experience, a competent case-discussion leader prompts prospective teachers to identify critical issues revealed by the events described; consider the varied perspectives of participants in those events; indicate the research-based principles of teaching and learning that might guide a teacher's response to the situation; and predict the possible consequences of alternative teacher actions. Proponents of case-based teacher education argue that this type of discussion encourages greater awareness of the complexities of teaching, promotes more reflectivity, and develops problem-identification and problem-solving skills.

Many teacher educators have become interested in the potential for prospective teachers to learn from the vicarious experience provided by cases. Some have used cases to provide realistic exemplars of research-based principles of effective teaching (e.g., Greenwood & Parkay, 1989). Some have published sets of cases that present realistic problems which defy simple solutions (Silverman, Welty, & Lyon, 1992). Some have encouraged prospective teachers to write cases based on their own experiences, to be shared and discussed with their peers (Kleinfeld, 1990; Shulman & Colbert, 1988). Lee Shulman (1996) notes that each case he uses with students must be a narrative about the teaching of subject matter, in order to engage students in "the careful contemplation of the complexities of substantive pedagogy" (p. 202). This particular genre of instructional case probably best promotes acquisition of pedagogical knowledge that will contribute directly to pedagogical content knowledge.

Kagan (1993) identifies three different uses for cases, and associates these with three different epistemological traditions. According to this view, when cases are used as instructional tools to help novices develop problem-solving skills, case-based teaching focuses on the analysis of typical classroom dilemmas, and promotes problem-solving procedures that are characteristic of teachers' thinking. This use emphasizes the generic qualities of classroom events, and the relationship between general principles of good teaching and the specific situations in which they may operate.

Kagan's other two uses both relate to teacher-constructed cases. She notes that cases are narratives, and thus they reflect the beliefs and meaning systems by which their authors construct and interpret experience. When novice or experienced teachers are encouraged to describe their own classroom experiences in collaborative case-writing exercises (e.g., Shulman, 1991), they may clarify and transform their understanding of the events depicted, and this can contribute to change in their beliefs and practice. Kagan associates this use of cases with the therapeutic tradition, for it focuses on self-exploration and the unique qualities of the individual teacher as well as the classroom situation portrayed.

In the third use cases written by teachers provide a source of data on teacher cognitions for analysis by teacher educators and researchers. Because of their narrative nature, and the individual interpretation of events inherent in the narrative, teacher-constructed cases can be considered to provide evidence about the mental constructs of their authors. Used in this way over time, teacher-written cases may display individual changes in beliefs and pedagogical decision-making. When classroom cases function as a device for evaluation of teacher cognitions, their

unique and generic qualities are both important, for analysis can reveal the unique thought patterns of the individual as well as the common patterns across a group of teachers.

While there is limited research available as yet to demonstrate the effects of case procedures in teacher education, there is a growing body of literature reporting on the experiences of teacher educators in use of cases (e.g., Shulman, 1992; Colbert, Desberg, & Trimble, 1996). A few studies have examined student outcomes associated with case analysis (Morine-Dershimer, 1996) and case writing (Shulman, 1991). Kleinfeld (1996) has observed an interesting response of prospective teachers following work on case writing: when an emotionally threatening situation is beginning to overwhelm them, they say, 'this is a case,' and thereby gain some objective distance from the situation. Evidence is slowly accumulating to demonstrate that the vicarious or transformed experience provided by cases can encourage teachers to view their real practical experience from an expanded perspective. Similarly, only a few teacher educators have reported on the use of teacher-constructed cases depicting personal practical experience as a way to gain insight into the perceptions of prospective teachers (e.g., Kagan & Tippins, 1991, 1993; Laboskey & Wilson, 1987), but the results of these explorations suggest that such cases can provide helpful evidence of professional growth.

To summarize, practical experience is necessary for the development of personal pedagogical knowledge, but it is not sufficient to insure productive professional growth. Classroom experience can be usefully supplemented by analysis of cases that provide realistic, contextualized exemplars of research-based principles of effective teaching, enabling novices to practice problem-solving skills. Further, classroom experience can be usefully re-examined and transformed when novices are encouraged to reconstruct significant events by writing cases to be discussed and analyzed by peers. Teacher-constructed cases can also be used by teacher educators and researchers to trace developmental changes in the cognitions of prospective teachers.

The Role of Personal Pedagogical Knowledge

Research on personal pedagogical knowledge is still a relatively new area of research on teaching, and there is much yet to be learned. Teacher educators and researchers, however, see this area of investigation as vitally important for improving our understanding of the process of learning to teach (Clandinin, 1993; Clandinin & Connelly, 1994). In terms of the concept of pedagogical knowledge explicated here, personal pedagogical knowledge is both an essential facet of pedagogical knowledge, and a critical component of pedagogical content knowledge.

As Figure 2 (presented earlier) denotes, the development of context-specific pedagogical knowledge occurs as prospective teachers reflect on experiences, and build connections between research-based general pedagogical knowledge and experience-based personal pedagogical knowledge. As they reflect on specific classroom events they are experiencing, prospective teachers can begin to identify the particular instructional strategies, discourse patterns, and managerial techniques that best promote pupil participation and learning in that particular classroom setting. They will use the resultant context-specific pedagogical knowledge to plan instruction, make interactive decisions during lessons, and evaluate outcomes.

Most teacher educators agree that this process of reflection ultimately determines the extent of professional development that occurs for any teacher (e.g., Rust, in press). Prior beliefs about teaching and learning that are uninfluenced by practical experience and uninformed by research-based general pedagogical knowledge can constrain professional development and curtail the instructional options considered. In the absence of systematic reflection on experience, context-specific pedagogical knowledge will be severely limited.

It is context-specific pedagogical knowledge that contributes most directly to pedagogical content knowledge (see Figure 1). Just as general knowledge of content, curriculum, goals, evaluation, and learners is filtered through knowledge of specific content, specific curriculum, specific goals, specific evaluation procedures, and specific learners to formulate a teacher's pedagogical content knowledge, so general pedagogical knowledge, informed by reflection on personal pedagogical knowledge, is filtered through context-specific pedagogical knowledge to assist in the construction of that pedagogical content knowledge.

IMPLICATIONS FOR SCIENCE TEACHING, SCIENCE TEACHER EDUCATION, AND RESEARCH

There is much still to be learned about each of these various facets of pedagogical knowledge, but it is clearly possible to draw some implications for practice from what is currently known. Before commenting on such implications, we need to note that the separation of facets and categories contributing to pedagogical knowledge and pedagogical content knowledge depicted in Figures 1 and 2, and extended to the organization of sections in this chapter, is an artifact of the analysis attempted here. In reality these elements flow together. It is literally impossible for a teacher to implement pedagogical knowledge in the absence of content. Similarly, we would argue, it is literally impossible to teach content effectively without using pedagogical knowledge and skills. Shulman's concept of pedagogical content knowledge is a unique contribution to research on teaching and to teacher education precisely because it unites these two critical elements of teacher thinking, elements which have been too long divorced in teacher education programs. While most of the research reported here has been carried out in relation to a variety of content areas, there are pieces that seem particularly pertinent to the teaching of science and the preparation of science teachers. The recommendations for practice offered here, however, would benefit from further research to identify relevant results.

Science Teaching

Research on teacher effects demonstrates the value of active teaching, supported by a classroom management system that enables teacher and students to spend time focused on appropriate academic tasks. Effective teachers articulate their expectations early and enforce them consistently. They maintain high levels of pupil involvement during instruction. These general guidelines can be applied readily to the teaching of science in order to promote improved pupil performance.

One specific feature of science teaching of importance here is the use of teacher demonstrations and student explorations conducted in the science laboratory. Safety rules for handling equipment and materials must be carefully taught and continually reinforced. Different expectations for appropriate behavior in different instructional settings within the laboratory need to be clearly delineated. Procedures appropriate for cooperative student investigations must be distinguished from those appropriate for individualized assignments or teacher-led discussions of student observations.

Research on classroom communication patterns also has particular implications for science teaching. Of critical importance here is the work on gender differences in classroom interaction. If talented women are to be encouraged to pursue careers in science, they must first be encouraged to participate actively in intellectual exchanges and challenges in science classrooms. Teacher acceptance of ideas initiated by female students, as well as responsiveness to questions they raise, can be useful for this purpose. Teacher praise directed at young women's academic contributions rather than their conforming behavior can also serve to promote confidence. Teacher planning of instructional activities that encourage cooperative problem-solving by students can further operate to increase women's involvement in science classes.

The work on instructional models and strategies can make an especially critical contribution to science teaching. The message that varied instructional goals are best served by varied instructional strategies is of primary importance here. Several strategies seem to be particularly appropriate for the varied goals inherent in science instruction.

Brown and Campione's (1990, 1994) community of learners model can help learners develop the skills of cooperative inquiry that are essential for most working scientists in the world today. The sharing of information and valuing of differences in skills and knowledge inherent in this model are critical components of the cross-disciplinary research carried out by many teams of scientists.

Both of the processes for teaching academic tasks (Rosenshine, 1993) can serve science teachers well. Direct instruction procedures are especially helpful for teaching algorithmic processes such as those used in solving physics problems. Expert scaffolding procedures can be used effectively to improve comprehension of information presented in science textbooks, as well as reports on scientific matters found in the popular press.

Productive strategies for science teaching belonging to the Information Processing Family (Joyce, Weil & Showers, 1992) include the memory model, the advance organizer model, the interpretation of data model, and the inquiry training model.

The memory model can facilitate student recall of factual information such as scientific terms and definitions. The advance organizer model can promote understanding of hierarchical relationships such as those common in scientific classification systems. The interpretation of data model can encourage development of skills in the reorganization of information, and it provides students with practice in both inductive and deductive thinking, leading to the formation of valid generalizations. The inquiry training model is designed to stimulate development of skill in the isolation and control of specific variables in order to arrive at explanations for complex and puzzling events.

Another model with particular pertinence for science teaching is included in Joyce and Weil's Social Family. The jurisprudential model can assist students in exploring competing values, clarifying their own positions in relation to complex social issues, and supporting these positions with available evidence. Given the number of social issues imbedded in applications of modern science and technology, this model can be an important tool in the science teacher's instructional repertoire.

Science Teacher Education

If these are accepted as important implications of pedagogical research for science teaching, certain implications for science teacher education must logically follow. Prospective science teachers will need to understand and be able to use the general principles of good classroom management. Further, they must be alerted to the intricacies of classroom communication processes, and be aware of the potential differences in responses of diverse pupil groups to typical patterns of questioning, allocation of turns to talk, and teacher feedback. Most importantly, they need to learn to use several of the alternative instructional processes appropriate for the varied goals of science teaching.

As noted earlier, these different aspects of pedagogical knowledge are interrelated, and probably should not be taught in isolation. Different instructional strategies require different classroom management procedures, and engage pupils in different patterns of communication. Thus practice in use of a particular instructional strategy can promote learning of all three aspects simultaneously.

It is clear from the research that the key word here is practice. Prospective teachers must practice these processes in actual lessons that they plan, implement, and evaluate. Initial practice should be provided in settings where the complexity of the classroom is controlled. Peer teaching (teaching mini lessons to small groups of other prospective teachers) is one useful way to provide such control. Micro teaching (teaching mini lessons to small groups of public school pupils) is another. Videotaping of lessons taught in either type of setting can provide students with an opportunity for careful review of their behavior in relation to classroom management, classroom communication patterns, and/or implementation of a specific instructional strategy or model. They can learn from review and discussion of each other's lessons, as well as from peer review and discussion of their own lessons.

Video or narrative cases can provide another avenue for controlled practice. Specific types of instructional events can be selected to provide prospective teachers with practice in identifying problems related to classroom management, classroom communication, or instructional strategy. In small-group or full-class discussions, students can explore alternative ways of responding to the problem situations, and support their proposed reactions by reference to research-based principles of pedagogy.

It can be particularly helpful for students to be confronted with instructional events that are difficult to observe in normal circumstances. Video cases developed by teacher educators can provide instances of such events. For example, in science laboratory exercises pupils are frequently directed to work together in independent study groups. Interaction within these groups can take many forms, some conducive to productive learning, and others detrimental to both pupil performance and self-esteem. Teachers cannot easily observe these types of interactions, since the patterns of communication tend to shift whenever the teacher approaches a pupil group. A stationary video camera focused on a pupil group soon fades into the background, and spontaneous, realistic pupil interaction can be captured on tape for later analysis by students preparing to be science teachers.

Each of these types of opportunity for controlled practice provides an additional opportunity for prospective teachers to reflect on experience. Through such thoughtful reflection the general pedagogical knowledge acquired from readings and college course activities can operate to encourage teacher candidates to test, revise or corroborate, and expand their personal pedagogical knowledge. Such active processing and integration of information from the two types of sources of pedagogical knowledge can promote the transformation of knowledge that is essential for later transfer to varied instructional settings and situations.

Controlled practice is a productive precursor to full-fledged classroom practice, but it should not be seen as a substitute for systematic and prolonged field experience. Prospective science teachers need extensive experience in classroom settings, observing excellent experienced teachers, and working with pupils individually, as well as in small and large groups. The experienced teachers with whom they work should be able to model effective use of a variety of instructional processes appropriate for science teaching. Experienced teachers and college supervisors working with prospective science teachers in field settings might well make use of expert scaffolding techniques to support their initial teaching attempts. Useful techniques would include: modeling specific instructional procedures; thinking aloud about interactive decisions (using videotaped playbacks of lessons); regulating the difficulty of initial teaching tasks; anticipating potential difficulties and alerting student teachers to these before a lesson begins; and providing checklists for them to use in evaluating their lessons. These procedures can be used to support learning of efficient classroom management procedures, and inclusive classroom communication processes, as well as alternative instructional strategies.

One final point is clear from the research. While systematic and prolonged practical experience in both controlled and natural instructional settings is essential in the preparation of science teachers, attention must also be paid to the prior beliefs and perceptions these prospective teachers bring with them as they enter a preparation program. Much of the science teaching which such teacher candidates experienced as high school and college students may have emphasized learning from textbooks and lectures, and rote memorization of factual information. Their metaphors for teaching may feature the teacher as source and dispenser of knowledge. Early exploration of both positive and negative connotations of a wide variety of alternative metaphors for teaching may serve to broaden their perspectives. As field experiences are introduced, teacher candidates also can engage in guided analysis of their natural metaphoric language use as revealed in their descriptions of their interactive teaching and thinking. Reflective journals or stimulated recall interviews over videotaped lessons can provide ready sources for examples of natural metaphoric language.

Future Research

The research currently available provides many clues about pedagogical knowledge that could be useful for the improvement of science teaching and science teacher education. Much remains to be learned, however. The processes of scientific investigation promote skills in systematic observation. Teacher educators engaged in the preparation of prospective science teachers could use these skills to great advantage in careful study of the impact of the procedures recommended here.

Each of the suggestions about preservice activities can generate a useful set of questions for further study. Examples include the following topics and questions:

Alternative instructional strategies -- what is the optimal number of alternative strategies to introduce in preservice programs? does the sequence in which alternative strategies are introduced influence learning or adoption of these models? is students' understanding/use of a given model enhanced by peer teaching in groups with varied subject matter specialties?

Field experiences -- do student teachers' abilities to interpret classroom management events improve more rapidly when cooperating teachers use scaffolding techniques such as thinking aloud about interactive decisions during videotaped playbacks of their lessons? what changes occur in student teachers' awareness of pupil cognitions as a result of systematic study of pupil patterns of communication in independent study groups focused on laboratory activities?

Prior beliefs - what are the metaphors for teaching and learning held by prospective science teachers entering teacher preparation programs? do these differ from the metaphors held by students preparing to teach other subjects? what are the beliefs about the nature of reality held by prospective science teachers? how do these relate to contemporary reform movements in science curricula?

In addition to research focused on students engaged in preparation programs, teacher educators should consider possibilities for studies of long-term program impact. For example, many techniques are currently used by teacher educators to encourage prospective teachers to reflect on general pedagogical knowledge and practical experience. Reflective journals, stimulated recall interviews over videotaped lessons, and analysis or construction of teaching cases are all procedures used to encourage novice teachers to examine their own behavior and thinking in relation to research-based pedagogical knowledge. There is little or no evidence, however, about the long-term effects of these types of activities on teachers' instructional practice and professional growth. Future research by teacher educators should follow graduates into their first few years of teaching to document the degree to which reflective techniques introduced during teacher training continue to support individual development of context-specific pedagogical knowledge.

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[2] As evidence of this effect, note the difference between the calls for proposals for the 1992 and 1994 annual conferences of the American Educational Research Association, Division K (Teaching and Teacher Education). In 1992 "Instruction in teaching and teacher education" was the heading for one of five sections, and "content-specific and context-specific pedagogy" was one of four sub-topics within that section. In 1994 "Teaching and teacher education in the content areas" was the heading for one of eight program sections, and "content knowledge" and "pedagogical content knowledge" were two of the four sub-topics. This program section also boasted three assistant chairs: one for literacy, arts, humanities, and social studies; and two for mathematics and science.

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JULIE GESS-NEWSOME

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 events. The studies in this section of the review look at teachers' conceptual knowledge and its relationship to classroom practice.

Subject Matter Structure

Conceptual knowledge is assumed to be organized in long term memory in a manner that is structured, integrated, and facilitates the storage and retrieval of information (Gagne & Glasser, 1987; Hiebert & Carpenter, 1992). Such networks of relationships, more formally called knowledge structures, are unique to the individual, may be contextually bound, and are emotionally more neutral than beliefs (Champagne et al, 1981; Roehler et al., 1988). It is intuitive to assume that teachers would have a knowledge structure for their subject matter.

Cognitive views of knowledge structures can be contrasted with philosophical ones. Shavelson notes that the "structure of a subject matter, ultimately, rests in the minds of the 'great scientists.' This structure is communicated through the scientists' writings in journals and advanced textbooks as well as through informal communication channels" (1974, p. 232). Schwab defined disciplinary structure as a "highly flexible pattern which is continually adapted and modified to fit the particular problems and situations to which it is applied....few, if any, disciplines have a single structure" (1978, p. 239). Finally, Beane (1995) reminds us that the subjects taught in schools are "representations" of the disciplines and their structures, and not the disciplines themselves.

Therefore, there are two conceptions of structure that emerge from the literature, one psychological and another philosophical. Though Champagne and colleagues (1981) noted that "the philosophical construct of discipline structure and the psychological notion of cognitive structure are central to many issues in science curriculum development and instruction" (p. 109), the casual integration of these two domains have raised concerns by number of scholars. Phillips (1983) cautioned that cognitive psychology and philosophy are based on very different goals and assumptions and cannot be easily interchanged, while questioning the appropriateness of the structure of the discipline as a teaching goal. While both academic fields are concerned with similar bodies of knowledge, school subjects tend to have harder disciplinary boundaries, whereas edge-cutting research often occurs at disciplinary intersections, blurring the distinctions (Beane, 1995).

One way to interpret the debate and distinguish between the philosophic and psychological reification of subject matter structure is to look at the intersection of individual private understandings of subject matter structure with the public, disciplinary aspects of the same knowledge. West, Fensham and Garrard (1985) define public knowledge as relatively static and visible, embodied by groups of individuals, and easily described as propositions, images, procedures, or algorithms. Private understandings are relatively more dynamic and more difficult to precisely describe. This tension between private understanding and public knowledge is played out in the different interpretations of subject matter structures: are they measures of internal organization of knowledge, or reformulations of disciplinary structures?

In practice these distinctions are hard to maintain. Teachers have a difficult time separating their views of the discipline from views of teaching the discipline (Grossman, 1990; Lederman, Gess-Newsome & Latz, 1994). Knowledge representations are useful in teacher research because they act as potential connections between cognitive structure and the structure of the discipline (Carlsen, 1991a; Hiebert & Carpenter, 1992). Research that has explored the organizational patterns of subject matter used by teachers have used the terms subject matter structures (Gess-Newsome & Lederman, 1993, 1995; Lederman et al., 1994), disciplinary conceptual schemes (Hashweh, 1987), and cognitive structures (Hauslein, Good & Cummins, 1992). Though specific allegiances to the cognitive or philosophic roots of these terms vary and are sometimes difficult to determine, it is apparent that research into *subject matter structures* attempts to capture an individual's private understandings of public disciplinary structures.

Nature of the Discipline

The definition of the *nature of a discipline* varies somewhat by the discipline that is being described. At the most basic level, the nature of the discipline "refers to the values and assumptions inherent to the development of scientific [disciplinary] knowledge" (Lederman, 1992, p. 331). Traditionally, the nature of a discipline includes a teacher's understanding of the history, philosophy, and sociology of the discipline, as well as the questions asked within the discipline, the modes of inquiry used, the nature of discourse, and the cannons of evidence that characterize accepted answers. Though Schwab (1978) has suggested that disciplines can be more precisely characterized by their substantive and syntactic elements, a division that is often used in the reviewed research, such distinctions confound other categorical representations selected for this review. For instance, substantial elements may include the conceptual knowledge and paradigms that guide an investigation, whereas syntactical structures include the cannons of evidence and proof used in a field of inquiry (Schwab, 1978). Distinctions between substantive and syntactical elements of a discipline blur when one considers such topics as the theory of evolution -- which can represent a paradigm and constrain acceptable forms of evidence -- lending merit to other means of distinguishing aspects of teacher knowledge (Carlsen, 1991a; Phillips, 1987).

Content-Specific Orientations to Teaching

The term "orientation" has been used in various studies to represent a number of interrelated ideas. For the purposes of this review, *content-specific teaching orientations* will be defined as teachers' beliefs about teaching and learning that are grounded in a framework used for organizing knowledge in their field (Grossman, 1991; Grossman, Wilson & Shulman, 1989). Though there is speculation that these content-specific orientations may be based on more generic epistemological stances than disciplinary structures (Smith & Neale, 1991; Porter & Freeman, 1986), this review will consider only research exploring orientations with a content-specific epistemological element. For example, generic epistemological stances may include views related to teaching for relevance or an inductive versus deductive approach to facilitating learning. Content-specific orientations include the selection of a molecular, evolutionary or ecological approach to biology instruction, or an emphasis on either the reader, text or context when teaching literature. As noted by Grossman (1991) and Gudmundsdottir (1990), though the knowledge held by two teachers of varying orientations may be the same, the orientation held will increase the relative importance and use of some pedagogical practices and diminish the use of others. From the above definition, it should be obvious that a teacher's orientation toward his/her content is a complex combination of content knowledge, beliefs, and values that have the potential to impact what and how students learn about their content.

Contextual Influences on Curricular Implementation

The section on *contextual influences on curricular implementation* acts a culmination of the influence of teachers' knowledge and beliefs on classroom practice. Knowledge, as it is socially and contextually formed, both influences and is influenced by the situations in which it is manifested (Talbert, McLaughlin & Rowan, 1993). This section includes the obvious impact of mandated materials on instruction, such as textbooks, curriculum guides, and standardized assessments. The opportunities and constraints represented by these materials interact with teacher cognition by reaffirming or challenging what is known and believed, and ultimately may shape what is practiced. In addition, central to any classroom context are the players in the constellation of education. Similar to the manner in which resource materials may reinforce, challenge, or change teacher knowledge and beliefs, students, parents, and school context variables can also exert a tremendous influence on how teachers translate their thoughts into action. As noted by Talbert, McLaughlin and Rowan (1993), teaching contexts are complex, diverse, embedded, and interactive, affecting teaching practices by impacting values, beliefs, policies, and resource allocation. Specifically, the studies in this section will look at the intersection of contextual variables with teachers' beliefs, knowledge, and judgments on the implemented curriculum.

While the five categories of subject matter knowledge used in this review are helpful for organizing the literature, they are not fully distinct. Thus, in some cases, studies will be discussed in more than one section.

REVIEW OF THE LITERATURE ON SECONDARY TEACHERS' SUBJECT MATTER KNOWLEDGE AND BELIEFS

Conceptual Knowledge

Several studies have compared novice and experienced teachers to determine the influence of subject matter knowledge on classroom practice. Barba and Rubba (1992) compared the declarative and procedural knowledge that 30 preservice and 30 inservice teachers used in solving earth and space science problems. Experienced teachers were found to bring more declarative knowledge to problem solving situations, solved problems more accurately using fewer steps, and generated more sub-routines and alternative paths than preservice teachers. The preservice teachers in this study had not mastered the high school level declarative knowledge assessed in the investigation. The authors suggest that, while both groups may hold the same amounts of declarative and procedural knowledge, the experts may have this knowledge structured in a manner that facilitates retrieval in problem solving situations. These findings are similar to those of Clermont, Borko and Krajcik (1994) who noted that novice teachers' declarative knowledge was inaccurate and inadequate for applying chemistry knowledge to teaching. In contrast, experienced chemistry teachers were more accurate in their explanations about and selection of appropriate demonstrations for teaching specific concepts, were more confident in their knowledge of chemistry as it applied to presenting chemical demonstrations, and possessed a more developed repertoire of content representations.

The impact of the mathematics knowledge of secondary teachers on classroom practice has also been explored. Even (1993) surveyed 152 prospective secondary mathematics teachers and interviewed a sub-sample of 10 teachers to determine their subject matter knowledge of functions. Despite completion of required math courses, the majority of the preservice teachers did not hold modern conceptions of functions. In simulated teaching situations, teachers with modern, rich and accurate conceptions of functions often regressed to algorithmic explanations when confronted with a student who was having difficulties. The preservice teachers without such rich understandings overemphasized procedural knowledge without concern for the limited conceptual student understandings that resulted. Inadequate mathematical understandings and over reliance on rules and procedural algorithms was also found by Baturo and Nason (1996) in the area of measurement and Ball (1990, 1991a) on the topic of fractions. Ball noted that both elementary and secondary preservice teachers lacked explicit and connected conceptual understandings of fractions, could successfully select and use algorithms without understanding the underlying mathematical concepts, and thought that learning math was synonymous with remembering rules. When comparing the preservice secondary mathematics teachers to their elementary counterparts, secondary preservice teachers were found to exceed their colleagues on in their ability to remember the rules but they did not have a more sophisticated mathematical understanding (Ball, 1990). Students in all three studies justified their emphasis on teaching mathematical rules over promoting conceptual understanding with their personal experiences as a mathematics student. Compartmentalized and fragmented knowledge, found in all three studies, "seriously misrepresents the logic and conceptual organization of the discipline to students, [and]... substantially increases the cognitive load required to 'do' or 'know' mathematics" (Ball, 1991a, p. 18). Ball cautions that "these results highlight the danger of assuming what teachers understand about the mathematics they teach" (p. 9, 1991a).

Czerniak and Lumpe (1996) assessed the attitudes of 168 K-12 teachers in Ohio about the implementation of a new inquiry-oriented state science curriculum. Fifty-seven percent of the teachers did not feel that they had the science background knowledge needed to successfully implement the reforms. Over 60% of the teachers surveyed reported using some of the strategies that were part of the reform effort at least once a week: learning styles, thematic approach, classroom management, alternative assessment, science-technology-society interactions, and cooperative learning. Reform strategies not used by the majority of teachers on a regular basis included instructional strategies related to equity, technology, subject matter knowledge, hands-on/minds-on activities, and the nature of science. It is important to note the content-specific orientation of the less used strategies and the more generic pedagogical nature of the strategies used–a finding that might be linked to teacher's lack of confidence in their content knowledge. In a follow-up study, Haney, Czerniak and Lumpe (1996) characterized the teachers most likely to implement elements of the reform as being relatively novice, female elementary teachers with a high familiarity with the statewide core curriculum and a high degree of self-efficacy. Secondary teachers were generally resistant to adopting the new core curriculum, though middle school teachers were judged as more willing to implement the new curriculum than were high school teachers.

Lantz & Kass (1987) surveyed 69 secondary chemistry teachers about their beliefs and values concerning the translation of chemistry curriculum materials into classroom practice, with in-depth interviews and observations of three teachers. The three factors identified as most influential in the interpretation and use of curriculum materials included teachers' constellation of values and beliefs (labeled as their functional paradigm for chemistry), their content and teaching background, and their teaching situation, with backgrounds in chemistry and chemistry teaching having the greatest overall influence. As the teachers gained more content background and teaching experience, they became more self-sufficient and relied less on officially approved materials. Teachers who were not chemistry majors relied more heavily on textbooks than chemistry majors of similar teaching experience. Chemistry majors were more likely than non-majors to positively rate the adequacy of their content background, particularly in relation to laboratory work, and were more likely to emphasize the tentative nature of scientific knowledge. The identification of valued and essential content topics varied with previously taught courses, suggesting that teachers are not likely to discard teaching practices or topics with which they had success from prior curriculum materials as they move toward implementing a new curriculum.

Three studies looked at the impact of high and low areas of knowledge in teachers with equivalent teaching experience. In a series of reports, Carlsen (1991b, 1993) compared the classroom discourse and activity structure of four novice teachers when engaged in teaching self-identified high and low knowledge biology topics. When teaching high knowledge topics, teachers were more likely to engage in lectures that presented new information, ask high level questions, review student work, and spend a greater number of days on the unit. Laboratories were characterized by more open-ended directions and encouragement of student-initiated explorations. When teaching low knowledge topics, the teachers talked for longer periods of time, held their speaking turns longer in whole class discussion, and asked students more questions, though the questions were typically of a low cognitive level. Student questions to the teacher were less common in low knowledge topics than in high knowledge topics. In contrast to the use of lectures in high knowledge topics, the teachers spent relatively more time in small group work in low knowledge topics. Laboratories were used with similar frequency across high and low knowledge topics, however, student exploration was more constrained by explicit written and verbal directions when in low knowledge areas. While a number of topics in the curriculum were omitted due to time, these topics were not based on knowledge level. Dobey and Schafer (1984) found that teachers of intermediate knowledge levels allowed their students more opportunities to engage in inquiry-oriented activities, whereas high knowledge teachers tended to lecture. Low knowledge teachers tended to control student exploration within the limits of their own knowledge. Hollon, Roth and Anderson (1991) report parallel results when studying experienced middle school science teachers. When faced with unfamiliar content, the teachers "managed student work rather than monitoring student understanding" (p. 165) by relying more heavily on the textbook, worksheets, and videotapes. Science content was treated as independent and unstructured facts; objectives were "covered" in a sequential and isolated fashion. Moreover, the teachers could not predict student outcomes on diagnostic measures and were therefore less likely to use student understanding as the starting place for instruction. Carlsen (1991b) suggested that the observed discourse and teaching patterns found in these studies may represent a way to control student opportunities for public discourse and thus eliminate the potential for students to move the content discussion beyond the teacher's level of expertise.

Two studies examined the similarities and differences in instructional practice when teachers taught in and outside of their area of certification. Hashweh (1987) explored inservice teachers' knowledge of biology and physics by asking three biology teachers and three physics teachers to plan simulated lessons on the topics of photosynthesis and levers. Within teacher comparisons were made across content areas. When teaching topics within their area of expertise, teachers had more detailed knowledge, and more knowledge of related concepts, foundational disciplinary principles, and specific methods of connecting the target concept to other concepts. Teaching outside of the content area was characterized as containing fewer details or connections to related topics and portrayed more conceptual inaccuracies. When faced with a text-based content structure, knowledgeable teachers were able to evaluate its usefulness and accepted it only if it matched their subject matter approach, whereas teachers outside their area of expertise adopted the text structure in the absence of an alternative. Regardless of content expertise, teachers modified text coverage, often eliminating material that they could not themselves remember or did not deem important for the organizational structure they elected to use. Laboratory or demonstration suggestions from the text were followed closely by unknowledgeable teachers whereas knowledgeable teachers modified these activities or generated new ones. Knowledgeable teachers were more likely to ask higher level questions, move beyond the textbook, require the synthesis of a number of related ideas, detect student misconceptions, and act on opportunities to enhance the content based on insightful student comments or fruitful digressions. Unknowledgeable teachers were found to rely on recall questions related to the content presented in the text and to be unsure of how to incorporate student comments into the flow of the lesson. These conclusions support the findings by Brickhouse and Bodner (1992) where a teacher in a low knowledge area rarely accepted alternative problem solutions from students.

While observing experienced secondary teachers plan, teach, and reflect on the success of lessons taught inside and outside their area of certification, Sanders, Borko and Lockard (1993) found that the experienced teachers often resorted to behaviors similar to those of a novice when outside their area of expertise; more time was spent on the planning and practicing of classroom lessons, and there was less sense of sequence, topic importance, content structure, student background knowledge, or the time required to teach various topics. Though these teachers relied heavily on their pedagogical knowledge formed in other content areas, they had difficulty in responding to content-specific student ideas and linking these ideas and questions back to the lesson. In contrast, within their content domain, planning was efficient and accurately represented what occurred in the classroom, both in terms of content coverage, anticipation of and reaction to student participation, and timing. As a result, the teachers' post-lesson reflection within the content area focused more on the level of student understanding achieved rather than the mechanical success or failure of a particular activity, as was more common in the lessons outside their area of expertise.

After observing two experienced social studies teachers who were considered exceptional in their ability to portray their content in exciting and dynamic ways, Wineburg and Wilson (1991) commented on the type of content knowledge that would be necessary in order to implement such lessons. These teachers were described as masters of their content with tightly organized networks of facts organized by overarching themes and ideas that gave the content coherence and interest. Both teachers viewed history as a human construct where stories were reconstructed based on evidence of the past. They held a generalized body of knowledge as well as theoretical models or methods of inquiry central to the discipline. This content background enabled the teachers to use a wide variety of content representations to make the link between the teacher held understandings and those ideas being constructed by students.

Summary and discussion. Hiebert & Carpenter (1992) remind us that, though the internal structures of knowledge cannot be precisely known, internal structuring of knowledge can be expected to bear a relationship to external representations of that knowledge. From the articles in this section a picture of the knowledge held by teachers at various points in their career can be created and a sense of how that knowledge changes over time can be gained.

Despite fairly high levels of confidence in their subject matter knowledge (Brookhart & Freeman, 1992) and a bachelor's degree in an academic area, most preservice teachers do not understand the content that they are to teach in a conceptually rich or accurate manner. Instead, the subject matter knowledge of most novices is fragmented, compartmentalized, and poorly organized, making it difficult to access this knowledge efficiently when teaching. As a result, many novice teachers are forced to rely on teaching the algorithms and facts that they remember from their own public school days (Talbert, McLaughlin & Rowan, 1993). Low levels of poorly organized subject matter knowledge impact instruction in a number of ways. When planning instruction, novice teachers overly rely on the textbook as opposed to students' understanding as an appropriate point of lesson departure. Learning is equated with remembering information, and thus reinforcing the belief in and use of algorithmic and fact-based knowledge. Such superficial content coverage hurts students by limiting conceptual understanding, misrepresenting the structure of the discipline, and preventing the construction of a strong conceptual knowledge base, thus limiting future learning opportunities. In order to keep the content within the expertise level of the teacher, lower level questions predominate and activities are constrained by strict procedural rules. The novice teacher is unable to spontaneously connect student comments and questions back to the formal lesson and often reject alternate student answers. The result is the "management of student work rather than monitoring student understanding" (Hollon, Roth & Anderson, 1991, p. 165).

Teachers with strong conceptual knowledge have more detailed knowledge of the topic, more connections and relationships to other topics, and can easily draw upon this knowledge in teaching and problem solving situations. Though experienced teachers hold many of the same content inaccuracies as novice teachers, the elaborate organization of this knowledge impacts both preactive and interactive teaching. Lesson planning begins with knowledge of the student and draws upon teaching activities and content representations previously found to be effective in achieving lesson goals. Texts and approved curriculum materials are used infrequently, with classroom instruction moving well beyond the text. Lessons are characterized by well-organized lectures and activities that emphasize the synthesis of information, challenge students with high level questioning, and allow students to actively explore topics.

When experienced teachers are placed in a situation where they are asked to teach a topic outside their area of expertise, many of the characteristics found in novices re-emerge. Though general pedagogical skills translate from past teaching experiences, planning is more cumbersome, lesson implementation more constrained, and goals for student learning more factual than conceptual.

What explanations exist for these patterns? Hiebert and Carpenter (1992) determined that an early focus on the learning of rules and facts often discourages learning for meaning. A close inspection of common courses in public schools and universities reveals teaching of this type. As a result, preservice teachers may have pre-existing inclinations to teach for factual and procedural knowledge rather than for conceptual understanding. Morine-Dershimer (1989), however, found that preservice teachers redefine and restructure subject matter understandings after teaching a lesson. Therefore, teaching itself may be a powerful tool in changing the subject matter knowledge and beliefs of teachers, moving knowledge from passive reception to active processing, and supporting the idea that knowledge must be used in order for it to be internalized and transformed (Eraut, 1994). As seductive as it may be to assume that content knowledge growth will occur simply as a product of teaching experience, learning from experience can be difficult to predict and may not always result in best practice (Buchmann & Schwille, 1983; Eraut, 1994). Evaluating the role of teaching on a teachers' knowledge of their subject matter has ramifications for our understanding of knowledge development and restructuring across a career and may shed light on the knowledge differences observed between novices and experts.

Subject Matter Structure

In the previous section, subject matter structure or organization was implicated as impacting teachers' classroom presentations by allowing for greater connections among content topics, facilitating the fluidity of teachers' use of student responses in classroom discourse, and increasing the ease of problem solving. In this section, research on teachers' conceptions of subject-specific organizations of knowledge are explored. It will be quickly evident that research in this area has been dominated by studies in biology, with some supporting studies in the social sciences.

Hauslein, Good and Cummins (1992) examined how 37 biology topics were sorted and organized by five groups of individuals: seven preservice biology teachers, eight biology majors, seven novice biology teachers, ten experienced biology teachers, and seven practicing biologists. The experienced teachers were found to possess well organized, hierarchically sequenced structures for biology and used broad biological principles as the basis of their classification. In comparison, the majors and preservice teachers were more narrow in their conceptual organization, using more categories. Though the preservice teachers recognized the interconnected nature of biology content, they linked almost all topics together using a flattened hierarchy, creating a highly unstructured map of questionable usefulness. The scientists were fluid in their categorization schemes, placing topics in more than one category, while teachers were more fixed, often placing topics together in the same manner in which they were taught. Increased teaching experience resulted in a more firmly entrenched pattern of topic classification. The authors detected a developmental pattern across those individuals with an intention to teach, stating that

> the transition does not seem to be one of achieving a deeper understanding of the biology concepts or to a greater degree of integration of the concepts, but rather a transition from a fairly large, loosely organized pool of biology concepts to one which is highly structured but limited to the expectations of the established curriculum (p. 939).

They also suggest subject matter use may impact its organization–biology teachers do not think about biology concepts separate from biology teaching. In contrast, since preservice teacher "use" of content is based on mastering content for exams, a structure is not developed until there is a need, which occurs when they start to teach. The structure employed by scientists and biology majors is more clearly based on laboratory research, explaining the more fluid nature of their content organization. The authors recommend that attempts to provide preservice teachers with subject matter structures occur earlier in their college careers.

Baxter, Richert and Saylor (1985) looked at the organization of biology content in five novice biology teachers. Based upon card sorts of ten themes identified as central to the discipline of biology, the teachers differed in their understandings of the role of inquiry in teaching science, the complexity of relationships among science concepts, and the relationship between general principles and specific facts. Two of the teachers viewed inquiry as a fundamental aspect of teaching science, recognized complex relationships among the topics, and believed in introducing broad conceptual frameworks for science content prior to introducing specific content. Two teachers saw inquiry as a set of specific skills to be mastered, perceived more linear relationships among science concepts, and thought that teaching specific concepts was central to good science teaching. The fifth teacher was placed in mid-continuum between these two groups. The background characteristic that distinguished the two groups was their level of content expertise (graduate work including a lab emphasis versus a non-laboratory based undergraduate degree) and the presence of a independent research project.

In series of investigations, Gess-Newsome, Lederman and Latz have looked at the subject matter structures of preservice teachers in the area of biology, secondary science, and pedagogy. Ten preservice teachers' conceptions of biology subject matter structure were followed across three science methods courses and into student teaching (Gess-Newsome & Lederman, 1993). Though the students in this study were not part of a formal cohort, they all took the same methods courses and student teaching seminar, all taught by the two authors. Once each quarter, students were given a written open-ended questionnaire asking them to describe their structure for biology. The preservice teachers were stunned and hesitant to respond when asked to describe the topics that make up biology and to represent relationships among the topics. Specific questioning in a later study (Lederman, Gess-Newsome & Latz, 1994) confirmed that preservice teachers understood the question being asked, but admitted to never before thinking about the organization of science content beyond that needed to successfully complete individual classes. Similarly, Ball (1990) found that secondary preservice mathematics teachers were unable to articulate and connect underlying mathematics concepts and principles. Over the four questionnaire administrations spanning the year of preservice preparation, students became more comfortable with the organizational pattern they created, one often resembling the college courses they had taken or the structure found in high school text books. The students attributed early subject matter structures to college courses and memories of high school, but recognized the fragmented nature of these understandings as they progressed through their science methods courses. Changes in subject matter structure as a result of teaching and reflecting on questionnaire responses were found, often evinced as greater content integration and simplification based on student needs. The preservice teachers eventually produced structures organized around concepts such as the nature of science, science-technology-society interactions, and science process skills–themes that were explicitly interwoven across their science methods courses and that are found in the national science reforms. The preservice teachers were proud of their articulated structures but admitted to a limited ability to translate them into classroom practice. Challenges to translation included concerns for student management, limited time to plan, the need to learn their content prior to teaching it, and the inability to focus on instruction over more than one or two days.

In contrast to the results of the above study, the preservice teachers studied by Lederman, Gess-Newsome and Latz (1994) and Lederman and Latz (1995) did not develop subject mater structures that resembled the integrative themes previously found. These two studies used similar data collection techniques to those in Gess-Newsome and Lederman (1993) with three important differences. First, conceptions of structure were collected for both subject matter and pedagogy. This was done to analyze the relationship preservice teachers may perceive between knowing and teaching their content. Second, the populations varied. In the 1994 study, the student participants consisted of 12 undergraduate secondary preservice science teachers in a cohort group. The 12 participants in the 1995 study were all graduate students, six previously completing a bachelor's degree in a science field, five a master's degree, and one a Ph.D. The third difference, and a possible explanation for the differences found among these studies, had to do with the course instructors. In the 1993 study, all three methods courses were taught by the two authors who held similar philosophical orientations and teaching approaches to the science methods courses; the results included the development of coherent subject matter structures based on themes found in the national reform documents. In the last two studies, various individuals taught the science methods courses, potentially resulting in a fragmented philosophical and instructional approach (Lederman et al., 1994). The result was the development of increasingly coherent conceptions of subject matter structure, but limited use of the themes so readily seen in the first investigation. In addition, the students in the last two studies developed subject matter structures that were less complex and believed that their subject matter structures could be easily translated into their teaching, a contrast to the findings of the first study. This contrast may suggest that the ease of subject matter structure translation may be directly related to structural simplicity versus complexity (Lederman et al., 1994). Most of the preservice teachers believed that structures for subject matter and pedagogy represent different forms of knowledge, with subject matter being accessed primarily for content explanations and representations, and pedagogy for issues related to lesson implementation (Lederman et al., 1994). Preservice teachers with far less content preparation were noted to develop more integrated structures in response to the planning and implementation of instruction, while students with extensive content preparation were more firmly committed to their initial conceptions of subject matter structure, a finding supported in a case study conducted by Powell (1994). This set of studies suggests that the logical location for the formation of a coherent and well-integrated subject matter structure is in the content area methods course.

Hoz, Tomir and Tamir (1990) compared the subject matter and pedagogical knowledge of seven biology and six geography teachers who varied on length of teaching experience (2-3 years versus over 10 years). Knowledge level was determined by analyzing concept maps created from preselected content and pedagogical terms. Teacher maps of biology, geography, and pedagogy were compared to those of university faculty who were considered experts in the domain and analyzed by producing quantitative measures related to term grouping and linking. The authors concluded that teachers, regardless of content area or teaching experience, do not hold knowledge of subject matter or pedagogy similar to that of experts in the field. Of the two domains, subject matter knowledge was generally closer to the knowledge of experts with retention credited to the explicit nature of its use in classroom teaching. Mastery of smaller groups of knowledge (such as a pairing between two concepts) was closer to the knowledge of experts than the organization of larger bodies of knowledge (expressed by groups of concepts). Subject matter knowledge was found to improve with biology teaching experience but remained stable for geography teachers. Pedagogical knowledge was noted to move farther from the knowledge of experts with time in the classroom for both groups of teachers.

Gess-Newsome and Lederman (1995) examined the self-described and implemented subject matter structure of five experienced biology teachers over the course of a semester. The teachers, ranging in experience from 7 to 26 years, were observed teaching biology approximately once a week and were pre and post interviewed about their teaching goals and conceptions of subject matter structure. Three of the teachers described subject matter structures that were based on discrete topics without conceptually integrative themes. Though these teachers viewed biology topics as interrelated, they did not provide specific examples of integration or describe how such a belief might be used in their instructional practice. Two of the teachers held views that were complex and rich in relationships. For all five teachers, the subject matter structures held were credited to experiences as a student in high school and college, and experiences teaching biology. Opportunities for reflection on content or reinforcement of science teaching beliefs, such as curriculum development, team-teaching, and science content workshops, distinguished those teachers who held integrated conceptions from those who did not. Teachers in rural schools with multiple subject area preparations were found to have fewer opportunities to reflect systematically on their discipline. The relationship of the described subject matter structures to those evident in classroom practice were complex, varied, and mediated by teacher intentions, content and pedagogical knowledge, student reactions, levels of teacher autonomy, and time to plan and implement instruction. Once a sequence and manner of teaching biology topics were established in each teacher's career, they seemed hesitant to change, findings supported by other studies (Lantz & Kass, 1987; Putnam, 1987; Wallace & Louden, 1992).

When examining changes in concept maps of content and pedagogy from undergraduate and graduate students involved in a micro-teaching course, Morine-Dershimer (1989) found that, following micro-teaching, students tended to refine their concept map of content by changing the number of categories while simultaneously increasing its logical organization. Graduate students and seniors described the interrelated and systematic nature of their content-based maps and used this information as part of the planning process. The undergraduate students did not describe or use their maps in this way. Refinements in content-based maps, particularly the move away from laws and formulas to a more concept-oriented approach, resulted from specific attempts to increase student learning. When reviewing their final maps, the undergraduate students often used the maps as a source of explanation for what they had taught, while the graduate students used them to explain where the content instruction would go in the future. Changes in teachers' conceptions of planning underwent a greater degree of change from pre to post map administration than did their conceptions of content. The author noted that the reflective peer teaching experience and the concept maps of content had a clear impact on the changes that were noted, offering both as tools for charting changes and as opportunities for fostering growth in the preservice teachers.

Gudmundsdottir & Shulman (1987) contrasted Harry, an American history teacher with 37 years experience and a master's degree specializing in the American revolution, with Chris, a novice social studies teacher with a bachelor's degree in anthropology. While Harry was able to articulate six different ways of organizing and linking the topics taught in American history, Chris struggled to learn the history and geography content on which his course was based, a trend found in other novice teachers (Brickhouse & Bodner, 1992). Chris recognized the advantages of linking his content together with " a good story line," a goal he was able to achieve when the content related to anthropology. For the many topics that could not be linked to anthropology, his major, Chris struggled to simultaneously visualize a complete unit, rarely capitalized on connections or developments from one unit to another, and often relied on a text or movie to take over the teaching of the topic. The authors argue that visualizing larger and larger content units as a part of an integrated whole may be an indirect indication of reaching expert status in content area teaching and recommend that preservice education should assist teachers in creating subject matter structures that will allow them to link key curricular concepts.

Summary and discussion. Understandings of the structure of the subject matter one intends to teach does not appear to be a natural consequence of graduating within a specified discipline or result from teaching experience. Instead, many prospective teachers appear to enter teaching with limited knowledge of the concepts and principles that undergird their discipline and provide it with conceptual coherence. Novices appear to select a subject matter structure on which to base their teaching early in their career. With coherent and sustained reinforcement across content-specific methods courses, some preservice teachers have created

elaborate and integrative subject matter structures based on the foundational principles espoused by the national reforms. These same individuals, however, often express an inability to implement these structures into classroom practice, often citing overwhelming concerns for classroom management and the inability to envision more than a few days of practice at one time. Other preservice teachers, without the opportunity to adopt or develop a more sophisticated subject matter structure, embrace relatively simple models of content similar to the textbook or the one used by their own college and high school teachers. Though these teachers experience fewer difficulties in envisioning the implementation of such structures into practice, these simple structures may run counter to the current reforms by emphasizing content coverage of isolated facts, limiting integration of process and product, and fostering few connections of school-based instruction with out-of-school experience. Laboratory and research experiences may be particularly effective in molding the subject matter structures of both scientists and science teachers. These structures, once formed, seem to be more resistant to change than the subject matter views held by teachers without such experiences.

Experienced teachers are more likely than novices to hold subject matter structures that are coherently structured and rich in relationships. Anderson (1989) highlights the advantages of having knowledge of the multiple structures that tie together a discipline when he comments:

> The academic disciplines are systems of knowledge so rich and complex that no one could ever fully understand all the structural relationships within them. The transformation of disciplinary knowledge for teaching, however, can be accomplished well only by people who are aware of the rich array of structural relationships within a discipline and who can use those relationships to reorganize their knowledge and make it accessible to students. (p. 95)

Experienced teachers, with greater exposure to their content, have structures for subject matter that span greater units of time than those of novice teachers who struggle to simultaneously envision even a few days of practice. Such an expert/novice difference highlights the potential advantage of a subject matter structure, begging the introduction of a subject matter structure to be studied and learned by all preservice teachers. No evidence exists, however, to evaluate on subject matter structures over another in terms of engendering preferred student outcomes. And, despite the intuitive appeal, teachers who possess multiple knowledge structures have not been found to be more effective in teaching their content than teachers with a single well-articulated subject matter structure. Perhaps more important than the questions that have not been answered are the questions that have: coherent subject matter structures have positive impacts on teaching practice, though their influence is mediated by subject matter structure complexity, pedagogical and content knowledge, teacher intentions and student reactions.

Views of the Nature of the Discipline

The research on teachers' views of the nature of their discipline includes conceptions of the manner in which knowledge is produced and accepted by the field, the body of knowledge that exists and the manner in which it is structured, and the epistemological variations that exist in the field. Though limited attention has been paid to teachers' conceptions of their discipline outside the area of science, where such a emphasis has existed for over 30 years (Lederman, 1992), several studies have been conducted in social studies.

In a review of research related to the nature of science, Lederman (1992) concluded that generally teachers do not hold adequate conceptions of the nature of science, that science methods courses produce significant changes in preservice teachers' understandings, and that academic variables such as the number of science courses, grade point average, and number of years teaching are not significantly related to teachers' conceptions of the nature of science. Successful techniques to improve teachers' conceptions of the nature of science included introducing the historical aspects of scientific knowledge or emphasizing explicit instruction on the nature of science. This section of the review will specifically examine the research that describes teachers' understandings of the nature of the discipline they teach and how this understanding impacts classroom instruction and, in some cases, student conceptions.

King (1991) examined the teaching goals of 13 preservice science teachers related to the history and philosophy of science prior to and following a science methods course. Preservice teachers' goals for science instruction included instilling an appreciation of and curiosity about science phenomenon and teaching critical thinking skills. Most of the preservice teachers had no formal preparation in the history and philosophy of science and, though they expressed an increased appreciation for the importance of this content after the course, were unsure how they would teach such content in the secondary classroom. For at least one student, the disparity between her college preparation, her current teaching emphasis on dispensing factual knowledge, and her new belief that science should be taught to encourage the critical examination of scientific ideas based on the history and philosophy of science, caused her to question the adequacy of her science preparation. The author concluded that science needs to be taught "not as a rhetoric of conclusions, but as a powerful form of making meaning of the world, often tentative and problematic" (p. 140). This understanding, however, was not held or promoted by his students.

Aguirre, Haggerty and Linder (1990) used an open-ended questionnaire to elicit the views of the nature of science, teaching, and learning held by 74 secondary preservice science teachers. Similar to the findings of Gess-Newsome, Lederman and Latz (1993, 1994, 1995), these teachers were puzzled by the question, "what is science?," and felt that they were being asked to reflect on the nature of science for the first time in their careers. Five distinct conceptions of the nature of science emerged: naive, experimental-inductionist, experimental-falsificationist, technological, and science as a three-phase process. Over 40% of the preservice teachers investigated held naive views characterized by science as a collection of facts and explanations based on observed phenomenon with no distinction between science and non-science. Less than 4% of the sample held the preferred "three-phase process" view in which theories are developed by scientists, tested, and then accepted or rejected by the scientific community. A transmission view of teaching was expressed by over 50% of their sample and coupled with a "discovery" view of learning (observations and manipulations of the natural world will result in the discovery of scientific truths). Though the translation of these views into teaching was not directly explored, the authors predicted that these teachers would teach in a manner consistent with their inadequate views of the nature of science and inconsistent with the teaching advocated by the current national reforms in science education.

Gallagher (1991) described the views of the nature of science held by 25 experienced secondary science teachers as "unsettling." These teachers emphasized science as a body of knowledge, spent more class time in developing terminology than on building relationships across concepts, and rarely engaged students in laboratory work. In observations of classroom practice, fewer than 10 days a year were spent on the methods of science. This content was typically presented at the beginning of the school year, was limited to the "steps of the scientific method," and emphasized the objectivity of scientific knowledge. Objectivity was described as the central feature of science that separated it from the other disciplines. Though all the teachers investigated were certified to teach science, held a major or minor in a science content area, and had over 10 years of teaching experience, their knowledge was limited to the products of science with no formal education in the history, philosophy, or sociology of science. Few of the teachers had any first hand experience with the process of exploring a scientific question in a manner that could produce new knowledge.

Lederman (1986; Lederman & Zeidler, 1987) compared the views of the nature of science held by 18 experienced biology teachers to their classroom practice, language use, and to the views of the nature of science held by their students prior to and following a semester of instruction. Lederman (1986) found that the teachers who were the most effective in creating positive changes in student conceptions of the nature of science emphasized inquiry-oriented questioning, active student participation, and problem solving in their instruction. Frequent teacher-student interactions were common with infrequent use of independent seatwork and a limited emphasis on rote recall. The atmosphere created by these teachers was supportive, pleasant, and risk free, where students were expected to think analytically about the content presented. These teacher behaviors, however, were not related to the teachers' conceptions of the nature of science. Lederman and Zeidler (1987) compared the specific classroom variables that distinguished teachers with high and low conceptions of the nature of science as measured on the Nature of Scientific Knowledge Scale (NSKS, Rubba & Andersen, 1978). Of the 44 classroom variables identified, only classroom down time was significantly related to a teacher's NSKS score. The authors caution that, though an understanding of the nature of science is important for teachers to possess, this knowledge does not directly translate into classroom practice. Other classroom constraints, such as administrative policies and classroom supplies, may impact teachers' practice more than their understanding of the nature of science.

Brickhouse (1990) investigated the views of three teachers, one novice and two experienced, on the nature of scientific theories, scientific processes, the progression and change of scientific knowledge, as well as the impact of these views on teaching. Overall, Brickhouse found that the teachers' views of the nature of science were consistent with instructional practice and beliefs about what and how science should be taught. For instance, Cathcart, an experienced teacher, believed that scientific processes led directly to scientific facts and theories. He believed this information to be within the cognitive capability of students and therefore emphasized the memorization of factual information. Process skills were taught separately from scientific knowledge. Lawson, the other experienced teacher, believed that scientific theories were tools for problem solving, a philosophy which directly translated to her classroom practice. Lawson's strong content preparation was offered as the source of her more accurate views of the nature of science. Compared to the two experienced teachers, McGee, the novice, was less likely to accomplish his teaching goals. The inconsistencies between his stated beliefs and his actual teaching practice was attributed to a reliance on the textbook to supplement his weak science knowledge base, his belief that students needed high degrees of structure to learn, student attitudes toward grades, and his perception of institutional constraints (also see Brickhouse & Bodner, 1992). Unlike McGee, the experienced teachers were consistent and successful in their translation of beliefs into practice. These findings contrast with those of Duschl and Wright (1989) who examined chemistry teachers' views of the nature of scientific theories and how this knowledge related to classroom practice and found that teachers gave little consideration to the nature of the subject matter when planning for science instruction. Factors that did impact the selection and implementation of instructional tasks included goals for student development, objectives imposed by the district curriculum, and accountability pressures.

In order to evaluate the role of views of the nature of science in the teaching of secondary science, Lederman (1995) selected five biology teachers with 2, 4, 9, 14, and 15 years of teaching experience who held views of the nature of science consistent with those found in the national science reforms. Each teacher was described as possessing a highly integrated and rich conceptual understanding of biology with the nature and history of science and science-technology-society interactions serving as unifying themes. Classroom observations and assessments of student understandings of the nature of science acted as a basis for comparison across the teachers. Clear differences emerged between the novice and more experienced teachers. Two of the experienced teachers were consistent between their views of the nature of science and classroom practice, though none of the teachers included student understanding of the nature of science as one of their explicitly stated instructional goals. The author suggests that this congruence of beliefs and practices may be a result of selecting instructional approaches that can be used to support a number of pedagogical purposes, including the nature of

science. In contrast, the two least experienced teachers were still struggling to develop an overall organizational plan for instruction. Similar to the novice in the Brickhouse (1990) study, these two teachers expressed frustration at the discrepancy between what they wanted to accomplish and the reality of the teaching situation. Classroom management rather than representation of disciplinary knowledge remained a primary focus. The one experienced teacher who was not consistent between her view of the nature of science and her instructional practice was overly concerned with presenting foundational biological knowledge, believing that the nature of science was too abstract to realistically present to her students. When examining student views of the nature of science following instruction, the majority of students did not hold views consistent with those expressed by the national science reforms or their teachers. The author concluded that teachers' conceptions of the nature of science do not necessarily influence classroom practice or student understanding and are mediated by teacher goals, experience, and context.

In a case study, MacDonald (1996) described how Gary, a chemistry teacher of 20 years, was able to create science lessons that explicitly emphasized both science concepts and the nature of science. His lessons were compared to those of two novice teachers. Two key features distinguished Gary from the novice teachers' lessons: context and continuity, and pedagogical suspense. Context was described as the recognition of the background knowledge that students needed to understand an idea; continuity, the connections developed between the current topic and past and future concepts; and pedagogical suspense, the timing and movement of ideas through the lesson. While all of these characteristics were present in the lesson of the experienced teacher, few existed in the lessons of the novice teachers. Gary was able to attend to the dual nature of his lesson while still monitoring and adjusting the impact of lesson delivery on students. The novices were able only to focus on the linear flow of the declarative content in their lesson. The author suggests the effort be made to help preservice teachers develop an explicit focus on the nature of science and an increased awareness of the concepts of context, continuity, and pedagogical suspense in lessons.

Few studies outside the area of science examine teachers' views of the nature of their discipline. In the social studies, Wilson and McDiarmid (1996) described their incoming assumptions as instructors about the background knowledge of inservice social studies teachers. Specifically, they believed that teachers entered classrooms with knowledge gained from an assortment of introductory content classes that rarely emphasized the process of history or facilitated a deep understanding of the connections among the various topics. This assumed knowledge base was contrasted with that recommended by the national reforms in history: an understanding not only of key historical events and actors, but also an understanding of how knowledge is created and accepted, of the role of personal biography in the interpretation of events, and of the various ways to engage students in the learning of history. Such assumptions about the knowledge inservice social studies teachers bring to the classroom were supported by two studies. Wilson and Wineburg (1988) compared the teaching of four novice social studies teachers along the dimensions of factual knowledge, place of interpretation and evidence, significance of chronology and continuity, and the meaning of causation–all elements related to the nature of history. Though all four novices held a bachelor's degree in a social science, only one held a degree in American History, the course they were assigned to teach. For the non-history majors (anthropology, economics, and political science), history was seen as a field of static facts–a belief developed during their experiences as public school students and not dislodged during their college education. Each teacher highlighted the aspects of history that they knew, such as the arts, culture, politics, and economics, and this background influenced how they saw the role of chronology in their teaching. While the historian and political science major saw interpretation and evidence as the process and mode of historical inquiry, these ideas were "fused" for the anthropologist and economist. Understandings of foundational historical themes and the role of causation were related to the background knowledge of the teacher, often colored by their disciplinary roots. As reported by the authors, "What is interesting in our findings is the way in which our teachers' undergraduate training influenced their teaching. The curriculum they were given and the courses they subsequently taught were shaped by what they did and did not know" (Wilson & Wineburg, 1988, pp. 534-535). Based on the narrow content specializations favored by universities, none of the teachers held a sufficiently broad understanding of history, forcing each teacher to learn new content as they taught. Unaware of the broad structures of history, the novices often overgeneralized the knowledge they did have. The lack of a disciplinary framework also prevented the novices from learning new content. For instance, without recognizing that history is based on interpretation, few novices sought alternative interpretations to present to their students. It was also noted that the goals the teachers held for their students were influenced by their background knowledge. High knowledge teachers sought to create enthusiasm and empower their students with the knowledge they were teaching. Low knowledge teachers relied on the textbook and quickly moved through the content.

The views of Price and Jenson (Wilson & Wineburg, 1991), two experienced and exceptional history teachers, act as a contrast to the study of the novice teachers in the previous study. Both teachers introduced their students to the nature of history as a discipline and as a way of knowing. Classroom presentations were consistent with their beliefs that history is a human endeavor based on the interpretation of data. Both teachers stressed that the history presented in the text was an account of past events rather than a description of the event itself, capitalizing on the interpretative nature of history to which they ascribed.

Summary and discussion. Research on teachers' understandings about the nature of the discipline has been primarily limited to work in science, though the few studies conducted in social studies concur with those findings. Teachers, regardless of their level of teaching experience or background knowledge, have very limited formal preparation in the nature, history, philosophy, or sociology of their discipline. Without such a background, teachers carry positivistic views of their discipline, teaching only the body of knowledge characteristic of their discipline with an emphasis on vocabulary rather than a balanced presentation of human and rule-based knowledge generation and cautious evaluation of knowledge claims.

These views support limited laboratory work and the presentation of science as *the* method of understanding the world. Such limited knowledge of the nature of the discipline may foil teachers' future attempts at learning their content by narrowing their search for information only to knowledge that supports their views and dismissing information that contradicts their beliefs. These limited views may also impact classroom teaching by allowing a teacher to overgeneralize the knowledge they possess beyond its appropriate use when faced with teaching content outside their area of specialization. Adams and Krockover (1997) point out that a large number of student teachers, particularly in the areas of science and math, are placed outside their area of preparation, increasing the impact of this problem.

Teaching behaviors do not mirror teacher's understanding of the nature of science, though teaching in concert with such understandings appears to occur more often in more experienced teachers than novices. Beginning teachers struggle to learn their content and maintain the flow of classroom life; these concerns diminish their ability or opportunity to consider issues related to the nature of science in either pre-active or post-active teaching. Experienced teachers, having mastered these initial skills, have more cognitive resources available to attend to the dual nature of lessons content (declarative knowledge and nature of the discipline) while maintaining pedagogical flow. While experienced teachers use teaching techniques that supported student understandings of the nature of science, many of these teachers did not hold explicit goals to teach students about the nature of science. In fact, many teachers, despite a high level of understanding of the nature of their discipline, are unsure of how to portray this understanding in their teaching. Regardless of a teachers goals, however, student understandings of the nature of science do not automatically correspond teachers' understandings. More importantly, a number of teaching behaviors have been identified that positively influence student conceptions of the nature of science.

Content-Specific Orientations to Teaching

It has been well documented that teachers will not implement curriculum materials that contradict their ideas about content and how that content should be taught (Porter & Freeman, 1986). Textbooks and external testing pressures have also been discussed as facilitators or inhibitors to change in subject matter instruction. An analysis of teachers' content-specific orientations to teaching offers one potential explanation for the adoption or rejection of curriculum materials. The studies reviewed in this section examine secondary teachers' content-specific orientations across the disciplines of science, mathematics, English, and social studies and their impact on teaching.

Benson (1989) examined the conceptions of biology, biological knowledge, and curriculum held by three experienced Canadian teachers. Though the author had anticipated that the teachers would hold constructivist views about the learning of science, he characterized them as realists, believing that scientists search for patterns that exist in nature and outside of themselves through empirically based methods. This view is contrasted with a constructivist view that recognizes science as one way of understanding the world, a human creation based on the social construction and analysis of derived patterns. The teachers' hierarchical conceptions of disciplinary knowledge were reflected in their emphasis on student memorization and master of lectures and text-based information prior to conceptually-based learning. Classroom practices, though impacted by teacher views of the nature of knowledge, were mitigated by the required curriculum, accountability of standardized tests and student grades, and personal views. The teacher with the lowest level of content knowledge was found to be the most wed to the government-mandated curriculum.

Hashweh (1996) used a survey to categorize secondary science teachers' views as either constructivist or empiricist and related these views to their teaching practices. The teachers who held constructivist views were more likely to detect student's alternative conceptions of content, have a richer repertoire of teaching strategies, use conceptual change teaching strategies, and value conceptual change strategies more than their empiricist counterparts. The author cited these teaching strategies as evidence of the impact of epistemological orientations on classroom practice.

An example of the deep influence of an incoming content orientation can be found in a study by Wildy and Wallace (1995). Mr. Ward, an experienced physics teacher was described as an excellent teacher based on his confidence and emphasis on the structure of the discipline. This orientation corresponded with a didactic teaching approach that produced strong student motivation and academic achievement. Though established in his content orientation and teaching practices, Mr. Ward made attempted to adopt a more application-based science program when a new national physics syllabus was introduced. The newly advocated teaching approach was recognized by Mr. Ward to be in conflict with his original orientation, masked the structure of the discipline that he valued, and contradicted the expectations of his students and their parents. Mr. Ward quickly returned to his original, more didactic style of teaching physics rather than expending the time and energy to adopt teaching practices that were in conflict with his orientation.

Similar examples of resistance to changes in content-specific teaching orientations are found in other studies. Hollon, Roth and Anderson (1991) noted that new teaching approaches must be accompanied by the mastery of a body of knowledge *and* new patterns of practice. In their study, teachers were presented with conceptual change curriculum materials that focused on a conceptual understanding of science content. The curriculum included decreased content coverage in favor of hands-on, conceptually-based learning approaches. Teachers who had established patterns of practice that emphasized content dispensation to passive students saw the conceptual change approach as academically "watered down." This perception resulted in teachers adding back "missing" content and reverting to previously mastered teaching techniques that contradicted those presented in the curriculum. Powell (1994) described a preservice teacher who entered the profession after a career in science and a held strong academic orientation toward the teaching and learning of his content that directly contrasted with his cooperating teacher's more affective orientation. Nonetheless, he adopted her classroom goals, which allowed

him to leave student teaching with his personal orientation untested. This form of strategic compliance (Lacey, 1977) has been noted in a number of studies on teacher change, particularly participation in university-based programs (Roderguez, 1993). The author notes that without the opportunity to confront his inconsistency or test the success of his own beliefs, this teacher left with his incoming orientation intact, missing an opportunity for growth.

Thompson (1984) conducted one of the few studies that exist on secondary mathematics teachers' beliefs, views and preferences about mathematics and its teaching. The three junior high school teachers of 3, 5 and 10 years teaching experience varied in their views about mathematics. Those who saw mathematics as static and taught for practical application were consistent in their views and their teaching. Similarly, the teachers who conceived of mathematics as problem solving also taught in a manner consistent with their views, stressing disciplinary understanding and student interest. Teacher's views, however, were not related in a simple way to their practice, being constrained by views of students, student level, enthusiasm for mathematics teaching, and concerns for classroom management. General views of teaching and classroom concerns tended to overwhelm subject-specific concerns, with views emphasizing mathematical connections coming from the more reflective teachers.

Several studies have considered the impact of teacher orientations toward literature and social studies on instruction. Grossman (1991) identified the reader, the text, or the context as the three primary orientations to reading literature, views which dominated both novice and experienced teachers' orientations. The differing orientations were found to express themselves in curriculum planning through the selection and implementation of activities that matched student-learning goals. Zancanella (1991) studied five junior high school teachers views of reading and found that implementation of personal orientations were limited by the school curriculum. More experienced teachers with more established orientations were better able to reject the district curriculum and maintain their personal goals for learning. The novice teachers in the study were the most likely to adopt the orientation portrayed in the district guidelines since they lacked an alternative theoretical framework and had a harder time distinguishing between what they wanted to do and what was required by the curriculum. Though the teachers in this study were not followed for a extended period of time, it is possible that the novice teachers would eventually reject the "borrowed" orientation, as was found by Grossman (1991).

Gudmundsdottir (1990) found that the orientations of English and social studies teachers were impacted by their conceptions of student needs, use of the text, selection of teaching methods, presentation of the content, and questioning patterns. In a related article, the author noted that the social studies teachers' orientations were based on differences in disciplinary preparation, with the views of teachers with an interdisciplinary background differing from individuals with a specialization in a single content area, such as history (Gudmundsdottir, 1991). The author states that having an orientation is a necessary but not sufficient condition for teaching excellence, and that, though novices have content knowledge, they often lack a model structured for pedagogical purposes. The lack of a content model for instruction results in novices being able to conceptualize only units or parts of units as opposed to courses of study.

Cornett (1990) studied the personal practical theories of an experienced high school social studies teacher. Five practical theories were elucidated with only one relating to conceptions of subject matter. Statements related to subject matter concerns, however, dominated the data set. As a prior middle school teacher, a tension existed between wanting students to have fun and to learn the content. Her orientation to social studies teaching guided her curriculum and instruction decision making, though her more generic classroom goals were valued over her subject specific goals.

Summary and discussion. Beliefs exert a powerful impact on the outcomes of teaching, as is evidenced by the studies presented in this section. It appears that teachers develop implicit content-specific orientations early in their careers, maybe as early as their own public school experiences. In fact, the more limited one's content background, the more likely one may be to rely on early classroom memories to develop an orientation (Mosenthall & Ball, 1992). Content-specific orientations influence how teachers perceive the teaching and learning of their content and impact classroom practice. Unfortunately, many orientations reinforce a view of teachers as dispensers of knowledge and of learning as remembering. These more generic views tend to supersede attention to more content specific goals and dominate teacher decision making. When teachers have weak initial orientations, they appear to adopt the orientations in embedded texts, curriculum guides, or university course work. Once established, orientations act as gate keepers for the acceptance or rejection of teaching material -- a match is sought. Experienced teachers have more firmly formed orientations and, when faced with the requirement to adopt a different orientation, often resort to a form of strategic compliance to external demands that maintains their original beliefs about their content and students (Rodriguez, 1993). Constraints to implementing teacher orientations are similar to those found in studies in other parts of this review: required curriculum, standardized testing, student grades, parent expectations, and personal views. Attempts to adopt new constructivist orientations, even when perceived important by the teacher, are often foiled by insufficient content knowledge. Insufficient subject matter understanding forces both novice and experienced teachers to learn their content. This demanding task, coupled with the request to adopt a new pedagogy, creates a cognitive burden that can be reduced by simply returning to familiar patterns of teaching and rejecting new content-specific orientations.

Contextual Influences on Curricular Implementation

Ultimately, examination of teacher subject matter knowledge is of little importance unless it is linked to teaching practice. While all of the studies in this review have focused on such links, the research reviewed in this section will specifically examine a secondary teacher's willingness to accept or reject curriculum, textbook, and assessment tools, as well as the impact of students, parents, and school context variables on teaching behaviors. Such studies represent the intersection of teacher knowledge and beliefs into the constellation of external influences that impact classroom practice.

Cronin-Jones (1991) selected two middle school teachers to implement a science curriculum based on wildlife issues that promoted a constructivist teaching philosophy. The objectives of the curriculum focused on knowledge, problem solving skills, and values and attitudes associated with wildlife and wildlife conservation. The two teachers each represented a type of academic preparation commonly found in middle school settings: one was prepared as a secondary teacher with a minor in biology, the other was prepared as an elementary teacher with no specific preparation in science. The author found that the underlying beliefs of the two teachers were inconsistent with those of the curriculum and influenced implementation. Contradictory teacher/curricular beliefs were held about how students learn, the teacher's role, the perceived level of student ability, and the relative importance of the content topics. Both teachers believed that the most important student outcome was factual knowledge and that students should learn through repeated drill and practice. The elementary-prepared teacher implemented less of the curriculum than the biology-prepared teacher, stating that the omitted lessons were inappropriate or of limited value. Similar curricular alterations, as a means of resolving conflicts between beliefs about what students should know and the information provided in a curriculum, have been reported by Hollon, Roth and Anderson (1991).

The primary role of the text as a determinant of what is taught in the classroom has been implicated in a number of studies (Gallagher, 1991; Wineburg & Wilson, 1991). In most cases, reliance on the text as the primary source of grade level appropriate knowledge occurs when teachers have limited knowledge about or confidence in their subject matter knowledge (Hashweh, 1987; Sanders, Borko & Lockard, 1993). This characterization of a limited knowledge base applies to novice teachers, and experienced teachers when teaching outside their area of expertise. Reynolds, Haymore, Ringstaff and Grossman (1988) interviewed and observed three mathematics and three English teachers as they completed a year of teacher preparation and moved into their first year of teaching. Supplemental data from biology and social studies teachers were also used to inform the results of this study. Questions guiding the research included the influence of subject matter understanding on the evaluation and adaptation of curricular materials, the influence of curriculum materials on subject matter knowledge, and the role of teaching experience on both subject matter knowledge and curriculum evaluation and use. Novice biology and social studies teachers were originally satisfied with the assigned course text, adopting the manner of content presentation contained. Text assessment was based on correspondence with college texts or courses, with tighter matches resulting in greater satisfaction. Teachers with weak content knowledge could not develop alternate course structures and thus were prone to adopt the structure portrayed in the text. The novice teachers became dissatisfied with the text, however, as knowledge of students' interests and motivations increased and as they became more committed to integrating topics. Differences in the willingness to change the text were influenced by time, curriculum mandates, orientations to the subject matter, and confidence in and degree of content knowledge.

While texts may be more useful for teachers unfamiliar with their content or students, the traditional structure of a text may also constrain teachers' opportunities to learn or change. Hollon, Roth and Anderson (1991), while examining the efforts of three experienced middle school science teachers to teach science for understanding using a conceptual change curriculum, discovered that teachers with weak content knowledge tended to rely on the organization of the text when implementing an unfamiliar curriculum. In an effort to move teachers toward more constructivist teaching practices, an emphasis on building relationships among content was reinforced through a series of workshops. Unfortunately, the "big picture" of the content that was needed to support instruction could not be found in a single text. Without the support of a text to conceptually integrate the content, the teachers were forced to rely on the fragmented content patterns found in the text to augment their limited content understandings. In this way, texts can be seen as both sources and constraints to teachers' knowledge and classroom lesson implementation.

In a survey of 69 high school chemistry teachers' views of instruction as it impacted curricular adoption, Lantz and Kass (1987) found that teachers believed that chemistry should be limited to topics in the curriculum guide, include topics of teacher interest, emphasize theoretical concepts and principles, value everyday applications, and include the nature of science. When presented with a new curriculum, experienced teachers retained topics from previously-taught chemistry classes that were valued for their pedagogical efficiency, academic rigor, and ability to motivate students. When teachers felt rushed for time, they omitted topics or activities that they did not regard as contributing to their students' understanding of basic chemistry topics. The result of new curriculum mandates, therefore, was the merging of some aspects of the new curriculum with the topics and practices teachers valued most from previous teaching experiences. There are similarities among these findings and those of several other studies. Duschl & Wright (1989), for example, looked at how 13 science teachers considered the nature of their subject matter when planning and delivering instruction. A finding of their study was that science teachers had two types of objectives: curricular objectives, which related to the content found in the curriculum guide; and personal objectives, those based on overall goals for students such as understanding science as process or gaining confidence. For lower level students, the primary source of objectives was the teachers' personal goals; for higher ability students, the goals were focused on the content in the curriculum guide. These two studies highlight the role of teacher's personal views about content on the selection of student goals and the implementation of curriculum.

Cornett, Yeotis and Terwilliger (1990) reported on the observations and interviews of one novice science teacher, Lori. Lori determined her teaching content based on her personal theories of instruction, none of which directly related to science academic content, but several that had content-specific affective components (e.g., science is fun, higher level learning, reinforcing concepts) that directly impacted student learning opportunities. As Lori started the school year, she defined the curriculum as the topics in the district science curriculum guide. This view was later replaced by her own determinations of what students most needed to learn. Though Lori had not viewed herself as a curriculum developer, she became more experimental and personalized her curriculum more as she became increasingly familiar with the students, and school and district guidelines.

Finally, Duffee and Aikenhead (1992) sought to understand how six high school science teacher used district-designed evaluation materials. The materials were designed to assess students' knowledge of the nature of science, science-technology-society interactions, and the values that underlie science–topics that were newly introduced to the science curriculum. Four of the teachers used the evaluation materials while two did not. Teachers assessed areas of the curriculum that matched their content perceptions and altered the district-designed evaluation practices to match their own values and beliefs. Adoption of the new science standards and the evaluation materials that measured these goals were more common among high knowledge teachers. Low knowledge teachers did not use the provided materials, emphasized factual knowledge, and believed their role was to transmit information to students.

Summary and discussion. The studies on the impacts of teachers' knowledge and beliefs on practice in this section are consistent with the findings presented in other parts of this review. Teachers do not use materials that do not match their views of teaching and learning. Materials, regardless of form, are used if they match the teacher's own perspectives, or are modified or discarded if they do not. Novice teachers, with limited teacher experience and knowledge of students, initially place more faith in the appropriateness of materials provided for them in texts and adopted curriculum guidelines, but quickly find their implicit beliefs rising to the forefront of decision making. Experienced teachers hold tightly to techniques and methods that have worked well for them in the past, valuing these materials for the pedagogical efficiency and ease of implementation. Reasons that prevent the adoption of materials include time, subject matter knowledge, orientation, and curriculum mandates.

Teacher's views of appropriate learning goals seem to be more generic than content specific. While Kennedy (1990) suggests that teacher preferences for lower or higher level learning may reflect teacher's understanding of the nature of their subject matter, Raudenbush, Rowan and Cheong (1993) note the importance of the teacher's disciplinary roots in establishing student goals. Teaching for higher level understanding has particularly pronounced tracking effects in science and mathematics, with teachers setting higher-order objectives for more advanced courses. The match between teacher preparation and subject matter in a particular class appear linked to a higher order emphasis. Based on a review of the literature, these authors offer little hope that raising the conceptual level of high school courses will be achieved by increasing the amount of preservice education, improving the match between content preparation and teaching assignment, de-emphasizing standardized tests, or implementing school organizational reforms. Evidence found in this review, however, suggests that the *way* teachers understand their content and thus teach it can be improved through university content and methods instruction.

IMPLICATIONS FOR PRACTICE

In the overall analysis, it is clear that the current educational system misses numerous opportunities to challenge teacher knowledge and beliefs in support of teaching goals advocated by the national reforms: teaching for understanding, providing students with a foundational understanding of the structure and nature of the discipline, engendering positive attitudes about content, and encouraging life-long learning and the application of knowledge. In this section, these opportunities for teacher growth and change will be identified.

It is apparent that the sources of teacher subject matter knowledge and beliefs are complex and diffuse, making change difficult. One solution is to call for system-wide educational reform, though a careful appraisal of the complexity of this call points to the danger in over reliance on such a solution in changing classroom (Cohen, 1995). Therefore, three opportunities for change in teacher development are identified and explored: university content courses, content-specific methods courses, and the induction period of the first three years of teaching practice. These opportunities require changes in relatively small and isolated components of the complex system of learning to teach and occur at pivotal points in the development of teacher knowledge and beliefs. For instance, within the current system, teacher preparation programs offer the greatest sustained contact with the smallest number of teachers at a critical crossroads in their development as teachers. Subject matter and education partners in teacher preparation have the tools, time, power, and potential to change the content and delivery of teacher preparation programs. Each of these opportunities for teacher development are discussed with the most promising practices related to change highlighted.

University Content Learning

In an attempt to characterize the expert teacher, Sternberg and Horvath (1995) identified the need for a deep and well-organized knowledge base that can be easily drawn upon during the act of teaching. Others have described the desired subject matter knowledge base of teachers as flexible, fluid, coherent, able to support the creation of alternative knowledge representations for students, and the able to support the selection among various pedagogical approaches and learning outcomes (Ball, 1991; Grossman, Wilson & Shulman, 1989; Kennedy, 1990). One of the past difficulties in identifying subject-specific knowledge goals has been the lack of consensus on exactly what content teachers should know in what form. Perhaps one means of escaping this dilemma is to, instead, identify the classroom practices that are desired and to recognize that teachers need sufficient knowledge to select and implement those behaviors. For instance, from this review, teachers having low levels of subject matter knowledge often teach for factual knowledge, involve students in lesson primarily through low level questions, are bound to content and course structures found in textbooks, have difficulty identifying student misconceptions, and decrease student opportunities to freely explore the content either through manipulatives or active discussion. These classroom practices do not support the kind of goals currently held for students. Instead, the teaching practices that are recognized as effective in producing student deep conceptual understanding and knowledge of the nature and structure of the discipline are similar to those practices which characterize high-knowledge teachers: high levels of inquiry-oriented and problem solving lessons; active student participation; frequent teacher-student interactions; social environments where risk is supported; open discussion of student ideas; accurate portrayal of disciplinary knowledge, nature, and structure; recognition and challenge of student misconceptions; and use of alternative representations or discrepant events in order to facilitate student learning (Hollon, Roth & Anderson, 1991; Lederman, 1992; Smith & Neale, 1991). Without such a substantial subject matter knowledge base, adoption of constructivist teaching methods may be unrealistic (Mosenthal & Ball, 1992; Smith & Neale, 1991).

So, what types of content courses should teachers take in order to gain such knowledge. As echoed by many of the authors included in this review, the issue in not the number of courses or their titles, but the manner in which these courses are taught. Most university courses can be characterized as factually-based, an instructional emphasis that has been shown to decrease attempts to gain more conceptual understandings (Ball, 1991; Hiebert & Carpenter, 1992). In addition, seat time in any classroom fosters the explicit learning of content as well as implicit information about the nature of the discipline, and assumptions about the teaching and learning of that discipline (Mosenthal & Ball, 1992). Therefore, what is needed is a change in the nature of the teaching of content courses. McEwan and Bull (1991) note that all knowledge has a pedagogic component since all knowledge, in some form, needs to be communicated if it is to be accepted. Using a pedagogic conception of subject matter leads to a number of potential teaching strategies for use in higher education. First, increased opportunities for students to work together would provide greater opportunities for active student learning. Thoughtfully designed assignments could make explicit student ideas and concpetions open for review and discussion among peers and instructors. Opportunities to describe the structure of the content being taught would help students identify connections among ideas, discourage the over-generalization of concepts, and impart a more accurate sense of the discipline. Creating alternative representations of key concepts would challenge students to understand the content in a more complete manner and offer a new interpretation for peer use or refinement. Such assignments would also force misconceptions into the public arena for identification and remediation. Laboratories, research, and other application opportunities would help students apply knowledge in alternative contexts and aid in establishing the interrelationships among facts, concepts, and procedures, a form of teaching associated with increased student achievement and satisfaction (Reynolds, 1992). Such opportunities draw upon the pedagogic elements of subject matter understanding, perhaps fostering movement toward the "ah ha" experience of new understanding after teaching a topic (McDiarmid, Ball & Anderson, 1989), and potentially decreasing the gulf between novice learning and teaching. It is conceivable that such methods of teaching would not only positively influence the knowledge base and attitudes of novice teachers, but of content majors as well.

Finally, teachers need additional opportunities to understand the nature and structure of their discipline. In an assessment of what teachers need in order to teach for understanding, Anderson (1989) identified a decreased emphasis on vocabulary and specialized knowledge, opting for a more broadly based understanding of the discipline, a recommendation that would support teachers placed outside of their content speciality when teaching (Adams & Krockover, 1997). Specifically, Anderson recommended that students learn more about the structure (relationships among and centrality of concepts), function (disciplinary processes, applications, and relevance), and development (historical and developmental) of their discipline while learning about their content. While one solution would be to require a separate class in the nature of the discipline, teaching such content concurrently with more traditional course content is a preferred method of instruction. Opportunities for reflection on the understandings of the nature and structure of the discipline then become necessary in order to make them explicit to students (Gess-Newsome & Lederman, 1993) and to challenge "insider" views of the nature of the discipline (Pajares, 1992).

Content-Specific Teaching Methods

Teaching is a complex, ill-structured situation where teachers are called upon to simultaneously respond to multiple situations and goals and to make and implement judgements with amazing speed (Doyle, 1977). When engaged in the teaching process, teachers attend foremost to students, then to issues of instruction, and lastly to objectives or the structure and organization of what is being taught (Clark & Peterson, 1986). It is apparent, then, that if systematic consideration of the subject matter is going to occur, it needs to be accomplished in the planning process, where it receives secondary attention following concerns for students (Clark & Peterson, 1986; Zahorick, 1970). A primary responsibility, then, of the content-specific methods course, is to help students carefully consider the content they are to teach. Novice teachers, with limited content knowledge, often focus on a teaching activity as a concrete means for portraying content, with little consideration for larger issues of disciplinary structure, connections of concepts within a lesson or across a curriculum, or the nature of the discipline (Gess-Newsome & Lederman, 1993; Reynolds, 1992; Shavelson & Stern, 1981). Methods courses present critical opportunities for students to consider content issues prior to teaching by asking for concept maps of lesson/unit structure and overt comparisons of lesson goals to overall teaching goals, and connections of the lesson to the nature and structure of the discipline (Gess-Newsome & Lederman, 1993; MacDonald, 1996; Morine-Dershimer, 1989). Concept maps are useful tool in facilitating connections in teacher knowledge when used following lesson implementation and evaluation, adding coherence to subject matter structures (Morine-Dershimer, 1989). Formation of habits such as the infusion of content organization, structure, and the nature

of the discipline into lesson planning is especially important to establish early in a teacher's career in light of the tremendous preoccupation with classroom management that exists in the first several years of teaching (Hollingsworth, 1989; Veenman, 1984).

Second, content-specific methods classes have the vital role of asking potential teachers to articulate their subject-specific teaching orientations, to examine these orientations in light of other goals for teaching and student learning, and to carefully assess alterative orientations for their strengths and weaknesses. Since subject matter orientation appear to be deeply held in the form of beliefs (Grossman, 1990; Gudmundsdottir, 1990), changes in such beliefs will require conceptual change strategies (Smith & Neale, 1991). Prerequisite to such changes would include a dissatisfaction with the originally held view, recognition of the usefulness of the new view, and successful experience with the new orientation (Smith & Neale, 1991). Accepting a new teaching orientation would need to be accompanied by the teacher belief in the appropriateness of adjusting the curriculum and faith that adjustments will result in increased student learning (Cornett, Yeotis & Terwilliger, 1990), however, it is not clear if successful implementation experiences with students are necessary prior to or following the acceptance of a new orientation (Berman & McLaughlin, 1975; Smith & Neale, 1991).

Finally, while having a well organized conceptual structure, understanding the nature of the discipline, and being able to articulate and defend a content-specific teaching orientation are all important goals and promote teacher development toward the national reforms, teachers of all experience levels need assistance in designing and evaluating teaching techniques that embody these views. Content-specific methods classes can assist teachers by modeling lessons of this nature, describing the goals and assumptions used when selecting and implementing the activities, and offer students supported opportunities to develop and implement similar lessons.

The Induction Period

Teaching practice undergoes the greatest changes in the first 1-3 years, with stabilization of teaching practices occurring in years 3 and 4 (Veenman, 1984). It is during this time that teachers refine their image of themselves as teachers and establish routines and procedures upon which future teaching practices will be based. Therefore, if permanent changes in teacher practice are to occur, they need to be established and reinforced during the induction period of the first three years of practice. Beginning teachers are initially overwhelmed with classroom management concerns and spend a great deal of time learning their content and planning lessons (Borko & Livingston, 1989). By the second year of classroom practice, management concerns dissipate and opportunities for increased attention on subject matter instruction exist (Reynolds, 1992). Decreasing the number of classroom preparations and ensuring that teachers are only assigned to courses within their field of specialization should reduce stress on novice teachers and allow for a quicker transition from survival strategies to careful consideration of instructional practice. Reynolds (1992), in a review of characteristics of competent beginning teachers, noted that novices have difficulty with the following types of subject-specific techniques: creating concrete and appropriate subject matter lessons, monitoring student understanding, constructing appropriate responses to student comments and questions, establishing conceptual connections within lessons and across the curriculum, and tailoring materials to the needs of individuals. With the high degree of content specific knowledge needed in each of these endeavors, mentoring, university programs, or other content-specific support structures are essential and can promote substantial gains for novice teachers. In addition, assistance in reflection on subject matter structure and the nature of the discipline, evaluation of teaching orientations and practices, and reviews of reform documents and their goals , and examination of and comparison to teaching goals and practices could assist the novice teacher in becoming a reflective professional and teaching in a manner consistent with students' learning with understanding.

IMPLICATIONS FOR RESEARCH

While this synthesis of the research on teachers subject matter knowledge and beliefs has implications for teacher preparation and support, with each suggestion bearing the careful analysis afforded by research, a number of additional issues related to research design and interpretation also exist. The three issues that will be discussed include the impact and generalizablity of subject-specific research, the effect and effectiveness of variations in teacher knowledge and beliefs, and the academic domain under which research is conducted.

Does the Subject Matter?

In drawing conclusions about the impacts of teacher subject matter knowledge and beliefs on practice, the disciplinary lines were purposefully blurred based on the consistency of findings across studies. Is this a justifiable practice? One premise of subject-specific research is that there are aspects of teaching within a discipline that are unique. Such an assumption is supported by research on the unique aspects of disciplinary instruction. Donald (1983) looked at the number of key concepts and the degree of centrality or linkage of those concepts in 16 university courses in order to create a representative structure for various disciplines. Science courses were found to have the greatest number of central terms and the highest level of term interconnection, resulting in a structure that potentially supported an "all-or-none" pattern of learning. In contrast, the humanities had the fewest central ideas and the fewest connections, resulting in a linear or loose-block formation. The social sciences were similar to the humanities, though they held more central ideas and course structure was represented with a web or cluster.

Siskin (1994), in a sociological analysis of high schools, identified disciplinary boundaries and their resulting school subjects as the primary influence on teacher's academic identity, world views, teaching roles, nature of knowledge, and views on teaching and learning. The emphasis on school subjects rather than disciplines allowed for groups of greater inclusion than may be found in a university setting; for instance, the cohesion of history, economics, psychology, geography, anthropology, sociology, and political science majors under the department of social science. Stodolsky and Grossman (1995) extended this work by exploring teachers' characterization of their subject matters along five dimensions that impact practice: degree of definition, scope or number of distinct fields included in the school subjects, degree of sequence, characterization of the subject as static or dynamic, and the required or elective status of the subject. Mathematics and foreign language teachers were described as possessing the highest level of agreement on what and how to teach, with an emphasis on high content coverage and a hierarchical and sequential organization of content across course offerings. Science was characterized as being multi-disciplinary with distinct courses joined by a common methodology. The degree of course distinction resulted in increased personal choice in curricular materials and low levels of intra-departmental sequencing, coordination or emphasis on content coverage. The social sciences were similar to the sciences in that they represented distinct courses with low levels of sequencing, coordination, and content coverage. However, social studies teachers experienced the lowest level of agreement regarding the content of the curriculum. English, with mid-levels of emphasis on content coverage, was loosely defined and enjoyed tremendous teacher autonomy in selection of content and teaching materials.

In a different type of analysis, Raudenbush, Rowan and Cheong (1993) looked at teachers' disciplinary perceptions in order to identify the basis for varying emphases in teaching for higher order thinking. Mathematics and science teachers were powerfully impacted by the effects of student tracking or level of the course content with greater emphasis on higher order thinking increasing with the grade level or track level of the student. Emphasis on higher order objectives, however, did not preclude the simultaneous pursuit of lower level objectives. Teacher preparation (i.e., literary versus writing emphasis and level of preparation) and school contexts impacted teacher use of higher order objectives in English and the social sciences, but were not evident in math or science.

Obviously, disciplinary roots impact teacher's perceptions of autonomy in content and curricular selection, emphasis on higher order objectives, and professional identification. Greater care is needed in future research to unravel the varying impacts of these influences on teacher's subject matter knowledge and beliefs and caution is essential when combining results across subject matter contexts.

Examination of Subject Matter Structures and Orientations

Teachers possess subject matter structures and orientations that, at least for the experienced teacher, subtly impact practice. This impact is particularly prevalent for content-specific orientations. To date, no studies have explored the differential effectiveness of various subject matter structures or orientations on student learning. Perhaps this avoidance is appropriate, preventing the preceptional panacea of indoctrinating all teachers into a single subject matter structure or orientation as a simple solution to improving student learning. Since these structures and orientations, however, are individually held and idiosyncratically developed, there is probably little chance that any strategy less labor-intensive than conceptual change approaches will ultimately result in uniform structural changes in teacher beliefs. Therefore, recognizing aspects of these subject-specific structures and orientations that result in stronger teaching practices or greater student learning appears to be a worthwhile and achievable goal. The national reform documents provide a platform upon which teacher's practices and their concomitant knowledge and beliefs can be examined in terms of student learning.

Boundaries among cognitive psychology, philosophy and practice

As the research on teacher cognition is explored, it is obvious that a tripartite system of theoretical underpinnings emerge. One approach to studying teacher cognition has been found in cognitive psychology. This research looks at models for the structure and functioning of the mind. From this field we have developed constructs such as schemata, mental models and images, and the intersection of these knowledge constructs with those for beliefs. It is through the lens of cognitive psychology that we can examine the private understandings of individuals and the construction of knowledge, evaluate tools that assist in learning, and assess strategies that tap into these understandings.

The second field of import is the philosophy of the disciplines. An examination of the discipline provides insight into the nature of its epistemological roots, the manner in which knowledge is gained and accepted, the content structures that allow for the placement of some ideas as more central than others, and the type and value of conceptual relationships. Philosophy provides us with the public knowledge that makes up the content taught and provides insight into the most appropriate mechanisms to convey that knowledge.

Finally, the world of practice represents the collision of the foundations of cognitive psychology and philosophy. In this arena, a teacher's private understandings of public disciplinary knowledge is sorted, transformed, sequenced and expressed as teaching practice. The public knowledge portrayed to students is filtered through the lens of teacher knowledge and belief. Along with the cognitive understandings of the teacher, a myriad of contextual constraints are introduced to the equation: school mandates and expectations, student support or resistance to classroom practices, the match or mismatch of students' private understandings with those of the teacher and/or the discipline, and teacher adjustments to their own cognitive structure while providing a public display of their private understandings.

What should be the basis of teacher knowledge and the research that explores it? While it seems that each of the research traditions described offers a unique lens in which to explore teaching, the intersection and synergistic combination of these efforts may provide the research community with the best mechanism to explore the complex issues surrounding teacher knowledge and beliefs.

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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 components: (a) orientations toward science teaching, (b) knowledge and beliefs about science curriculum, (c) knowledge and beliefs about students' understanding of specific science topics, (d) knowledge and beliefs about assessment in science, and (e) knowledge and beliefs about instructional strategies for teaching science. 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

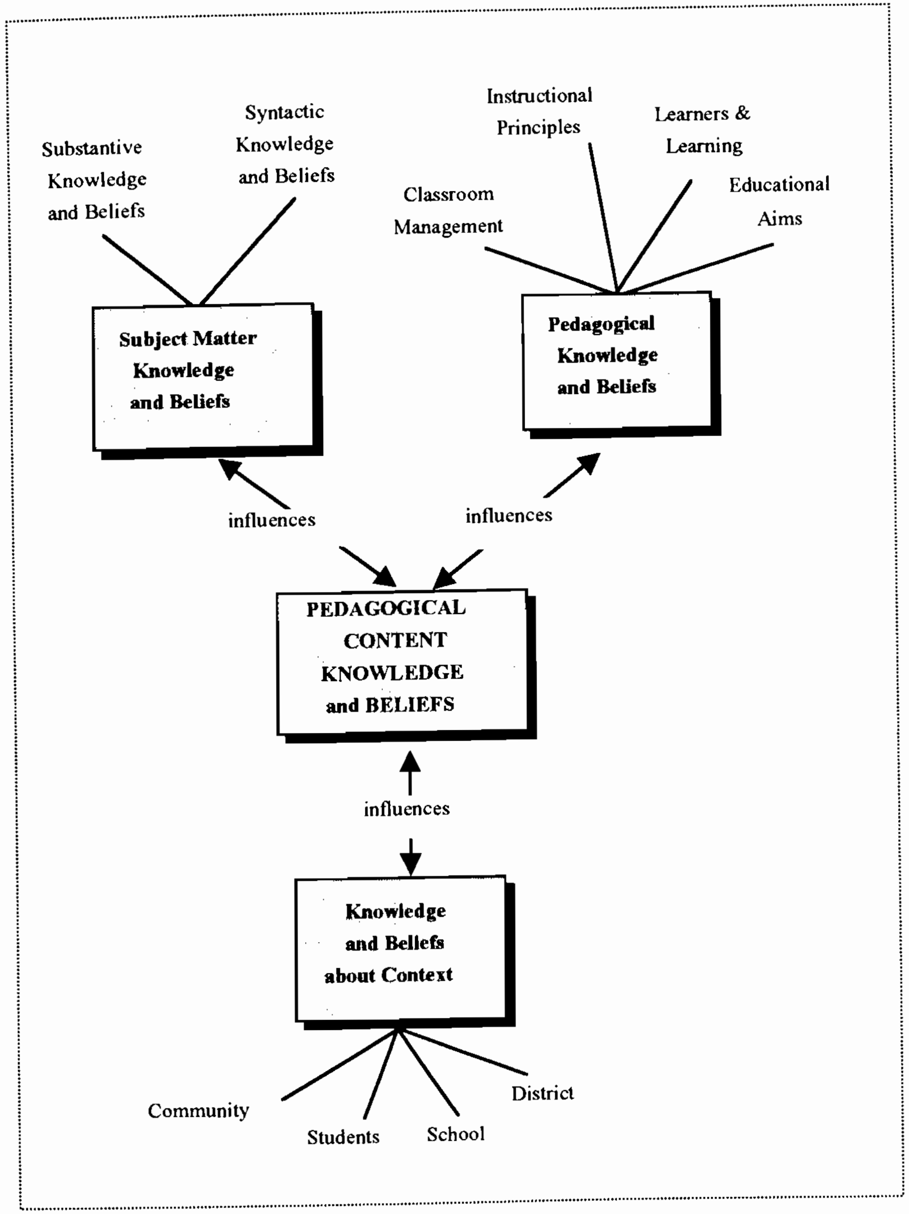

Figure 1. A model of the relationships among the domains of teacher knowledge. [Modified from Grossman (1990)]

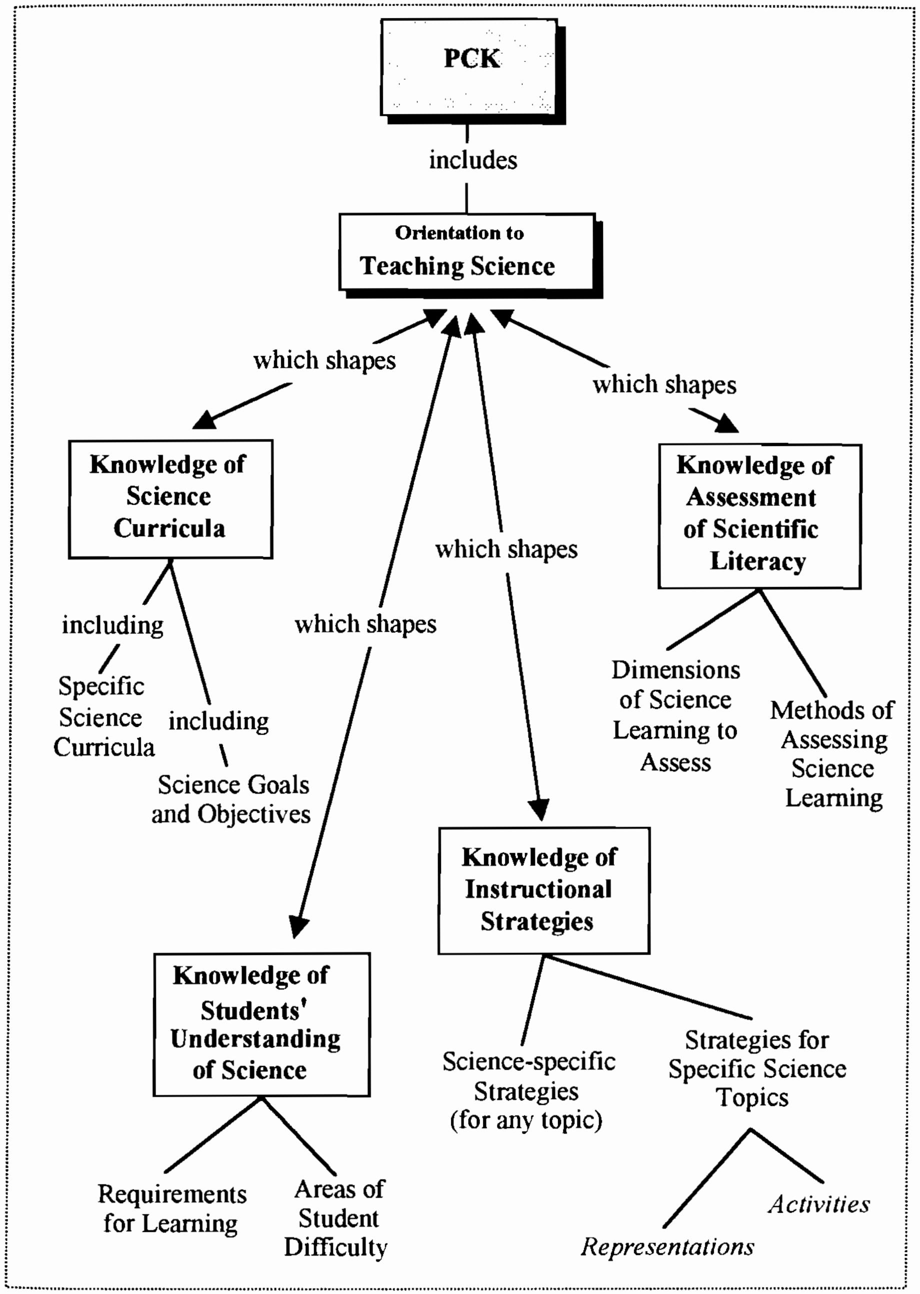

Figure 2. Components of pedagogical content knowledge for science teaching.

TABLE I
The Goals of Different Orientations to Teaching Science

ORIENTATION	GOAL OF TEACHING SCIENCE
Process	Help students develop the "science process skills." (e.g., SAPA)
Academic Rigor (Lantz & Kass, 1987)	Represent a particular body of knowledge (e.g., chemistry).
Didactic	Transmit the facts of science.
Conceptual Change (Roth, Anderson, & Smith, 1987)	Facilitate the development of scientific knowledge by confronting students with contexts to explain that challenge their naïve conceptions.
Activity-driven (Anderson, & Smith, 1987)	Have students be active with materials; "hands-on" experiences.
Discovery (Karplus, 1963)	Provide opportunities for students on their own to discover targeted science concepts.
Project-based Science (Ruopp et. al 1993; Marx et al., 1994)	Involve students in investigating solutions to authentic problems.
Inquiry (Tamir, 1983)	Represent science as inquiry.
Guided Inquiry (Magnusson & Palincsar, 1995)	Constitute a community of learners whose members share responsibility for understanding the physical world, particularly with respect to using the tools of science.

TABLE II
The Nature of Instruction Associated with Different Orientations to Teaching Science

ORIENTATION	CHARACTERISTICS OF INSTRUCTION
Process	Teacher introduces students to the thinking processes employed by scientists to acquire new knowledge. Students engage in activities to develop thinking process and integrated thinking skills.
Academic Rigor	Students are challenged with difficult problems and activities. Laboratory work and demonstrations are used to verify science concepts by demonstrating the relationship between particular concepts and phenomena.
Didactic	The teacher presents information, generally through lecture or discussion, and questions directed to students are to hold them accountable for knowing the facts produced by science.
Conceptual Change	Students are pressed for their views about the world and consider the adequacy of alternative explanations. The teacher facilitates discussion and debate necessary to establish valid knowledge claims.
Activity-driven	Students participate in "hands-on" activities used for verification or discovery. The chosen activities may not be conceptually coherent if teachers do not understand the purpose of particular activities and as a consequence omit or inappropriately modify critical aspects of them.
Discovery	*Student-centered.* Students explore the natural world following their own interests and discover patterns of how the world works during their explorations.
Project-based Science	*Project-centered.* Teacher and student activity centers around a "driving" question that organizes concepts and principles and drives activities within a topic of study. Through investigation, students develop a series of artifacts (products) that reflect their emerging understandings.
Inquiry	*Investigation-centered.* The teacher supports students in defining and investigating problems, drawing conclusions, and assessing the validity of knowledge from their conclusions.
Guided Inquiry	*Learning community-centered.* The teacher and students participate in defining and investigating problems, determining patterns, inventing and testing explanations, and evaluating the utility and validity of their data and the adequacy of their conclusions. The teacher scaffolds students' efforts to use the material and intellectual tools of science, toward their independent use of them.

happen with the materials. He would expect his students to discover that there are different types of circuits and he would supply the appropriate name for the different types as students discovered them. The purpose of the instructional activity would be for students to discover what they can about electrical phenomena through pursuing their own questions. In contrast, the teacher with a "conceptual change" orientation might begin by having her students talk about their ideas about electricity to have them become aware of their own ideas and differences between their ideas and others, and to give her some sense of some of the misconceptions they have about electricity. She might have them proceed by working with a particular circuit that she shows them how to make, expecting that it would challenge their misconceptions, and she would press the students to generate explanations to account for their observations of the circuit. She would expect the students to compare the explanations of one another to identify differences among them, and she might provide the view of scientists for them compare as well with their own explanations. The hope is that students would be persuaded by the greater explanatory power of the scientific view to adopt that view following opportunities to test out and apply their understanding of it.

Finally, in contrast yet again, the teacher with a "guided inquiry" orientation might begin by engaging her class in the task to establish a question or problem related to exploring electricity. For example, if she proposed that her students undertake the task of "lighting" scale models of buildings that they design and build, they would discuss what they would need to know and be able to do to accomplish that task, such as generating light and being able to control it (e.g., turning on and off, one light working independently of another).[6] That conversation would lead to determining and conducting investigations to understand electrical behavior in circuits, and determining patterns that distinguish different types of circuits. The teacher would have the students report their ideas about the behavior of electricity to the class during each cycle of exploration so that, as a learning community, they could determine the best ideas to go forward with to proceed to the next cycle of investigation. This reporting might lead to cycles of investigation in which students seek information about how scientists think about electricity. At some point she would engage her students in inventing explanations or models to account for the relationship they have identified,[7] and the views of scientists might be sought at this point again as an additional resource of information with which to build their understanding of electricity.

These scenarios illustrate the hypothesized central role of this component of PCK in decision-making relative to planning, enacting, and reflecting upon teaching. Few studies have been conducted, however, that directly assess teachers' orientations to teaching science in order to put that claim to an empirical test. Research that has been conducted includes the work of Hewson and Hewson (1989) who developed a specific approach for identifying teachers' conceptions of teaching science. These researchers were reluctant, however, to use their scheme to categorize a group of teachers they studied because they claimed it would "[wash] out the interesting nuances between [them]" (p. 207). In other research that has discussed teachers' orientations, researchers have labeled teachers as having particular

orientations, but attempts have not been made to more specifically determine the teachers' knowledge relative to those designations. Nevertheless, one interesting finding from this research is that teachers can hold multiple orientations, including ones such as didactic and discovery that have incompatible goals for teaching science (Smith & Neale, 1989).

Knowledge of Science Curriculum

This component of pedagogical content knowledge consists of two categories: mandated goals and objectives, and specific curricular programs and materials. Shulman and colleagues originally considered curricular knowledge to be a separate domain of the knowledge base for teaching (Wilson, Shulman, & Richert, 1988). Following the lead of Grossman (1990), we have included it as part of pedagogical content knowledge because it represents knowledge that distinguishes the content specialist from the pedagogue – a hallmark of pedagogical content knowledge.

Knowledge of Goals and Objectives

This category of the curricular knowledge component of pedagogical content knowledge includes teachers' knowledge of the goals and objectives for students in the subject(s) they are teaching, as well as the articulation of those guidelines across topics addressed during the school year. It also includes the knowledge teachers have about the vertical curriculum in their subject(s); that is, what students have learned in previous years and what they are expected to learn in later years. (Grossman, 1990)

Examples of sources for knowledge of goals and objectives include national- or state-level documents that outline frameworks for guiding decision-making with respect to science curriculum and instruction (e.g., AAAS, 1989; California State Board of Education, 1990; Michigan State Board of Education, 1991). Schools and districts may also have documents that indicate, for specific courses or programs, what concepts are to be addressed to meet mandated goals. Effective science teachers are knowledgeable about these documents.

Knowledge of Specific Curricular Programs

This category of teachers' knowledge of science curriculum consists of knowledge of the programs and materials that are relevant to teaching a particular domain of science and specific topics within that domain. Substantial curriculum development in science education has occurred for each level of schooling over the past 30 years. As a result, there are typically several programs at each grade level and for each subject area, about which teachers should be knowledgeable. For example, a chemistry teacher might be expected to be knowledgeable about curricula for teaching chemistry, including programs such as CHEM Study and CBA (Chemical Bond Approach) which were developed in the 1960s, IAC (Interdisciplinary

Approaches to Chemistry) which was developed in the 1970s, and CHEMCOM (Chemistry in the Community) which was developed in the 1980s. Similarly, an elementary school teacher might be expected to be knowledgeable about ESS (Elementary Science Study) and SCIIS (Science Curriculum Improvement Study) which were developed in the 1960s, and GEMS (Great Explorations in Math and Science) and Insights which were developed in the 1980s. Teachers' knowledge of curricula such as these would include knowledge of the general learning goals of the curriculum as well as the activities and materials to be used in meeting those goals.

Several studies that provide a picture of the general state of science education (e.g., Helgeson, Blosser & Howe, 1977; Stake & Easley, 1978; Weiss, 1978, 1987) have reported that the vast majority of teachers surveyed were not knowledgeable about nationally-funded curriculum projects relevant to their teaching. There is also evidence that teachers who are knowledgeable about programs may not agree with their learning goals and as a result may substantially modify them or reject important parts of materials (Cronin-Jones, 1991; Mitchener & Anderson, 1989; Welch, 1981). This finding provides some evidence of the issue of coherence with respect to the components of PCK, in this case the lack of coherence of teachers' orientations toward science teaching and the focus of the curricular materials.

Knowledge of Students' Understanding of Science

This component of pedagogical content knowledge refers to the knowledge teachers must have about students in order to help them develop specific scientific knowledge. It includes two categories of knowledge: requirements for learning specific science concepts, and areas of science that students find difficult.

Knowledge of Requirements For Learning

This category consists of teachers' knowledge and beliefs about prerequisite knowledge for learning specific scientific knowledge, as well as their understanding of variations in students' approaches to learning as they relate to the development of knowledge within specific topic areas. Teacher knowledge of prerequisite knowledge required for students to learn specific concepts includes knowledge of the abilities and skills that students might need. For example, if a teacher's goal is to help students learn about temperature by investigating phenomena undergoing thermodynamic changes, she must know how to help students develop the understandings and skills necessary to collect and interpret temperature data, such as reading a thermometer. Teachers' knowledge of variations in approaches to learning includes knowing how students of differing developmental or ability levels or different learning styles may vary in their approaches to learning as they relate to developing specific understandings. One illustration of this aspect of teacher pedagogical content knowledge concerns helping students to understand molecular-level phenomena in chemistry. A variety of representations can be used to illustrate molecular structure; however, a particular representation may be more readily understood by some students than others. Some students may be able to envision a three-dimensional structure from a chemical formula whereas others require a drawing or model of the molecule. Effective teachers are aware of students' differing needs and can respond appropriately.

Knowledge of Areas of Student Difficulty

This category refers to teachers' knowledge of the science concepts or topics that students find difficult to learn. There are several reasons why students find learning difficult in science, and teachers should be knowledgeable about each type of difficulty.

For some science topics, learning is difficult because the concepts are very abstract and/or they lack any connection to the students' common experiences (e.g., the mole, protein synthesis, quantum mechanics, cellular respiration). Teachers need to know which topics fall into this category and what aspects of these topics students find most inaccessible.

Other topics are difficult because instruction centers on problem solving and students do not know how to think effectively about problems and plan strategies to find solutions. In these cases, it is important for teachers to be knowledgeable about the kinds of errors that students commonly make, and the types of "real-world experiential knowledge" that they need to comprehend novel problems (Stevens & Collins, 1980). There has been a substantial amount of research examining problem solving within specific science topics (see Part III in Gabel, 1994); hence, there is substantial information to help teachers develop pedagogical content knowledge about students' difficulties with problem solving. With respect to the topic of motion, for example, an effective science teacher would know that students often have difficulty solving kinematics problems because they attend to surface features of the problems. Research has found, for example, that if a problem involves an inclined plane, it is common for students to think that certain equations are used to solve inclined plane problems and they search for the equations they previously used to solve problems involving inclined planes. They do not think to begin solving the problem by considering what underlying principles (e.g., conservation laws) might be applicable to a particular situation and should be used to set up the problem (Champagne, Klopfer, & Gunstone, 1982).

A third type of difficulty students encounter when learning science involves topic areas in which their prior knowledge is *contrary* to the targeted scientific concepts. Knowledge of this type is typically referred to as misconceptions,[8] and misconceptions are a common feature of science learning (e.g., Driver & Easley, 1978; Confrey, 1990; Wandersee, Mintzes, & Novak, 1994). Scientific concepts for which students have misconceptions can be difficult to learn because misconceptions are typically favored over scientific knowledge because they are sensible and coherent and have utility for the student in everyday life. In contrast, the targeted scientific concepts may seem incoherent and useless to the learner. Wandersee, Mintzes, & Novak (1994) caution that attributing students' lack of development of scientific knowledge to interference from misconceptions is misleading in that there is evidence that misconceptions are not equally resistant to change. As a result they suggest that "it is important to differentiate between the concepts that might require high-powered conceptual change strategies and those that are equally likely to yield to well-planned conventional methods," (p. 186). Furthermore, others argue that the view of misconceptions as interfering agents that must be removed and replaced ignores the constructivist basis of learning (e.g., Magnusson, Boyle, & Templin, 1994; Magnusson, Templin, & Boyle, 1997; Smith, DiSessa, & Roschelle, 1993). These researchers argue that misconceptions are the product of reasonable, personal sense-making, and that they can continue to evolve and change and result in desired scientific knowledge.

Regardless of one's view of the role of misconceptions in learning, this is student knowledge about which teachers should be knowledgeable with respect to the topics they teach because it will help them interpret students' actions and ideas. Numerous studies have documented students' misconceptions at various levels of schooling and in various scientific domains. The majority of studies have focused on physical science concepts, particularly in the area of physics; nevertheless, there is substantial information about students' misconceptions for many topics (Driver, Guesne, & Tiberghien, 1985; Driver, Squires, Rushworth, & Wood-Robinson, 1994; Pfundt and Duit, 1991). An example of desired pedagogical content knowledge with respect to students' understanding about motion is that students think that objects stay in motion because a force continually acts upon them and cease to move when no force is acting, and that this interpretation is a reasonable deduction from students' experiences in the friction-filled world in which we live. Other topics areas in which students have difficulty, and common misconceptions that lead to students' difficulties include the following: (a) light - *color is an intrinsic property of a substance* (Guesne, 1985), (b) lunar phases - *the phases of the moon are due to the shadow of the earth on the moon* (Keuthe, 1963), (c) nature of matter - *spaces between atoms or molecules of gas are filled with air* (Nussbaum, 1985), (d) plant nutrition - *plants get their food from the soil* (Bell, 1985), and (e) human systems - *a separate system from the circulatory system carries air to the heart and other structures in the body* (Arnaudin & Mintzes, 1985).

Research about science teachers' pedagogical content knowledge of students' understandings has not been widespread, but the studies that exist report similar findings and provide some indication of the knowledge that teachers typically have. One study, a survey of secondary school teachers, listed the 15 topics that biology, chemistry, physics, and earth science teachers rated as most as difficult for their students (Finley, Stewart, & Yarroch, 1982). The study did not provide information about why some topics were rated as more difficult than others, so it is not known whether the ratings indicated teachers' knowledge and concerns about students' misconceptions, their difficulties with problem solving, or other issues.

Other studies have directly assessed teachers' knowledge of students' understanding. The pattern of findings from this type of study is that although teachers have some knowledge about students' difficulties, they commonly lack important knowledge necessary to help students overcome those difficulties. For example, an investigation of physics teachers' knowledge of students' understandings about force and gravity found that, as a group, the teachers identified nearly all of the common misconceptions that had been identified by the researchers; however, individually, they tended to be aware of only a few common misconceptions and were not aware of all of the misconceptions held by their own students. Moreover, one-third of the teachers (7 of 20) held common misconceptions themselves (Berg & Brouwer, 1991)! A study of elementary school teachers who participated in a project introducing them to conceptual change strategies for teaching about light similarly reported that students' misconceptions about which the teachers were not knowledgeable were ones that they themselves held (Smith & Neale, 1989).[9]

Research examining experienced middle school teachers' knowledge of students' understanding about temperature and heat energy also reported that teachers lacked crucial knowledge to promote student learning. This research was conducted as part of the University of Maryland's Middle School Probeware Project (UMMPP), a teacher enhancement project designed to help teachers use microcomputer-based laboratories for teaching about heat energy and temperature. At the beginning of the project, 92% (n=13) of the teachers who participated in the research exhibited misconceptions about heat energy and temperature (Krajcik & Layman, 1989). Of those who remained in the project for two years (n=8), half of them still exhibited some misconceptions. In addition, after two years in the project, teachers were not equally aware of the prevalence of errors in student reasoning about heat energy phenomena, and the explanations that they provided to account for students' reasoning errors differed (Magnusson, Borko, & Krajcik, 1994). This finding was considered important by the researchers because differences in the teachers' explanations implied differences in the instructional responses they would use to help students reason more accurately about heat energy phenomena. Furthermore, assessment of the *students'* knowledge indicated that only the teachers who thought that particular errors were <u>un</u>common <u>had</u> students who exhibited those reasoning errors <u>after</u> instruction in the topic area (Magnusson, Borko, Krajcik, & Layman, 1994; Magnusson, 1991). The researchers reasoned that this result may have been a consequence of the teachers' lack of pedagogical content knowledge because they were not aware of the likelihood of students' errors or the need to address them.

The UMMPP research, and that conducted by Smith and Neale (1989, 1991), both indicate that with appropriate in-service experiences, teachers can become more knowledgeable about common misconceptions. However, Smith and Neale reported that increased knowledge of students' understandings did not ensure that teachers could respond in appropriate ways when students exhibited misconceptions. They described that even though increased knowledge led the project teachers to pay more attention to their students' thinking than in their previous teaching, and even though some teachers exhibited some successful instances of recognizing and addressing students' misconceptions, in the majority of cases the teachers ignored students' misconceptions or struggled for ways to respond to them. Some undesirable responses by the teachers were to correct the misconception and supply a more detailed explanation rather than probing for the student's reasoning. From this pattern of findings, Smith and Neale concluded that acquiring pedagogical content knowledge does not guarantee the ability to respond effectively during instruction. Their findings may also illustrate the independence of the components of pedagogical content knowledge in that changes in teachers' knowledge of one component may not be accompanied by changes in other components that are also required for effective teaching.

Knowledge of Assessment in Science

We conceptualize this component of pedagogical content knowledge, which was originally proposed by Tamir (1988), as consisting of two categories: knowledge of the dimensions of science learning that are important to assess, and knowledge of the methods by which that learning can be assessed.

Knowledge of Dimensions of Science Learning to Assess

This category refers to teachers' knowledge of the aspects of students' learning that are important to assess within a particular unit of study. In keeping with a major goal of school science, which is to produce a scientifically literate citizenry (Hurd, 1989), the dimensions upon which teacher knowledge in this category is based are those of scientific literacy. One example of a recent view of the possible dimensions of scientific literacy is the framework for the science component of the 1990 National Assessment of Educational Progress (NAEP). It identifies conceptual understanding, interdisciplinary themes, nature of science, scientific investigation, and practical reasoning as important dimensions of science learning to assess (Champagne, 1989). At this time of continuing national-level development of perspectives regarding science teaching and learning – such as exemplified by the national science education standards (National Research Council, 1994) – we do not describe a particular framework of scientific literacy to define teacher knowledge relative to this category. Rather, we simply argue is that it is important for teachers to be knowledgeable about some conceptualization of scientific literacy to inform their decision-making relative to classroom assessment of science learning for specific topics.

Whatever the dimensions of scientific literacy, it is likely that some dimensions will be more easily addressed than others for a particular topic of study and, hence, might be considered important to consider in planning and enacting teaching on that topic. Thus, effective teachers should know what dimensions or aspect of a dimension of scientific literacy should be assessed in a particular unit. As an example, it is more difficult to empirically investigate the solar system than weather. As a result, an effective teacher would plan to assess students' understandings regarding the planning and conduct of empirical investigations during the study of weather by having them actually carry out such investigations, and she would plan to utilize a different method of assessment during the study of the solar system. This illustration brings us to the other category of teacher knowledge of assessment: knowledge of methods of assessment.

Knowledge of Methods of Assessment

This category of pedagogical content knowledge refers to teachers' knowledge of the ways that might be employed to assess the specific aspects of student learning that are important to a particular unit of study. There are a number of methods of assessment, some of which are more appropriate for assessing some aspects of student learning than others. For example, students' conceptual understanding may be adequately assessed by written tests whereas their understanding of scientific investigation may require assessment through a laboratory practical examination (e.g., Lunetta, Hofstein, & Giddings, 1981; Tamir, 1974) or laboratory notebook.

Considerable attention is being given to assessment within the science education community at this time, including attention to changing assessment practices and the development of new methods such as performance-based assessments and portfolios (e.g., Duschl & Gitomer, 1991; Kulm & Malcom, 1991). These methods highlight that *student-generated products* provide important opportunities for assessment, whether evaluated at the end of a unit of study or during the course of study. Examples of student-generated products that have been used to assess student learning include journal entries, written laboratory reports, and artifacts such as drawings, working models, or multi-media documents (see appendix in Kulm & Malcom, 1991).

Teachers' knowledge of methods of assessment includes knowledge of specific instruments or procedures, approaches or activities that can be used during a particular unit of study to assess important dimensions of science learning, as well as the advantages and disadvantages associated with employing a particular assessment device or technique. Research examining science teachers' use of assessment indicates that teachers at all levels of schooling largely depend upon teacher-constructed or curriculum-embedded objective tests that evaluate the conceptual understanding dimension of scientific literacy (Doran, Lawrenz, Helgeson, 1994). These findings do not indicate whether that practice results from a lack of knowledge of other methods, a lack of knowledge of the need to evaluate other dimensions of scientific literacy, or other issues. As efforts to define scientific literacy at all grade levels continue, and as new instruments and procedures continue to be developed and become more prominent in this "decade of reform in student assessment" in science education (Tamir, 1993, p. 535), pedagogical content knowledge in this area is likely to change substantially over the next 10 years.

Knowledge of Instructional Strategies

Teachers' knowledge of the instructional strategies component of pedagogical content knowledge is comprised of two categories: knowledge of *subject*-specific strategies, and knowledge of *topic*-specific strategies. Strategies in these categories differ with respect to their scope. Subject-specific strategies are broadly applicable; they are specific to teaching *science* as opposed to other subjects. Topic-specific strategies are much narrower in scope; they apply to teaching particular *topics* within a domain of science.

Knowledge of Subject-specific Strategies

Strategies included in this category represent general approaches to or overall schemes for enacting science instruction. Teachers' knowledge of subject-specific strategies is related to the "orientations to teaching science" component of pedagogical content knowledge in that there are general approaches to science instruction that are consistent with the goals of particular orientations.

A number of subject-specific strategies have been developed in science education, many of them consisting of a three- or four-phase instructional sequence. Perhaps the best known of the subject-specific strategies is the "learning cycle," a three-phase instructional strategy consisting of *exploration*, *term introduction*, and *concept application* (Karplus & Thier, 1967; Lawson, Abraham, & Renner, 1989). The learning cycle has been used for discovery and inquiry-oriented instruction, as well as conceptual change-oriented instruction (see Tobin, Tippins, & Gallard, 1994, pp. 76-79). Strategies that have been developed more recently (e.g., the Generative Learning Model, conceptual change strategies, Guided Inquiry) have typically added phases designed to support conceptual change, such as eliciting students' pre-instructional conceptions (e.g., Osborne & Freyberg, 1985), presenting anomalous data to create cognitive conflict (e.g., Nussbaum & Novick, 1982), distinguishing between real world patterns that can be "discovered" and explanations for them that must be invented (e.g., Magnusson & Palincsar, 1995), emphasizing public presentation and discussion of patterns and explanations (ibid), or scaffolding student debate about the adequacy of alternative explanations (e.g., Anderson & Smith, 1987). Teachers' knowledge of subject-specific strategies for science teaching consists of the ability to describe and demonstrate a strategy and its phases.

We surmise, based on the fact that there is a substantial body of research literature describing efforts to help teachers become knowledgeable about such strategies (see reviews by Anderson & Mitchener, 1994; Tobin, Tippins, & Gallard, 1994), that teacher knowledge of strategies for teaching science is limited. Supporting that assertion is evidence from studies examining the impact of the inquiry-based science curriculum development in the 1960s and 1970s, which reported that teachers perceived themselves as ill-prepared to teach inquiry-oriented instruction (e.g., Helgeson, Blosser, & Howe, 1977; Stake & Easley, 1978; Weiss, 1978).

Research focused on teachers who participated in programs to help them adopt new strategies for teaching science provides evidence that a teacher's ability to use a subject-specific strategy may be dependent upon knowledge from other domains. Anderson and Smith (1987) described instances of teachers changing from "didactic or discovery teaching to the use of conceptual change teaching strategies" without any explicit instruction in the new strategies that they were observed using (p. 104). The teachers attributed their change to increased knowledge of subject matter and the understandings of their students (one component of pedagogical content knowledge). In a similar vein, a lack of subject matter knowledge (e.g., Smith & Neale, 1989) and a lack of pedagogical knowledge (Marek, Eubanks, & Gallaher, 1990) have both been linked to the ineffective use of subject-specific strategies, suggesting that the development of pedagogical content knowledge relative to this component requires drawing upon knowledge from each of the three base domains of teacher knowledge: subject matter, pedagogy, and context.

There is also evidence that teachers' use of strategies is influenced by their beliefs. Research has documented that some teachers resisted changing their practices to match those of an innovative approach because their beliefs differed from the premises of the new approach (Cronin-Jones, 1991; Mitchener & Anderson, 1989; Olson, 1981). Interestingly, a common area of difference in each of these studies concerned beliefs about the teacher's role, which is a dimension of teaching that several components of pedagogical content knowledge would impact. We think these findings indicate that the transformation of general knowledge into pedagogical content knowledge is not a straightforward matter of having knowledge; it is also an intentional act in which teachers choose to reconstruct their understanding to fit a situation. Thus, the content of a teacher's pedagogical content knowledge may reflect a selection of knowledge from the base domains.

Knowledge of Topic-specific Strategies

This category of pedagogical content knowledge refers to teachers' knowledge of specific strategies that are useful for helping students comprehend specific science concepts. There are two categories of this type of knowledge – representations and activities. Although they are not mutually exclusive (e.g., specific activities may involve particular representations of a concept or relationship) it is conceptually useful to consider them as distinct categories.

Topic-specific representations. This category refers to teachers' knowledge of ways to represent specific concepts or principles in order to facilitate student learning, as well as knowledge of the relative strengths and weaknesses of particular representations. We also include in this category a teacher's ability to invent representations to aid students in developing understanding of specific concepts or relationships.

Representations can be illustrations, examples, models, or analogies. Using an example from electricity, there are multiple analogies for representing the concept of an electric circuit: water flowing through pipes in a closed system with a pump, a bicycle chain or a train, or "teeming crowds" (Hewitt, 1993). Each analogy has conceptual advantages and disadvantages with respect to the others. For example, the popular water flow model reinforces a source-receiver model of electricity and implies that electrons move rapidly in the same direction; a bicycle chain model similarly implies that electrons move in the same direction but does not suggest a source-receiver model; and teeming crowds make it possible to conceive of electron flow in an electric circuit as occurring slowly and randomly, albeit drifting in a common direction. The water flow and teeming crowds models offer one representation of resistance (narrowing in the pipe through which the water is flowing or in an opening through which the crowd has to pass), whereas a bicycle chain model is limited in representing resistance.

An effective teacher must judge whether and when a representation will be useful to support and extend the comprehension of students in a particular teaching situation. An example of the pedagogical content knowledge of one teacher in this respect is presented by Berg and Brouwer (1991). They discuss the teaching of a physics teacher who stated that his most powerful strategy for helping students believe that the path of an object in circular motion (e.g., a ball on a string being whirled about one's head) will become a straight line if the force exerted perpendicular to the motion of the ball is removed (the string is cut), is an anecdote about his personal experience on a merry-go-round. The teacher's anecdote relates how he was riding on the edge of the merry-go-round and when he let go, to his surprise he landed in a bush that he had seen straight in front of him when he let go. In the teacher's words, "it's only anecdotal, but it seems to convince students better than a demo or doing the mathematical derivation." (p. 15)

In the research of which we are aware, teachers generally have not been asked directly about the representations they use in science teaching; rather, information about teachers' knowledge has been inferred from their practice. For example, from examination of teachers' use of analogies, Dagher & Cossman (1992) described 10 types of analogies used by teachers for the purpose of explaining science concepts, and they reported substantial variations in the number and variety of explanations given by the teachers they studied (n=20). They did not discuss the strengths or limitations of any particular explanations used by the teachers they studied, but they did report that 25% of the statements identified as explanations were scientifically inaccurate, and that 25% of the teachers in their sample utilized such explanations.

Some researchers have reported that limited knowledge of topic-specific representations can negatively impact science instruction. Sanders and colleagues intensively studied three secondary science teachers and reported that teachers had difficulty sustaining momentum in a lesson, sometimes confusing themselves and their students when they struggled to respond to student questions requiring more detailed or different representations (Sanders, Borko, & Lockard, 1993). These findings led to the conclusion that this type of pedagogical content knowledge may be particularly dependent on subject matter knowledge because the participating teachers were more likely to exhibit these problems when teaching outside of their area of expertise. This conclusion is not unexpected given the nature of this category: knowing or inventing representations of science concepts to help students comprehend them seems necessarily dependent upon having subject matter knowledge relative to the concepts.

Despite this claim of the dependence of the development of this aspect of pedagogical content knowledge on subject matter knowledge, we caution against an inference that teachers will necessarily develop desired pedagogical content knowledge if they have sufficient subject matter knowledge. In other words, having

subject matter knowledge does not guarantee that it will become transformed into representations that will help students comprehend targeted concepts or that teachers will be adept at deciding when it is pedagogically best to use particular representations. For example, Linn and colleagues describe a heat flow model that they advocate for use to help middle school students understanding thermodynamic phenomena. This model is similar to the caloric theory popular in the mid-1800s, but it includes the provision that heat energy does not have mass. From a scientific perspective, this model is inaccurate because it implies that heat energy is contained in a body; however, they argue that it is more appropriate to use than other models (such as kinetic molecular theory) because it supports accurate qualitative reasoning (Linn & Songer, 1991). In teacher knowledge terms, this model is important pedagogical content knowledge for teaching thermodynamics, but because it is scientifically inaccurate, those with subject matter expertise in this topic area would not likely have this knowledge or know of its pedagogical utility.

In contrast to Linn and Songer, Arons (1991) stresses that (for college students) heat energy should never be referred to as though it is contained in a body, "even in the early stages of development of the concept" because it "raises severe impediments to clear formation of the concept of conservation of energy, even at an elementary level" (p. 120-121). Arons' contradictory recommendation, compared to Linn and colleagues, illustrates the situation-specific nature of pedagogical content knowledge: Arons' recommendation concerns the teaching of college students rather than middle school students.

Topic-specific activities. This category refers to knowledge of the *activities* that can be used to help students comprehend specific concepts or relationships; for example, problems, demonstrations, simulations, investigations, or experiments. Pedagogical content knowledge of this type also includes teachers' knowledge of the conceptual power of a particular activity; that is, the extent to which an activity presents, signals, or clarifies important information about a specific concept or relationship. Consider, for example, the question of how to decide what activities to use with middle school students to help them understand the distinction between temperature and heat energy. Important tools that students can use to investigate thermodynamic phenomena include two microcomputer-based devices: a temperature probe and a heat pulser.[10] A heat pulser makes it possible to "control" the amount of heat energy transferred into a system, allowing students to transfer measurable quantities of heat energy in the form of "pulses" that they can count. A temperature probe can record temperature data which can be graphically presented on a computer monitor as it is collected. Used together, students can examine the temperature "history" at particular places in a system as heat energy is transferred into and out of it. With this technology, one possible activity that can help students understand the distinction between heat energy and temperature is to have them determine the amount of energy it takes to raise the temperature of two quantities of water by the same amount. By counting the "pulses" of heat energy, students can determine that it takes much more energy to raise the temperature of a large volume of water the same amount as a small volume. Because the temperature change for both volumes is the same but the amount of heat energy transferred is different, this activity clearly signals that heat is a different entity than temperature, which is contrary to the thinking of many students.

One finding from research about teacher knowledge of topic-specific activities is that it more likely for a teacher who has taught a particular subject for a long period of time to have knowledge of this type than it is for a novice to have such knowledge. Clermont and colleagues, for example, compared the knowledge of experienced and novice teachers of chemistry. They reported that the experienced teachers knew more variations of a demonstration for teaching specific chemistry concepts than did novice teachers (Clermont, Borko, & Krajcik, 1994). The experienced teachers were also better at detecting errors and misleading statements when shown someone conducting a typical demonstration for a specific chemistry concept. And, they were more cognizant of the complexity of a demonstration and could suggest ways to make it simpler in order to aid student understanding.

On the other hand, being an experienced teacher does not guarantee that one will know conceptually strong or powerful activities. Findings from the UMMP Project indicated that at the end of the project, teachers differed markedly in their knowledge of activities that were conceptually strong for helping students understand the distinction between heat energy and temperature (Magnusson, Borko, & Krajcik, 1994). This was true despite the fact that many of the teachers taught the same curriculum. Similar findings were reported by Berg and Brouwer (1991) with respect to physics teachers' knowledge of activities that could help students develop desired understandings when they had misconceptions about force and gravity.

Research has shown that teachers' knowledge of topic-specific strategies can increase as a result of involvement in teacher enhancement programs. This was true for the teachers in the UMMP Project and for the novice teachers studied by Clermont and colleagues. Teachers who participated in the UMMP Project typically began with little knowledge of activities for helping students understand the distinction between heat energy and temperature because those concepts had not been prominent in their teaching. Their knowledge increased substantially over the two-year course of the project (Krajcik, Layman, Starr, & Magnusson, 1991). In the study by Clermont and colleagues, increased knowledge was reported for the novice teachers even though their experience lasted only two-weeks (Clermont, Krajcik, & Borko, 1993). They credited the intensity and specific focus of the workshop for its success, but also cautioned that the increased knowledge occurred for only one of the many topics that chemistry teachers commonly address in their teaching.

Smith and Neale (1991) also reported that the elementary school teachers who participated in their four-week summer institute increased their knowledge of activities for teaching about light; however, they also noted that differences occurred among the teachers and that those differences were related to differences in the teachers' subject matter knowledge. For example, only the teacher with strong subject matter knowledge was able to conceive of activities to do with students that were different from those used as part of the summer institute. This dependence upon subject matter knowledge was also described in studies by Hashweh (1987), and Sanders, Borko, and Lockard (1993), both of which investigated teachers in teaching situations within and outside of their areas of expertise.

Hashweh reported that when teachers were knowledgeable in a content area they were able to modify activities included in reference materials and eliminate ones they judged to be tangential to the targeted conceptual understandings. He also reported that teachers with strong content knowledge could devise student activities or demonstrations not mentioned in the references whereas those who were not knowledgeable could not do so. Sanders and colleagues reported that teachers teaching outside of their area of expertise had difficulty making important judgments about activities described in resource materials, such as judging whether an activity or demonstration would work.

These findings suggest that developing this aspect of pedagogical content knowledge may also be dependent upon subject matter knowledge. As with a similar conclusion regarding the "representations" category of the topic-specific strategy component of pedagogical content knowledge, this result is not surprising, partly because it is natural for teachers to use their own experiences learning science to develop or revise activities for their teaching. Again, however, we caution against the inference that sufficient subject matter knowledge is all that is needed for the development of desired knowledge of this aspect of pedagogical content knowledge. Indeed, some research has demonstrated the lack of validity of that conclusion. In a study of middle school teachers, Hollon, Roth, and Anderson (1991) found that, despite their superior subject matter knowledge, some teachers were not able to effectively use that knowledge to help their students develop scientific knowledge.

Summary

The representation of pedagogical content knowledge shown in Figure 2 signals two important ideas about pedagogical content knowledge. First, the individual components that are shown indicate that there are different types of subject-specific pedagogical knowledge that are used in teaching science. Within each component, teachers have specific knowledge differentiated by topic, although they might not have similarly elaborated knowledge in each topic area. Effective teachers need to develop knowledge with respect to <u>all</u> of the aspects of pedagogical content knowledge, and with respect to <u>all</u> of the topics they teach. Second, by designating these components as part of a single construct – pedagogical content knowledge – we indicate that the components function as parts of a whole. As a result, lack of coherence between components can be problematic in developing and using pedagogical content knowledge, and increased knowledge of a single component may not be sufficient to effect change in practice. Thus, because the components may interact in highly complex ways, a teacher's knowledge of a particular component may not be predictive of her teaching practice, and, while it is useful to understand the particular components of pedagogical knowledge, it is also important to understand how they interact and how their interaction influences teaching.

THEORETICAL CONSIDERATIONS

Some scholars argue that pedagogical content knowledge is not sufficiently distinct from other types of knowledge to warrant its identification as a separate domain (e.g., Carlsen, 1991b). We consider the question of whether it is or is not a unique domain of knowledge to be a matter of definition that is a function of how one chooses to carve up the knowledge bases of teaching. There is no one right way to do this. A critical consideration in this debate is what we gain and lose in understanding teaching by defining pedagogical content knowledge as a separate construct. Does the construct of pedagogical content knowledge help the teacher educator plan and implement pre-service and in-service preparation programs? Does it help the teacher develop into a more competent teacher? Does the construct of pedagogical content knowledge help the researcher understand teaching and define pedagogical expertise?

The Value of Pedagogical Content Knowledge as a Construct

Our position is that there is value, both conceptually and practically, in defining pedagogical content knowledge as a separate domain of knowledge for teaching. Conceptually, we see the construct of pedagogical content knowledge as useful for two reasons. First, its conceptualization as knowledge that results from a transformation of other domains of knowledge signals that it is more than the sum of its parts, more than simply fitting together bits of knowledge from different domains. Second, because this knowledge is conceptualized as being constructed through the processes of planning, reflection, and teaching specific subject matter, it represents knowledge that is "uniquely the province of teachers, their own special form of professional understanding" (Shulman, 1987, p. 8). As such, this construct represents an important tool for defining what it means to be a competent or expert science teacher.

The practical value of pedagogical content knowledge as a construct has to do with its potential to define important dimensions of expertise in science teaching that can guide the focus and design of pre-service and in-service teacher education programs. Many science teachers and science teacher educators have a wealth of knowledge about how to help particular students understand ideas such as force, photosynthesis, or heat energy; they know the best analogies to use, the best demonstrations to include, and the best activities in which to involve students. Our identification of this knowledge as pedagogical content knowledge recognizes its importance as distinguished from subject matter or pedagogical knowledge. Further, our conceptualization of the components of pedagogical content knowledge provides an important conceptual tool for helping teachers of science construct the specific knowledge they need to be effective teachers.

We find it interesting that content specialists and generalists in education seldom consider pedagogical content knowledge to be sufficiently different from their domains of expertise to be important to discuss. A question to pose in considering

that position is whether we have evidence to the contrary. Generalists in education typically address issues that are important to learning regardless of subject matter. Is that sufficient for effective teaching? Research cited earlier in the chapter suggests otherwise. Content specialists typically focus on the extent to which a particular topic is accurately and completely represented. Is that sufficient to help others understand? Again, results cited earlier provide a contrary picture. As an additional example, Bellamy (1990) reported that knowledgeable high school teachers were not equally effective in helping their students understand genetics. In particular, she described assessments of the students of teachers who taught different techniques for solving genetics problems. One teacher believed that students should solve genetics problems in the same way that geneticists would. As a consequence, he emphasized the probability method for finding genotypes and de-emphasized use of the Punnett square. His students were not as successful at solving genetics problems as were students of other teachers who used the Punnett square. In addition, some of the teachers using the Punnett square provided visual connections with the underlying biology, and their students were better able to answer genetics questions concerning the process of meiosis.

This and previous examples provide evidence that the domain of pedagogical content knowledge lies outside the expert knowledge of the typical content specialist and the general educator. To ensure that pedagogical content knowledge will receive the attention it warrants in facilitating the development of effective teachers of science, we argue that it is important to designate it as a unique domain within the professional knowledge base. In the final sections of this chapter we describe the implications of pedagogical content knowledge for the design and implementation of teacher education programs that are likely to support and facilitate the development of effective science teachers.

Finally, although we argue for the value of defining pedagogical content knowledge as a separate construct, we do not claim that there are clear distinctions between pedagogical content knowledge and other knowledge domains used in teaching (e.g., subject matter knowledge, general pedagogical knowledge). Rather, the boundaries that exist between domains are "fuzzy" (Marks, 1990). In part, this is due to the fact that pedagogical content knowledge represents an integrated knowledge system, but equally important is the recognition that the distinctions between domains are necessarily arbitrary and ambiguous. Bearing that in mind, we now describe our thinking about how pedagogical content knowledge develops.

A Model of Pedagogical Content Knowledge Development

There are many ways to think about the interaction of the domains of knowledge in the development of pedagogical content knowledge. Figure 1 is one possible model. In that figure, the lines stemming from the major domains of knowledge (shaded figures) indicate that each knowledge base influences the development of pedagogical content knowledge. We find this model to be useful in depicting the general influence of the domains of knowledge upon one another, but we raise the possibility that the domains of knowledge may unequally influence the development of pedagogical content knowledge due to differences in the amount of knowledge in each domain. We depict such a situation in Figure 3. In this figure, the amount of knowledge in a domain is indicated by the size of the box representing it, and the thickness of the lines linking the domains indicate their relative influence upon one another. In the case of Teacher A, the figure indicates that this teacher has substantially more subject matter knowledge than the two other types of knowledge that are key to effective teaching. As a result, we hypothesize that the development of her pedagogical content knowledge is influenced primarily by her knowledge of subject matter. In contrast, for Teacher B for whom pedagogical knowledge is dominant, we hypothesize that the transformation of her knowledge into pedagogical content knowledge will be influenced mostly by the nature of her pedagogical knowledge. These differences may mean that if these teachers taught the same topics in the same educational context they would develop different pedagogical content knowledge, but we would expect there to be significant overlap in the knowledge developed by each. Thus, we argue that there are different routes or multiple pathways to developing pedagogical content knowledge for specific topics.change the problem to that shown in Part B of the figure if she were to give it to her eighth grade students. This version of the problem would be more meaningful to them, and could therefore help them to persist until they reach a solution. Furthermore, her knowledge of subject matter and pedagogy indicates to her that she should change the problem even further to the version shown in Part C because the questions in that version will prompt her students to think in ways that are beneficial for developing scientific knowledge. The questions that are listed serve to signal to students the thinking that they need to do to fully respond to the problem. This transformation from what appears in Part A of the figure illustrates how a teacher might develop pedagogical content knowledge by drawing upon knowledge of subject matter, pedagogy, and context.

Once the teacher has established an appropriate problem, what kinds of experiences should she provide to students to prepare them to solve the problem? A teacher developing pedagogical content knowledge might go through the following thinking process. Let's assume our hypothetical teacher knows that one possible activity to use is to have students set up the situation in the problem and observe what happens. One weakness of the activity represented in Part C of Figure 4, however, is that the phenomenon does not clearly signal that heat energy and temperature are different entities because the change in those quantities is in the same direction (temperature is decreasing and so is the amount of energy in the system as it is transferred in the form of heat). In addition, the difference in the amount of time to cool does not necessarily indicate to students that there is a difference in the amount of energy transferred because some students attribute that difference to be a function of the "ease" with which heat energy can "escape" (Magnusson, 1993). Assuming our teacher was knowledgeable about these weaknesses, she might conclude that this activity is not sufficiently powerful to warrant its use. She considers, however, that the power of the activity could be increased by adding a requirement that students calculate the relative amount of

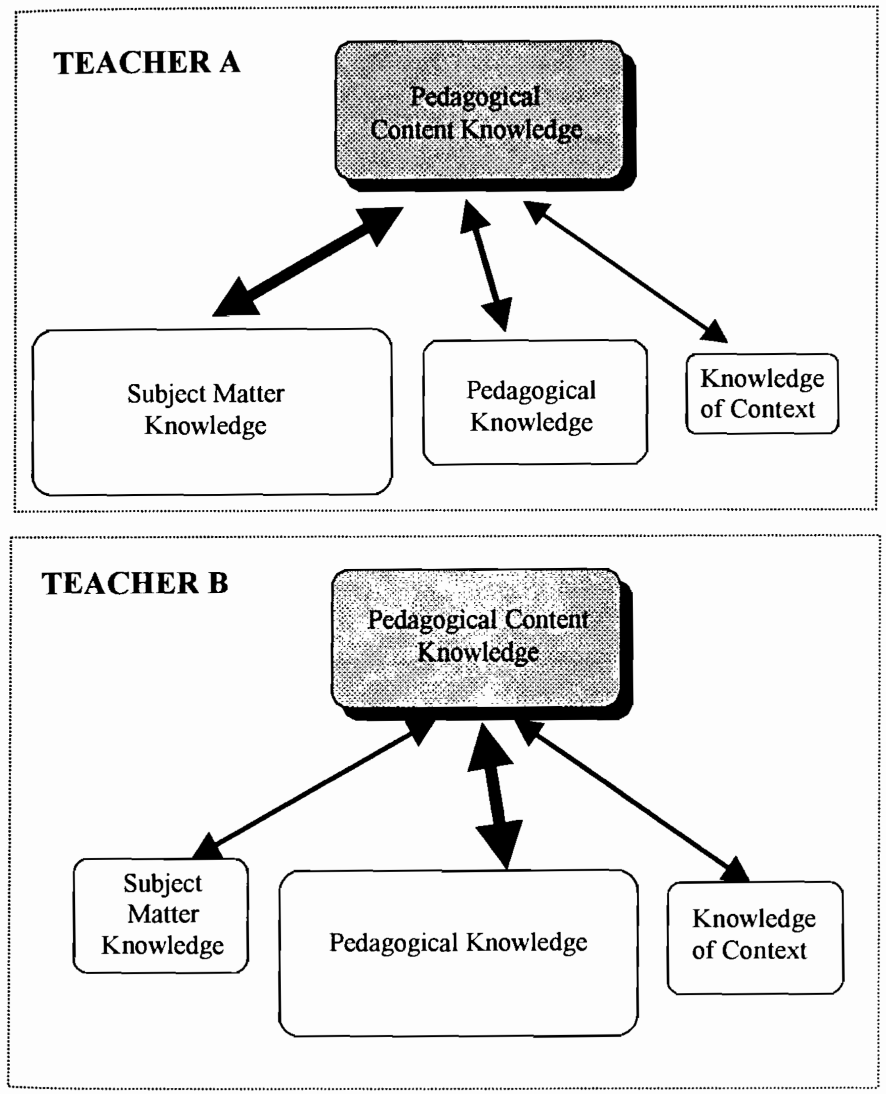

Figure 3. A model illustrating differential influences of the development of PCK for two hypothetical teachers.

heat energy transferred from each cup, but she may also be concerned that this change may not be sufficient to ensure that all of the students will understand the distinction between heat energy and temperature. Knowing about the heat pulser, our teacher might develop the idea that she could have her students create the situation shown in Part C of Figure 4 by using the heat pulser and determining how many pulses it takes to raise the hot chocolate to the desired temperature. Thus, she decides that during the class discussion of how to test their explanations, she will guide students to consider using this strategy.

A) Upon cooling, will these beakers of water lose the same or a different amount of heat energy ?

B) Upon cooling, will one of these students' hot chocolate lose more heat energy?

C) Cooling Hot Chocolate [with same diagram as B above]

1. Do you think one of these cups of hot chocolate takes longer to cool?
   Why do you think so?
   Describe how you could find out, and check your prediction.
2. After cooling, do you think the amount of heat energy they have lost is the same or different?
   Why do you think so?
   Describe how you could find out, and check your prediction.
3. Provide an explanation that would account for your predictions.
4. Test your predictions and revise your explanation as needed to account for your observations.

Figure 4. Contexts for developing scientific knowledge about the relationship between temperature and heat energy.

This example illustrates the specificity and non-linearity of the thinking that leads to the development of pedagogical content knowledge. It is not necessarily common for teachers to go through the process just described. Further, even if they do, they may not end up with knowing the most powerful strategies for helping students develop desired understandings. In addition, because this type of knowledge is so specific, teachers must develop it for each topic of study they teach. These issues underscore the need for programs to help and support teachers in the development of pedagogical content knowledge.

IMPLICATIONS FOR TEACHER EDUCATION

In this final section of the chapter we address implications of theory and research on pedagogical content knowledge for teacher education. We begin by setting teacher education efforts in the context of today's reform movement in science education. We then focus on four sets of recommendations for helping teachers learn to teach in news ways:

1. helping teachers examine their pre-existing knowledge and beliefs;
2. addressing the relationship between subject matter knowledge and pedagogical content knowledge;
3. situating learning experiences for teachers in meaningful contexts; and
4. using a model of components of pedagogical content knowledge to guide learning-to-teach experiences.

Science Education Reform

Current reform rhetoric in science education is asking teachers to teach science in a way that is, for many, fundamentally different from how they were taught. The constructivist views of knowledge and learning upon which the reform recommendations are based differ markedly from the behaviorist view that was dominant when many teachers were prepared and socialized into teaching. Furthermore, for many teachers (both novice and experienced), approaches to teaching science based on constructivist views of knowledge and learning differ from their existing orientations to teaching science and beliefs about science learning and teaching. Given what we know about the role of knowledge and beliefs in teaching and learning to teach, this difference has significant implications for science teacher education – both pre-service and in-service. Moreover, because pedagogical content knowledge results from a transformation of knowledge from other domains, the incompatibility of existing knowledge and beliefs in those domains, with desired knowledge and beliefs, necessarily limits the development of desired pedagogical content knowledge.

Addressing Pre-existing Knowledge and Beliefs

Teachers' knowledge and beliefs serve as filters through which they come to understand the components of pedagogical content knowledge. These understandings, in turn, determine how specific components of pedagogical content knowledge are utilized in classroom teaching. Just as students' existing knowledge and beliefs serve as the starting point for their learning, teachers' knowledge and beliefs are important resources and constraints on change. Because of the mismatch between the knowledge and beliefs of many teachers and those required to meet the vision of current reform, efforts to help teachers make significant changes in their teaching (e.g., to incorporate new science curricula, instructional strategies and representations into their science teaching) must help them to acquire new knowledge and beliefs (e.g., new conceptions of science teaching). In these situations, the same knowledge and beliefs that function as filters through which change takes place are also critical targets of change. Programs that hope to help novice and experienced teachers think and teach in new ways must challenge their pre-existing beliefs (Cohen & Ball, 1990; Borko & Putnam, 1996).

For example, constructivist models of learning suggest that students can benefit from planning, conducting, and determining their own conclusions from investigations. Guided Inquiry – an attempt to instantiate sociocultural and constructivist theory in classrooms – expects that students will be involved in just such activity, in a collaborative manner as part of a learning community, with the goal of understanding a particular problem or issue using tools reflective of the scientific community. The teacher's role in this type of teaching is very different from that derived from a behaviorist model in which teaching is viewed as transmitting information, and different yet again from cognitive constructivist notions that mainly consider learning from an individual perspective. Teachers must change their underlying assumptions about teaching and learning in order to successfully enact such instruction, but even in cases of teachers having compatible views, it takes time to build and transform the knowledge required to enact instruction as complex and sophisticated as Guided Inquiry (e.g., Magnusson & Palincsar, 1995).

To address this issue, just as it is important for teachers to understand students' conceptions and alternative conceptions in science, it is important for teacher educators to understand teachers' conceptions and alternative conceptions about the teaching of science. That knowledge is critical to building and conducting programs that facilitate the change process. Further, just as it is important for teachers to facilitate conceptual development by providing opportunities for their students to examine, elaborate, and integrate new concepts into their existing conceptual frameworks, teacher educators must provide opportunities for teachers to examine, elaborate, and integrate new knowledge and beliefs about teaching and learning science into their existing systems of knowledge and beliefs. This goal can be addressed through activities such as observing, analyzing, and reflecting upon one's own or another's teaching. Some teacher educators are exploring the use of multimedia technology for facilitating this type of activity. For example, Lampert and Ball (1990) have created a multimedia program from which users can inquire about teaching by accessing video images of a lesson accompanied by linked information providing the teacher's reflection on the lesson, entries from student journals, and a timeline showing the lessons that proceeded and followed it. Soloway and his colleagues have developed a multimedia tool, structured around video-based teacher cases accompanied by teacher and researcher written and oral commentary, to promote teachers' understanding of project-based science by illustrating instructional possibilities, features, and strategies (Soloway, Krajcik, Blumenfeld, & Marx, 1993).

Subject Matter Knowledge and Pedagogical Content Knowledge

In addition to concerns regarding the role of knowledge and beliefs in the development of expertise in science teaching, research evidence that suggests the dependence of subject matter knowledge on the development of pedagogical content knowledge warrants specific attention to teachers' subject matter knowledge. Whereas there is evidence that subject matter knowledge is not sufficient to insure effective teaching of subject matter, some critical amount of subject matter knowledge seems to be necessary to develop the pedagogical content knowledge required to meet current reform recommendations. This circumstance is of particular concern with respect to elementary school teachers because they typically have substantially less subject matter knowledge than persons who teach at higher levels of schooling. However, it is also relevant to middle or high school teachers whose subject matter preparation may be narrow with respect to the topics they are required to teach (e.g., Carlsen, 1993). Just as we now expect students to be able to use their knowledge to explain real world phenomena, teachers must be able to do that as well, and their subject matter preparation may not have adequately prepared them for the task. Many teachers may not have had opportunities to formulate questions from observing real world phenomena, develop investigations to answer their questions, or construct explanations from the data produced by those investigations. Such experiences will help them develop the subject matter knowledge needed for developing desired pedagogical content knowledge.

At the pre-service level, program features consistent with this view include pairing or combining science content courses with science methods courses focused on teaching the same content. These features are characteristic of elementary and middle school science teacher preparation programs at some universities (Rubba, Campbell, & Dana, 1993; Stake et al., 1993). For example, in *Integrating Knowledge Bases: An Upper - Elementary Teacher Preparation Program Emphasizing the Teaching of Science*, Krajcik and his colleagues developed an elementary teacher preparation program that featured an integration of the subject matter and professional education coursework with clinical experiences that provided a context for learning about and practicing science teaching (Krajcik, Blumenfeld, Starr, Palincsar, & Coppola, 1993).

At the in-service level, the influence of subject matter on the development of pedagogical content knowledge means that programs that only address pedagogy may not provide enough information for teachers to develop effective practices. Further, programs that strictly focus on subject matter are not likely to be as effective as those in which subject matter and subject-specific pedagogy are both addressed.

Another concern arises from the fact that most programs that focus on subject matter along with subject-specific pedagogy can only address a few of the topics teachers are responsible for teaching. Given that teachers' experiences within one topic area may not be sufficient to support them in engaging in desired practices within other topic areas, we must develop ways for teachers and teacher educators to share subject-specific information for teaching science as a support for teachers in extending their new understandings and practices to topic areas beyond those which might have been the focus of particular teacher education programs. The increasing availability of telecommunications in the schools provides one possible strategy for addressing this need. For example, teachers could email one another to share ideas and experiences while teaching similar topics. An electronic database could be formed and indexed so that teachers could easily access a range of representations or activities used by others to facilitate student learning.

Situating Teachers' Learning Experiences in Meaningful Contexts

Another set of suggestions, strongly supported by research on learning to teach, relates to the importance of situating learning-to-teach experiences in meaningful contexts (Borko & Putnam, 1996). One aspect of this recommendation is that we provide opportunities for teachers to experience, as learners, the instruction they are being prepared to conduct. If teachers are to be successful in creating classroom environments in which science subject matter and learners are treated in new ways, they must experience such learning environments themselves. For example, if science teachers are to support their students in constructing and evaluating their own explanations, then the teachers must participate in similar activities. Similarly, if teachers are to support student learning through the use of technology such as the heat pulser, then they must have learning experiences with technology. Simply telling teachers that they should have their students construct and evaluate explanations or use technology in problem solving activities, does not provide sufficient information or support to enable them to successfully put those ideas into practice.

A second aspect of this recommendation is that teachers must have the opportunity to learn about new instructional strategies and ideas in meaningful and supportive contexts. Meaningful contexts are actual classroom situations. Supportive contexts are ones in which teachers are scaffolded as they take on the challenge of developing new practices. At the pre-service level, teacher education programs should incorporate a substantial classroom-based component in which students have meaningful teaching opportunities. Further, pre-service teachers should be expected to critically reflect upon their teaching, and they should receive support and careful feedback from others who are more experienced and knowledgeable, to aid them in that process. At the in-service level, teachers should have the opportunity to receive

support and feedback from school district staff personnel, university teacher educators and other teachers as they attempt to incorporate new instructional representations and activities into their ongoing classroom practices.

One model of this type of experience is described by Krajcik, Blumenfeld, Marx, and Soloway (1994). It consists of repeating cycles of collaboration, enactment, and reflection. The collaboration occurs through worksessions in which teachers and researchers inform, critique, and support one another. Enactment involves the planning and carrying out of new practices. Finally, reflection involves such activities as writing journals of one's experience and viewing videotape of one's teaching. The knowledge that teachers gain through these types of multi-faceted experiences that acknowledge the complexity and ambiguity of classroom teaching is likely to be accessible and flexible enough to result in future successful teaching experiences and desired student outcomes. In contrast, although intensive out-of-classroom experiences such as university-based methods courses for pre-service teachers and summer institutes for experienced teachers may have an important role to play in teachers' learning, their benefits are unlikely to be realized without complementary classroom-based opportunities. Without integrated experiences, teachers are unlikely to make meaningful or long-term changes in their instructional practices.

We must also recognize that change takes time, and that facilitating change that encompasses beliefs as well as practices can take years. Teachers and teacher educators should consider programs that provide support and encourage critical reflection over a period of years. Models such as Professional Development Schools (Holmes Group, 1990), in which universities and schools collaborate over extended periods of time are examples of such programs.

Guidance Provided by a Model of the Components of PCK

Our last set of suggestions is specific to pedagogical content knowledge as represented by Figure 2. The figure can serve as a map for planning science teacher education experiences and for specifying desired knowledge outcomes of those experiences. Specifically, the components of pedagogical content knowledge suggest the importance of including the following elements in science teacher education programs:

- The goals of science education and their relationship to purposes for teaching science (knowledge of *orientations to teaching science*, knowledge of *science goals and objectives*).
- Instructional strategies that match particular orientations to teaching science (knowledge of *subject-specific strategies*, knowledge of *specific science curricula*).
- Planning, conducting, and reflecting upon teaching specific science topics, guided by considerations of students' understandings (knowledge of *students' understanding*, knowledge of *science assessment*),

and the appropriateness/value of using particular instructional strategies (knowledge of *topic-specific strategies*).

- Planning and administration of assessments that are compatible with one's orientation to science teaching and targeted goals and objectives (knowledge of *science assessment*).

Ideally, for a science teacher education program to be comprehensive and coherent, all of these areas should be addressed. However, we recognize the difficulty of that undertaking, and we do not suggest that programs which focus on only a subset of the components cannot be successful. Instead, we caution that teacher educators should be aware of the possibility that teachers may not have requisite knowledge of components not addressed by the program that would help them effectively use the knowledge they develop from the program. Further, participants may have pre-existing pedagogical content knowledge and beliefs in areas not addressed by the program that are incompatible with the program's goals, and which might undermine effectiveness of the program in helping teachers develop new practices.

In addition, given that pedagogical content knowledge is transformed as a result of teaching, and that one must develop pedagogical content knowledge for each topic that one teaches, pre-service teachers will only be able to develop a fraction of the pedagogical content knowledge they will need to be effective. Hence, it is critical that pedagogical content knowledge development be the focus of work with practicing teachers as well. Experiences at conferences such as National Science Teachers Association conventions provide one type of opportunity for teachers' continued knowledge development. Many presentations are instances in which pedagogical content knowledge is shared; however, too often the information that is provided is insufficient for teachers in the audience to make optimal use of it when they apply it to their own teaching situation. As a professional community, we can do more to educate presenters to provide more detailed information. We can also encourage different types of sessions in which participating teachers can teach and reflect upon their teaching with the help of those with the necessary expertise. In addition, the science education community can make it a priority to provide other avenues of support for teachers to continue developing and refining their pedagogical content knowledge. This action is particularly needed at this time when the knowledge required for effective science teaching is greater than it has ever been due to the breadth and depth of contemporary goals for science education, and the demands of inquiry-based teaching.

Finally, at this time of focus on national standards to guide the credentialling of teachers, we must recognize that pedagogical content knowledge is at the heart of teaching in ways consistent with the standards. The components of pedagogical content knowledge can help us view those standards in ways that will maximize the development of programs that can support teachers in developing the knowledge required for successful teaching.

IMPLICATIONS FOR RESEARCH

Despite the utility of pedagogical content knowledge as argued in this chapter and illustrated in the research that was cited, this concept has not received much attention in the field of science education. For example, although the small number of studies examining pedagogical content knowledge that were described in this chapter were only intended to be representative of the research in this area, they comprise a substantial proportion of existing work. One implication that can be drawn from this chapter is that much more research is needed to define desired pedagogical content knowledge for specific science topics, and to examine its influence on teachers' practice in specific teaching situations.

Another recommendation concerns the ways in which researchers examine teachers' pedagogical content knowledge. Because we are (or should be) trying to capture the complexity of changes in teachers' knowledge, beliefs, and practices across components of pedagogical content knowledge (as well as across knowledge domains), it is important to use multiple data sources. Observations of teachers in their classrooms as well as in teacher education settings; interviews with teachers about their knowledge, beliefs and practices; and interviews with other persons central to change efforts are all important sources of information about teaching. Further, because change is a slow process, it is important to study teachers over time – both during and after their participation in teacher education programs.

Finally, although we consider our conceptualization of pedagogical content knowledge to be a powerful tool for understanding science teaching, we think it is important that discussion regarding its conceptualization and utility continues, particularly as new research becomes available. By continuing to challenge and revise our thinking, the science education community is likely to develop sharper and more varied lenses with which to examine and understand science teaching and learning.

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[1] Shulman named this type of knowledge pedagogical content knowledge because he initially conceptualized it as developing from a teacher's knowledge of content and pedagogy.

[2] Notice that the names in each of the shaded boxes describe the domain as consisting of "knowledge and beliefs." Our choice to designate the domains as including beliefs signals that when information from any of them is accessed for teaching, that information may be an amalgam of knowledge and beliefs. The designation of knowledge and beliefs should be applied as well to each component of the major domains, even though the term "belief" was not repeated in those boxes in the figure. The remainder of the chapter text uses the term "knowledge" in labeling the domains and their components rather than "knowledge and beliefs" because the knowledge dimension has received the most attention from science educators. Nevertheless, it is important to remember that beliefs are associated with that knowledge as well.

[3] Again, we have used only the term knowledge in labeling the components in the figure even though in all cases they include knowledge and beliefs.

[4] Other science educators have referred to this component as a "functional paradigm" (Lantz & Kass, 1987); Grossman (1990) referred to it as an "overarching conception" of teaching.

[5] Descriptions of some of the orientations were informed by the following articles: Anderson and Smith (1987) and Smith and Neale (1991).

[6] A project of this type was carried out in a number of elementary school classrooms as part of a university/school collaboration led by Magnusson (Magnusson, Karr, George, & Boyle, 1994; Magnusson, Boyle, & George, 1994).

[7] Further description and illustration of this type of progression of instructional activity is presented in Magnusson and Palincsar (1995).
[8] Other terms that have been used to describe these ideas are misconceptions (Helm, 1980), preconceptions (Ausubel, 1968), lay conceptions (Magnusson, Boyle, & Templin, 1994), alternative frameworks (Driver & Easley, 1978), naive theories (Resnick, 1983), and children's science (Gilbert, Osborne, & Fensham, 1982).
[9] These findings are confirmed by a number of studies examining teachers' content knowledge. See section of review (pp. 189-190) by Wandersee, Mintzes, and Novak (1994) on alternative conceptions in science.
[10] These are electronic devices attached to a computer. They can be purchased from Vernier Software.

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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-

J. Gess-Newsome and N. G. Lederman (Eds.) PCK and Science Education, **133-144.**

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.

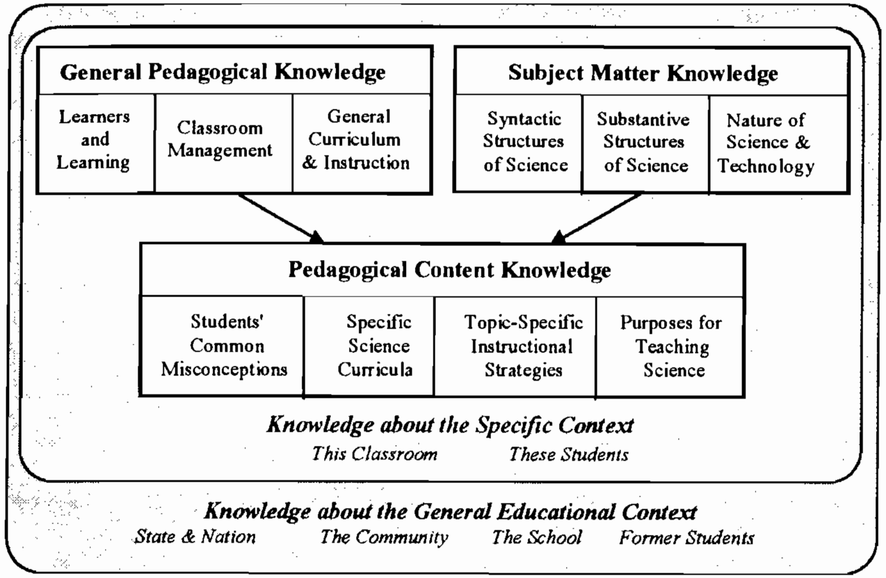

Figure 1. Domains of teacher knowledge

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).

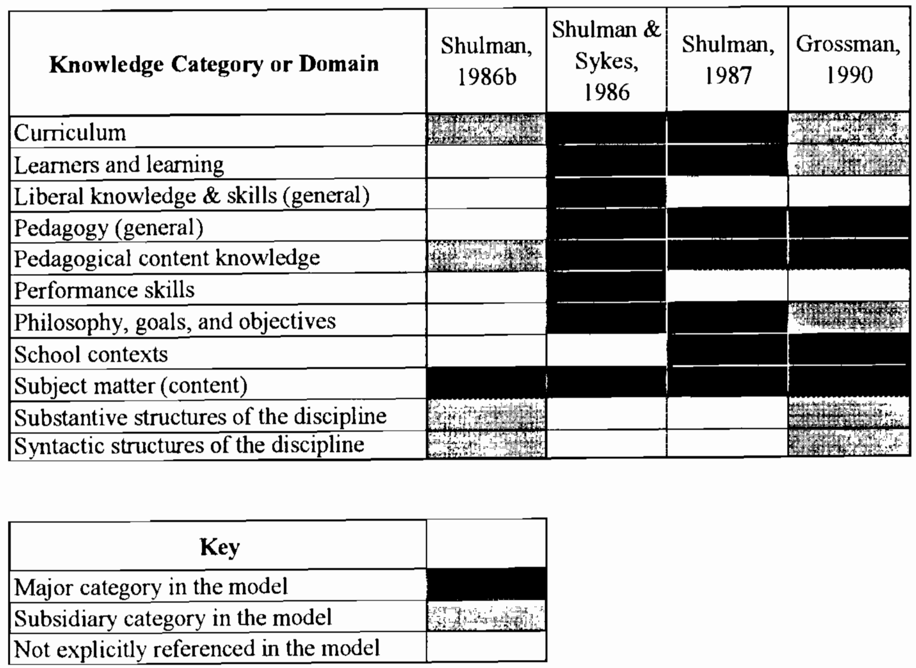

Figure 2. Domains of Teacher Knowledge: Four Alternatives

"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 profession, an issue that has been rarely mentioned in the literature on teacher knowledge since.

Two categories of teacher knowledge were mentioned in the Carnegie paper, but then disappeared from subsequent structural descriptions. They were General/Liberal Education ("including basic skills of reading, math, writing, and reasoning") and Performance Skills ("including voice, manner, poise") (p. 7). The paper also contained an early version of a model of pedagogical reasoning and action, elaborated later elsewhere.

"Knowledge and Teaching: Foundations of the New Reform" (Shulman, 1987) appeared the following year in *Harvard Educational Review*. Seven domains of teacher knowledge were listed in the paper (see Figure 2). One noteworthy change in the structure was that what had been called "Foundations of Professional Understanding" in the Carnegie paper was renamed "Knowledge of Educational Contexts, ranging from the workings of the group or classroom, the governance and financing of school districts, to the character of communities and cultures" (Shulman, 1987, p. 8). Pedagogical content knowledge was defined as "that special amalgam of content and pedagogy that is uniquely the province of teachers, their own special form of professional understanding" (p. 8).

The treatment in "Knowledge and Teaching" of the domains of teacher knowledge was brief; the paper had other goals. These included describing four major sources for the knowledge base of teaching (scholarship in content disciplines, educational materials and structures, formal educational scholarship, and the wisdom of practice) and proposing a "model of pedagogical reasoning and action." The latter model (which included stages labeled Comprehension, Transformation, Instruction, Evaluation, Reflection, and New Comprehensions) was to receive less attention than Shulman's teacher knowledge framework (with its PCK domain), which proved to be useful to researchers who were not exclusively concerned with teacher cognitions, but needed a conception of teacher knowledge to study other educational questions.

Shulman and his students would later propose variants on this general model of the domains of teacher knowledge (Grossman, Wilson, & Shulman, 1989; Hashweh, 1987; Wilson, Shulman, & Richert, 1987), but the general categories would remain fairly stable. Grossman's (1990) book, *The Making of a Teacher*, revisited each of these domains in some detail, specifically enumerating the following four components: (1) Knowledge of students' understandings, conceptions, and misconceptions; (2) Curricular knowledge; (3) Knowledge of instructional strategies and representations for teaching particular topics; and (4) Knowledge and beliefs about the purposes of teaching one's subject (Grossman's framework is summarized in Figure 2). Two noteworthy features of this classification are that the second and fourth of these components were folded into the conception of pedagogical content knowledge (other frameworks had overlooked them or placed them elsewhere).

Pedagogical Content Knowledge: A Poststructural View

Shifting to a poststructural perspective on teacher knowledge, several objections might be raised to the preceding description.[6] First, *the view of knowledge as fixed and systematic would be rejected.* Word-labels like "pedagogical content knowledge" and the concepts to which they map are always used by *someone.* Words and concepts are not fixed objects of meaning, and cannot be bound to real-world referents permanently and unambiguously. In Foucaultian terms, "truth" is embedded in a discourse community, and is inseparable from that community. A *structuralist* might argue that skilled teachers use pedagogical content knowledge in a context-dependent fashion–perhaps using a different analogy to describe "force" in a rural classroom than in an urban classroom. A *poststructuralist* might respond that in the urban context, the teacher's unspoken rural analogy is not pedagogical content knowledge at all. More significantly, a poststructuralist would not expect to find that teachers hold a single fixed set of beliefs about the purposes for teaching science (a PCK issue in Figure 1), or even a stable view of the nature of science and technology (a subject matter knowledge issue). Instead, this "knowledge" might be formed anew in each new educational context.

Second, *a poststructural view would assert the interdependency of knowledge and power.* Discourse communities are characterized by asymmetries in power, and these asymmetries determine how truth is defined.[7] For example, if "pedagogical content knowledge" is established by disciplinary specialists (e.g., physicists, physics teacher educators, physics teachers), it is likely to take a different form than if it is established by other scientific experts (such as engineers). Even within a group having disciplinary homogeneity, asymmetries in power will affect the definition of knowledge: during deliberations about a new physics curriculum, for example, physics teachers might be expected to defer to Ph.D. physicists on subject matter issues. By defining science in a disciplinary fashion, our structural model of teacher knowledge increases the likelihood that *teachers'* conceptions of subject matter will be subordinated to the conceptions of more powerful experts.

Third, *a poststructural view would object to the displacement of the individual from the center of meaning.* "Where," might a poststructural critic ask, "is the student in this model? Or, for that matter, the teacher?" The model fixes subject matter structures in ways that are only ambiguously related to the local actors in the educational drama, via "knowledge about the context." In Figure 1, subject matter knowledge is defined, in large part, by the structures of the scientific disciplines. But why not define it in a more learner-centered fashion? For example, one might ask, "What do my 13 year old students know about plants?" It is likely that the students' conceptions will differ greatly from those of a botanist, foregrounding both common misconceptions (plants get their food through their roots) and knowledge that is not narrowly botanical (the function of plants in the human diet, the importance of plants in the natural and designed landscape, and so on). Given the widespread use of conceptual change theory in science education, it is worth asking whether a more learner-centered view is warranted in defining the domains of subject matter knowledge and PCK.

Finally, *a structural view fails to adequately consider the historical and cultural dimensions of knowledge*. This problem is most likely to occur if subject matter knowledge is defined in narrow disciplinary terms.[8] In science, assertions become truth through the eradication of the traces of their construction (Latour & Woolgar, 1986). Along with the first person voice, scientific writing typically eliminates reference to the social, gendered, cultural, and economic context of investigations. What is left in official accounts are experiments that "do themselves" in response to purely empirical puzzles. This face of science is socioculturally antiseptic, and may make science less comprehensible and less attractive to groups that have been historically underrepresented (Bleier, 1991; Cunningham & Helms, 1998). It is also incorrect.

Turning to pedagogical content knowledge, a poststructural critic might worry that the domain is nothing more than a strategic invention designed to enhance the status and power of teacher educators (Labaree, 1992). The relationship between teachers' knowledge and the professional status of teachers' work has a history worth exploring, one that is conspicuously absent from structural representations like Figure 1 (Sockett, 1987; Strike, 1990).

In summary, the principal criticisms of the structural approach to teacher knowledge are that it represents knowledge as fixed and external to teachers and students, that it naïvely overlooks the relationship between power and knowledge, and that it removes knowledge from its historical and cultural context. If these poststructural concerns are taken seriously, they call into question the implicit goal of ideological neutrality in the entire program of research on teacher knowledge. If teacher knowledge is more -- rather than less -- context-dependent, individualistic, and historically contingent, then clearly we cannot avoid struggling with some difficult questions. For example, by studying what expert teachers know, we cannot automatically answer the question, "What should novice teachers know?" And the "wisdom of practice" discovered in affluent schools offers few simple lessons for teaching in general. Contingencies persist.

DOMAINS OF TEACHER KNOWLEDGE: AN UPDATE FOR SCIENCE EDUCATION

Figure 1 is a reformulation of previously published domains of science teacher knowledge, offered in response to developments in the study of teacher knowledge and to changes in science education nationally. The model differs from Grossman's (1990) general model of teacher knowledge in several ways. First, to *subject matter knowledge*, I have added an explicit reference to the nature of science and technology, necessary if teachers are to address the curricular goals and objectives proposed in major initiatives like Project 2061 (American Association for the Advancement of Science, 1993). Unfortunately, traditional subject matter majors (e.g., in Chemistry) offer few opportunities for prospective teachers to develop their understandings of the nature of science and technology. Yet it appears that these understandings may be central to the teachers' task of creating sociologically

authentic science experiences (Cunningham, 1995; Cunningham, 1998). Study of the history, philosophy, and sociology of science should be included in teacher education programs (Buchmann, 1984), although it is not clear where room for this study will be found (Carlsen, Cunningham, & Lowmaster, 1995).

Second, although I have retained Schwab's useful conceptions of substantive and syntactic structures, it is important to broaden how these structures are operationalized in research and policymaking. If teachers are to teach the new science curricula successfully, their *subject matter knowledge* should include the structures of the sciences, not just the structures of physics, or chemistry, or biology; and non-trivial understandings of the structures of mathematics and engineering as well. At first blush, this appears an enormous challenge; after all, as Shulman pointed out in *Educational Researcher* (Shulman, 1986b, p. 9), in 1986 a well-prepared biology teacher would be expected to be familiar with at least three different organizational frameworks for biology alone, corresponding to the three different BSCS textbooks. Since then, however, BSCS has decided that evolutionary theory provides a superior conceptual organizer for biological literacy (BSCS, 1993), and AAAS, NSTA, and the National Research Council have published books that should be helpful in educating more multidisciplinary science teachers.

Third, within *pedagogical content knowledge*, I include "understanding of students' common misconceptions" and "topic-specific instructional strategies," both categories with special significance in science education. Within the latter category I would include much of the knowledge that science teachers draw upon in choosing and using models, orchestrating substantive classroom discourse, and managing laboratory activities.

Fourth, in this diagram, I endeavor to emphasize the importance of context, and its unique relationship to the various knowledge domains. Shulman has pointed out that his view does not posit that static knowledge structures are held by teachers across contexts, and in fact the research that informed Shulman's model followed teachers through at least the first two years of their professional practice–a period during which teachers' knowledge is reshaped considerably (Grossman & Shulman, 1994). The induction period to teaching is a wonderful time to examine the role of context in teacher knowledge, because the teacher's movement from student to student teacher to teacher provides a physical-spatial and sociological "edge effect," where conceptions of subject matter are manifested in different places in different ways. Another opportune setting for the study of context effects is the classroom in which significant educational innovation is taking place. In studying the effects of computer "saturation" in an Apple Classroom of Tomorrow (ACOT), Piliero (1994) demonstrated the particular importance of local events in challenging teachers' previously held beliefs and understandings. Her research also shows that the relationship between context and pedagogical content knowledge is much more complex than "the former influences how the latter is expressed." Contextual factors can lead to the creation of new PCK, and new PCK (such as the capacity to see insights in students' ideas) may stimulate the teacher to understand students differently and to recreate the classroom setting–its arrangement, the tasks students are given, the placement of the teacher–in short, to *change* the context of instruction.

Taken together, these changes update the structural view of teacher knowledge, and bring it into better alignment with contemporary thinking about science and science teaching. But, greater attentiveness to context notwithstanding, this updated view retains both the strengths and the weaknesses of structuralism. Alternative views, like that of poststructuralism, may prove useful for periodically reviewing the nature of teacher knowledge and its use in research and policy making.

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[1] In a paper commissioned by the Carnegie Forum on Education and the Economy, Shulman and Gary Sykes wrote, "While the claim 'a knowledge base exists' is demonstrably true, that base is also regrettably underdeveloped, minimally codified and limited in its acceptability to both teachers and teacher educators. The National Board initiative thus has two coordinate purposes: to base a new system of assessment on the knowledge base of teaching and simultaneously to accelerate the clarification, codification and augmentation of that base through the very development of the assessment system itself (Shulman & Sykes, 1986, p. 7).

[2] This description of structuralism is based on the analysis of Saussure (1916/1966) by Cleo Cherryholmes (1988).

[3] The unidirectional arrows leading from "General pedagogical knowledge" and "Subject matter knowledge" to "Pedagogical content knowledge" are intended to reflect the prevailing view of an epistemological hierarchy: PCK requires these other forms of knowledge, not vice versa. Figure 1 is not intended to be a process diagram.

[4] Here the first term in each opposition characterizes my Figure 1.

[5] Shulman's footnote listed knowledge of general pedagogy; knowledge of learners and their backgrounds; principles of school organization, management, and school finance; and the historical, social, and cultural foundations of education.

[6] My account of poststructuralism is based on the analysis of Foucault and Derrida by Cleo Cherryholmes (Cherryholmes, 1988). The reader may also be interested in Cherryholmes's analysis of the structure of the disciplines (pp. 135-141). Other useful sources were Lyotard (1984)and Readings (1996).

[7] From a Foucaultian perspective, the relationship between power and knowledge is reciprocal, not unidirectional. "When viewed from a genealogical perspective, power cannot be accorded a privileged position in relation to knowledge. Power and knowledge are inextricably linked and neither can be regarded as being in a 'secondary position' in relation to the other" (Jones, 1990, p. 94).

[8] This is a problem that one encounters in Shulman (1986b), where content knowledge is defined in Schwabian terms, but less in Shulman (1987), where content knowledge "rests on two foundation: the accumulated literature and studies in the content area, and the historical and philosophical scholarship on the nature of knowledge in those fields of study" (p. 9).

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SECTION III

EMERGING LINES OF RESEARCH IN SCIENCE TEACHER EDUCATION

JULIET A. BAXTER AND NORMAN G. LEDERMAN

6. ASSESSMENT AND MEASUREMENT OF PEDAGOGICAL CONTENT KNOWLEDGE

Introduction

During the past decade pedagogical content knowledge has been embraced by a wide variety of researchers and educators. Both preservice and inservice teacher educators have begun to evaluate their success at enriching teachers' pedagogical content knowledge (Smith & Neale, 1989, 1991), while researchers in various disciplines have studied the impact of pedagogical content knowledge on teachers' beliefs, classroom practice and students' understanding (Grossman, 1990; Hashweh, 1985, 1987; Lederman & Zeidler, 1987; Peterson, Fennema, Carpenter, & Loef, 1989; Wilson & Wineburg, 1988). It is clear that teacher educators and researchers have identified pedagogical content knowledge as a critical component of the knowledge needed to teach (Shulman, 1987).

To study pedagogical content knowledge, researchers and teacher educators have developed an array of methodologies and techniques, such as paper and pencil tests (in particular, multiple-choice exams), concept maps, pictorial representations, interviews and multi-method evaluations. These techniques have been used to pursue goals such as teacher evaluation, staff development, and program development. The purpose of this chapter is to review methodologies and techniques that have been used to assess teachers' pedagogical content knowledge or its related components. The primary emphasis will be on studies of pedagogical content knowledge that focus on the teaching of science; however, we also refer to studies from other disciplines that might prove useful in thinking about how pedagogical content knowledge can inform teaching in science.

Challenges to studying pedagogical content

Although many have built upon Shulman's (1986) original definition of pedagogical content knowledge, he captured it best in his writings:

> A second kind of content knowledge is pedagogical knowledge, which goes beyond knowledge of the subject matter per se to the dimension of subject matter for teaching. The category of pedagogical content knowledge 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 demonstration–in a word, ways of representing and formulating the subject that make it comprehensible to others....Pedagogical content knowledge also includes an understanding of what makes the learning of

J. Gess-Newsome and N. G. Lederman (Eds.) PCK and Science Education, **147-161.**

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).

Thus, pedagogical content knowledge differs from both content knowledge and general pedagogical knowledge. Content knowledge is the knowledge held by a content expert, what the research chemist understands about the discipline of chemistry. General pedagogical knowledge is the knowledge of experienced teachers, such as knowledge of how to organize a classroom and manage students during instruction.

Kagan (1990) identified a number of challenges to assessing teacher cognition; many of her concerns apply to the study of pedagogical content knowledge. First, pedagogical content knowledge cannot be observed directly. By definition, pedagogical content knowledge is partly an internal construct; it is a teacher's understanding of content-specific examples that best represent specific topics, and knowledge of common student difficulties with specific topics. When attempting to study a teacher's knowledge of "best examples," we cannot rely exclusively on observational data as a teacher may use only a small portion of his/her accumulated store of examples during a particular teaching episode. We, as observers, would never see the examples that the teacher decided not to use. In addition, an observation would not reveal why the teacher chose to use some examples while avoiding others. Observations provide only a limited view of pedagogical content knowledge; we must ask teachers to articulate their knowledge. We will discuss a variety of techniques used to help teachers articulate their knowledge. These techniques range from open-ended prompts to structured interviews, and each has its strengths and weaknesses.

Kagan (1990) also notes that even when techniques to elicit teacher cognition are well designed and carefully administered, teachers' cognition, which includes pedagogical content knowledge, is often held unconsciously. Teachers do not always possess the language to express their thoughts and beliefs, or they may refrain from expressing unpopular beliefs. Another difficulty with the pedagogical content knowledge methodologies is that they are generally time-consuming to develop, administer, and analyze. Most assessments of pedagogical content knowledge are qualitative in nature, relying on cognitive techniques, such as interviews that generate lengthy transcripts to be analyzed, and concept mapping that requires the interpretation of involved coding systems. The paper and pencil instruments that have been developed require significant effort to complete and often considerable time and energy to analyze; no one has developed a 20-item paper and pencil instrument that captures pedagogical content knowledge. When a relatively brief instrument is used, it is typically one of many techniques used to develop a complete picture of an individual's pedagogical content knowledge (cf. Hashweh, 1985, 1987; Peterson, Fennema, Carpenter, & Loef, 1989).

Objectives

The intent of this chapter is to review techniques that have been used to assess pedagogical content knowledge and its related knowledge domain (e.g., subject matter knowledge) in the teaching of the sciences. In collecting studies that represent different techniques, we have not prepared an exhaustive review, but rather selected representative studies that best capture a particular technique and the issues associated with using that technique.

Methods of evaluating pedagogical content knowledge

In the decade since the term pedagogical content knowledge appeared, a large body of related research has developed. Grossman and Yerian (1992) identified more than 38 studies of some aspect of pedagogical content knowledge; however, only a small portion of those studies focus on teaching the sciences. As our focus is on the methodologies used to assess pedagogical content knowledge, we have organized the studies by the technique used to assess pedagogical content knowledge. The studies fall into three groups: (a) convergent and inferential techniques, (b) concept mapping, card sorts, and pictorial representations, and (c) multi-method evaluations.

Convergent and inferential techniques

Convergent and inferential techniques include Likert-type self-report scales, multiple-choice items and short answer formats. What is common to all of these formats is that they use predetermined verbal descriptions of desired teacher knowledge as the criteria for comparing verbal answers of pre- and in-service teachers. Although these formats have been widely used to measure teachers' attitudes and beliefs, they have not received much attention for the assessment of pedagogical content knowledge in any discipline, much less in the sciences.

Kromrey and Renfrow (1991) have used multiple-choice test items for measuring what they call content-specific pedagogical knowledge (C-P). They distinguish content-specific pedagogical knowledge from content knowledge and general pedagogical knowledge, so their construct, C-P, certainly sounds like pedagogical content knowledge with a slight variation in label.

Kromrey and Renfrow developed a working definition of items that assess pedagogical content knowledge. They call these "C-P items." The class of C-P items includes those items for which the examinee's determination of the correct response depends upon knowledge of the treatment of content in educational situations (p. 5). They exclude items that solely address content, as well as items that "address general pedagogical principles in the absence of content-specific interpretations" (p. 5).

They stress that C-P items reflect the process of teaching the content, not the non-instructional practice of the discipline. They further distinguish among four categories of C-P items: error-diagnosis, communicating with the learner, organization of instruction, and learner characteristics. Error-diagnosis items require the teacher to identify the student's logical error (e.g., the student did not convert to a common denominator). Communicating-with-the-learner items require the teacher to identify appropriate communication between teacher and student (e.g., when a student appears to be confused, what would be the "next step" activity or query to help the student understand the problem?). Organization-of-instruction items focus on teachers' plans for instruction (e.g., a failed activity is described and a successful corrected activity is described. The respondent identifies a reason the correction worked). Learner characteristic items assess teachers' knowledge of developmental norms within the discipline, or sequences of skill development (e.g., a teacher is having trouble teaching addition of fractions to first graders. Why?).

Kromrey and Renfrow note that these four categories are not exhaustive, but simply reflect the types of items that have been developed thus far. Kromrey and Renfrow's working definition and four categories of C-P items are a noble start to an extremely difficult task (i.e., assessing the complex, content-and context-specific knowledge called pedagogical content knowledge). They have identified the problem space -- the intersection of knowledge about content and knowledge about pedagogy -- as well as an initial organization; however, there is still much work to be done.

Kromrey and Renfrow allude to a major concern related to psychometrics. Although they produced promising initial results regarding the item difficulty and reliability of their instruments, they suggest the need to examine other psychometric properties. It is critical that they examine the construct validity of their C-P items, for if these carefully constructed and reliable items are not measuring what we intend to measure, namely pedagogical content knowledge, then these efforts are misplaced.

Kromrey and Renfrow note a second concern: C-P items are more difficult to write, edit and analyze than content or general pedagogy items. C-P items are longer. Given the content- and context-specific nature of pedagogical content knowledge, C-P items must capture an instructional episode in some detail. The item must include information on students and the specific topic and instructional setting. In addition, the distractors for C-P items must be skillfully crafted so they are plausible, yet not defensible. Again, adequate detail must be provided in each choice so that content-specific knowledge is needed to identify the correct answer. In summary, convergent and inferential methods of assessing pedagogical content knowledge have not been widely used. Kromrey and Renfrow have developed multiple-choice items that contrast with content knowledge and general pedagogical knowledge, but they have not yet established what these items do measure. Kagan's (1990) concept of ecological validity is helpful in this context. She defines ecological validity as:

> ...the kinds of evidence researchers provide concerning the relevance of a measurement technique to classroom life. Are teachers' performances on a particular tool or task related to their classroom behaviors or to valued student outcomes? (Kagan, p. 422).

The question remains as to how well performance on multiple-choice items reflects classroom instruction and "valued student outcomes."

Critique of convergent techniques

The assumption underlying Kromrey and Renfrow's multiple choice exams is that a set of right answers do exist; the sample items they offer are well designed and have a clear right answer. Our concern is that these items may overlook the essence of pedagogical content knowledge, which is the specific content and context in which teaching and learning occur. For example, a sample C-P item establishes the content and context in the following sentence: "Mrs. Stevens will introduce addition to her first-grade SLD class" (Kromrey & Renfrow, p. 16). The item offers a gross oversimplification of context, as any first grade teacher can vividly explain. There are differences across buildings, cities, within buildings from year to year that all influence how teachers teach. Assessments of pedagogical content knowledge need to highlight a teacher's ability to deal with the unusual, non-generalizable aspects of teaching. Kromrey and Renfrow's multiple-choice items are certainly an economical means of improving current teacher tests; however, it is not clear that their tests are actually tapping new domains of knowledge.

In general, educators are questioning the use of multiple-choice exams. Haertel (1991) cites lengthy criticisms of the continued use of multiple-choice exams to assess teacher knowledge. He notes criticisms of these tests for showing poor criterion-related validity, failing to measure many critical teaching skills and their adverse impact on minority representation in the teaching profession. Before we embark on the time-consuming and expensive route of developing multiple-choice tests of pedagogical content knowledge, we need to examine these criticisms carefully. As Kagan (1990) cautions:

> Any researcher who uses a short-answer test of teacher belief (i.e., an instrument consisting of prefabricated statements) runs the risk of obtaining bogus data, because standardized statements may mask or misrepresent a particular teacher's highly personalized perceptions and definitions. At the very least, we need studies of test wiseness, dishonesty, and the effects of language before short-answer tests of teacher belief can be regarded as reliable. (p. 426).

The question with multiple choice exams is what do they really tell us about teachers?

Concept mapping, card sorts, and pictorial representations

Concept mapping has been used by cognitive researchers to measure knowledge structures as represented by key terms and the relationships among those terms. Typically, researchers ask their subjects to generate words and phrases about a particular label or concept. The subjects are then asked to group the words in ways that make sense to them and explain their groups. Often the subjects are asked to draw pictures or maps that illustrate the key terms and relationships among them. An important assumption underlying this research is that concept maps reflect the organization of information as it resides in long term memory.

Card sort tasks were used extensively by Shulman and his students within the Knowledge Growth in Teaching Program. In a card sort task a set of "cards" are provided by the researcher with each card containing a particular concept, idea, principle, etc. The teacher is then asked to place the cards in an arrangement that best illustrates the relationship among the "items" contained on the cards. In effect, this approach is an alternative to concept mapping because the topics are provided by the researcher and there is more flexibility in terms of final format.

Both concept maps and card sort tasks can be criticized, however, on the grounds that they are too restrictive. Each approach requires either a particular format (hierarchical, static and two-dimensional) or use of particular ideas in the representation of one's conceptual schema. As a consequence, the researcher is only provided with how the research subject views the ideas presented by the researcher or a representation that is restricted to a particular hierarchical format.

Morine-Dershimer (1989) used concept maps to examine changes in the knowledge structures of preservice teachers. At the beginning and end of a methods course, Morine-Dershimer asked the students to draw two concept maps: one about the concept that they taught in their peer teaching lesson during the course, and the second depicting the concept of "teacher planning." The students supplied their own key terms and were free to use any graphic design that they chose. The maps were analyzed for area and density.

Morine-Dershimer found a substantial increase in the number of main categories included in the maps and a slight increase in the number of subordinate levels. She inferred that this reflected an increase in conceptual understanding of the lesson topics and of the notion of teacher planning. She concluded that the maps can contribute to our understanding of how novices develop their knowledge base for teaching. In addition, the maps can also provide novices with feedback regarding changes in their understanding.

In an effort to avoid the concerns associated with concept maps and card sort tasks, Gess-Newsome and Lederman (1993) used an open-ended approach to assess the content and stability of 10 preservice biology teachers' knowledge of biology. They asked their subjects to answer the following questions:

1. What topics make up your primary teaching content area? If you were to use these topics to diagram your content area, what would it look like?
2. Have you ever thought about your content area in the way you have been asked to do so above?

Individuals were provided the freedom to select whatever concepts, ideas, etc. that best represented their subject matter area and allowed the freedom to represent the relationship among these ideas in any way that best represented their views. Gess-Newsome and Lederman believed their approach (i.e., pictorial representations) provided a more valid representation of preservice teachers' views on subject matter.

Ten subjects responded to these questions four times: on the first day of their science methods course, five weeks later in the middle of the term, at the end of the ten week term, and four months later during their student teaching experience. Gess-Newsome and Lederman analyzed their data qualitatively: they looked for (a) patterns in the relationships among topics included in each subject's representations and (b) changes in the subjects' representations over time.

Gess-Newsome and Lederman concluded that preservice teachers did not possess a coherent knowledge structure of biology, as their representations reflected a list of college science courses with few connections between listed topics. Of particular interest to the study of pedagogical content knowledge are the changes that Gess-Newsome and Lederman found when they analyzed the fourth set of pictorial representations that were administered during their subjects' student teaching experience. These representations typically included the same biology content from earlier representations, but in addition, subjects included topics related to the teaching of biology (e.g., scientific method, problem solving, history of science). Gess-Newsome and Lederman concluded that their subjects were able to reflect on their understanding of biology by completing the series of pictorial representations. They asserted that these repeated reflections helped the teachers develop a "coherent schema for their subject matter" (p. 23).

Critique of concept mapping, card sort tasks, and pictorial representations

Concept mapping and card sorts have been developed and used primarily as a research tool to study teachers' knowledge and beliefs. Kagan (1990) notes that a major flaw of concept-mapping studies is that researchers typically use them only in short-term studies: researchers have not thus far studied the persistence of desired changes after a course is completed. Kagan suggests that concept maps are best used to measure short-term changes that might ultimately be transient and therefore of little value in understanding pedagogical content knowledge. The same criticism can be levied against both card sorts and pictorial representations.

A second concern with concept mapping and card sorts is the ambiguity surrounding exactly what the resulting map or sort represents. Phillips (1983) and others seriously question the underlying assumption that concept maps and card sorts reflect internal memory structures. Two individuals demonstrating the same performance may possess very different knowledge, organized in different ways. It has yet to be established that a concept map or card sort is a literal representation of how knowledge is stored in memory. Most researchers fail to address this issue directly.

Although concept mapping and card sorts have traditionally been used for research, the work of both Morine-Dershimer (1989) and Gess-Newsome and Lederman (1993) suggests that such representations may prove to be useful tools in teacher education. Morine-Dershimer concluded that concept maps can provide preservice teachers with valuable feedback on their knowledge. Gess-Newsome and Lederman suggest a more direct link, noting that their subjects engaged in focused reflections on their understanding and teaching as a result of developing four pictorial representations over the course of a year.

Multi-method evaluation

Without question, most studies of pedagogical content knowledge employ multiple methods. In general, these studies use a variety of techniques such as interviews, concept maps, and video-prompted recall, to collect data. Next, the researchers triangulate the data from these multiple sources. Finally, the researchers infer a general profile of the teachers' pedagogical content knowledge.

Hashweh (1987) designed a wide array of tasks to evaluate teachers' content knowledge and general pedagogical knowledge. He found that the data he collected also provided insights into pedagogical content knowledge. His initial goal was to evaluate teachers' knowledge of content (biology and physics) and knowledge of learning; however, as he explored these two types of knowledge using a variety of techniques, a third type of knowledge appeared again and again. Hashweh found that as the teachers talked about their subjects and their teaching, they repeatedly introduced content-specific examples.

Hashweh designed tasks to asses teachers' content knowledge, conceptions of learning, instructional planning and view of instruction. He used three tasks to assess teachers' content knowledge. In Task 1 teachers were to provide a summary of a topic. They were then prompted to relate the topic to: (a) other ideas in the discipline, (b) other areas of knowledge and (c) the students' experience. Task 2 involved concept mapping. The teachers were asked to draw a map by connecting 20 terms in their teaching area (i.e., biology or physics) and then explain the connections. For Task 3 the teachers were asked to sort "exam questions" into groups depending on the common ideas or concepts needed to answer the questions. To study the teachers' conceptions of learning, Hashweh conducted a clinical interview focused on the teachers' understanding of teaching for conceptual change. Hashweh examined the teachers' instructional planning by asking them to plan a lesson using a chapter from a science text that he provided. Finally, he asked the teachers to respond to a series of critical episodes (e.g., a student question that might reflect a preconception) to understand their view of instruction.

The data generated by these tasks revealed many aspects of pedagogical content knowledge. For example, when planning a lesson based on a chapter from a textbook, the teachers discussed possible levels of treatment of the topic. In their comments they included analyses of both simple and complex versions of a topic. Their decisions as to which level of a topic to teach were based on their understanding of students.

Hewson and Hewson (1989) examined teachers' conceptions of teaching science. They developed a structured interview that included short, written scenarios designed to represent instances and non-instances of science teaching. The teachers responded in terms of whether or not science teaching was occurring, what else they would need to know to make that judgment, and the reasoning behind their response. The teachers' responses were audio taped and then transcribed.

To analyze the teachers' responses, Hewson and Hewson developed a multi-step process. First, they defined and utilized six coding categories: nature of science, learning, learner characteristics, rationale for instruction, preferred instructional techniques, and conceptions of teaching science. For example, the definition used to code a response "nature of science" was:

> Statement refers to the content to be taught, objective of the teaching; natural phenomena that are investigated; the methods of investigation; explanations in terms of concepts, principles, and theories; the uses to which the knowledge is put, including prediction, application, problem solving, etc. Example: "Much of science consists of classification, putting things in boxes." (p.199)

After coding a transcript from an interview, summary statements were written for each of the six categories. Whenever possible, direct quotes from the transcripts were used. The six categorical summaries were then combined into a global summary for each teacher.

Using this procedure at the beginning and end of a course with 30 preservice teachers, Hewson and Hewson were able to chart changes and consistencies in the teachers' conceptions of teaching science. Eventually, Hewson and Hewson plan to study relationships between the teachers' conceptions of teaching science and their actual classroom instruction.

Smith and Neale (1991) studied teachers' pedagogical content knowledge in the context of an in-service program designed to support "conceptual change not only in teachers' substantive content knowledge, but also in their ideas about teaching science and their knowledge of children's ideas" (p. 186). They built their program around the conceptual change model of instruction, which focuses on common misunderstandings held by students. When applying the conceptual change model, teachers present activities that help students identify, question and begin to resolve inconsistencies in their thinking about scientific ideas. Smith and Neale worked with teachers during a four-week summer workshop and followed them during the school year as well.

To document changes, they videotaped the teachers' instruction before and during the summer workshop, interviewed them, and asked them to write in journals. All three sources of data were carefully analyzed. Videotapes of classroom teaching and audiotapes of interviews were transcribed and then coded by independent raters. The transcripts of the videotapes were analyzed for features of conceptual change teaching: lesson segments, content, teacher role, student role, and activities and materials. For example, they used the following definition to code instances of conceptual change teaching related to content: Content of instruction is organized around significant, general schemes or mental representations that children have about natural phenomena, and toward the development of more powerful, scientifically accurate, conceptual models.

1. Teacher asks for conceptual understanding, rather than just factual procedural knowledge.
2. Teacher's content presentation is accurate.

3. Teacher defines terms and monitors use.
4. Teacher uses examples metaphors and analogies.
5. Teacher's examples metaphors and analogies are conceptually accurate.
6. Teacher's examples metaphors and analogies are developmentally appropriate to children's level.
7. Teacher links conceptual content to children's informal experiences.
8. Teacher links present lesson conceptually to previous lessons (Smith & Neale, 1989, p. 6).

Using their coding categories, Smith and Neale were able to document changes in the teachers' translation of substantive content into classroom teaching -- one aspect of pedagogical content knowledge. They analyzed changes in teachers' (a) knowledge of children's ideas in science, (b) teaching strategies, and (c) use of metaphors, analogies, and examples in lessons.

Smith and Neale analyzed the transcripts of audio taped interviews to document teachers' orientations to science teaching and learning. They coded the transcripts using four different orientations: discovery, processes, didactic/content mastery, and conceptual change. What emerged from Smith and Neale's study was a rich, multifaceted view of teacher knowledge.

Critique of multi-method evaluation

The array of techniques used by Hashweh (1985) provided a rich view of pedagogical content knowledge. His work clearly illustrates the importance of multiple sources of data. If used in isolation, each of his techniques raise methodological questions concerning confirmability and validity. It is only when a variety of data sources are used to build a global profile of a teacher's knowledge that these methodological issues are addressed.

By studying biology as well as physics, he also underlined the importance of pedagogical content knowledge in that the content-specific knowledge of the physics teachers was different from the content-specific knowledge of the biology teachers. For example, the most helpful examples and common stumbling blocks were different for the two disciplines.

Hashweh's analysis of the teachers' concept maps was a departure from traditional concept mapping in that the protocols of the teachers' explanations were the focus of his analysis, rather than the concept maps themselves. Hashweh, along with many others, expressed concern over the assumption that concept maps are isomorphic to internal cognitive representations. He thus eschewed the concept-mapping analysis of links for a protocol analysis in which he developed a coding system to identify teachers' knowledge.

Hashweh's work is problematic in that many of his techniques are extremely cumbersome and difficult to replicate. Both his data collection and analysis are time- and energy-intensive. Hashweh's study highlights the need to make difficult decisions as to which data sources are needed to build a global profile of pedagogical content knowledge.

A serious concern with Hewson and Hewson's interview is that it is time consuming to administer and analyze. Each interview requires 30 to 40 minutes to administer. An audiotape is then transcribed and finally subjected to multi-step coding and summarizing. The purpose for such a labor- and time-intensive process needs to be clear and convincing.

A second concern is that it is not apparent how Hewson and Hewson's interview procedure will bring about change, as they do not take a normative position; they offer no judgments or standards for evaluating teachers. They acknowledge that their work "does not ... stress a particular conception of teaching science, so it is plausible that the major effect of the intervention will be to help people clarify their own existing views, rather than leading to major changes in those views" (p. 207). Again, one's purpose will determine whether or not this is a problem.

Hewson and Hewson's Interview about Instances shows great promise in helping teachers think about and examine their pedagogical content knowledge. By offering multiple specific situations they invite teachers to explore their assumptions about teaching as well as their knowledge of teaching specific topics in science.

Smith and Neale (1989) offer a model for program evaluation. They started with a clear conception of what they meant by good science teaching (i.e., conceptual change model). Working from that model, they then developed techniques to help teachers understand how their knowledge differed from knowledge needed to teach conceptual change. It is critical that Smith and Neale also included classroom observations, as they and the teachers in their project were able to document the impact of the project activities on classroom practice.

Kagan (1990) notes a number of features that she feels contributed to the success Smith and Neale had in relating teachers' performances on questionnaires and experimental tasks to classroom teaching. Most notably, they chose to measure: (a) pedagogical beliefs specific not only to a content field but to certain topics within that field; (b) molar, pervasive pedagogical orientations that affect every aspect of a teacher's classroom practice; (c) a very specific instructional model derived from a large body of theoretical and empirical literature; and (d) relatively long-term change in beliefs. Clearly, the descriptions of the multi-method evaluations suggest that the assessment of pedagogical content knowledge is neither simple nor obvious.

The three types of techniques that have been used to study pedagogical content knowledge were each developed with a particular goal in mind. The multiple choice items of Kromrey and Renfrow (1991) were intended to improve teacher evaluation. Presently, multiple-choice teacher examinations assess content knowledge and knowledge of general pedagogy. Kromrey and Renfrow designed items to evaluate pedagogical content knowledge and, thus, worked to allow teachers to demonstrate a critical and often overlooked aspect of the knowledge needed when teaching.

The concept maps used by Morine-Dershimer (1989) and pictorial representations used by Gess-Newsome and Lederman (1993) were initially used as research tools to explore the knowledge structures of teachers. As discussed earlier, critics have questioned the assumptions underlying concept maps. However, when viewed in the context of staff development, concept maps may prove useful. While completing a series of concept maps, the preservice teachers that Gess-Newsome and Lederman studied reflected on their content knowledge and gradually modified their understanding of biology to include themes and topics that might enrich their teaching. The concept representations functioned as a formative rather than summative assessment.

The multi-method evaluations have addressed a number of goals. Hashweh's (1987) interviews and concept maps were designed to explore pedagogical content knowledge and thus contribute to our understanding of it. Similarly, Hewson and Hewson's (1989) interviews were intended as research tools; however, in the course of their work they found that teachers were influenced by participating in their study. They suggested that many of their techniques might prove useful in the professional development of teachers, providing opportunities for teachers to reflect on their knowledge and practice. Smith and Neale (1989, 1991) developed a variety of techniques to evaluate their program on conceptual change.

DISCUSSION AND IMPLICATIONS

As we have stated, pedagogical content knowledge (PCK) is a highly complex construct that is not easily assessed. By definition, PCK is both an external and internal construct, as it is constituted by what a teacher knows, what a teacher does, and the reasons for the teacher's actions. The challenge for researchers is to design studies that examine all three aspects of PCK. Research that focuses on what a teacher knows can only inform us about teacher understanding of subject matter and pedagogy and how that understanding may be organized. This limited view of PCK results regardless of assessment approach when the focus is solely on knowledge.

The translation of teachers' knowledge into classroom practice is clearly a critical aspect of PCK and obligates us to observe actual teaching segments. Indeed, many believe that teachers' actions are a more accurate representation of teachers' knowledge than the usual array of self-report measures, whether convergent or divergent. However, research that relies primarily on teachers' actions to assess knowledge is also problematic. The low correlations of the process-product research on teaching suggest that myriad factors influence classroom instruction and student understanding (Brophy & Good, 1986). Consequently, the level of consistency between teacher's observed behavior and their knowledge and beliefs is highly variable. Just as a narrow focus on knowledge limits our understanding of PCK, an overemphasis on classroom practice may well present a distorted view of teachers' knowledge.

Teachers' decision making, the third aspect of PCK, is a complex and slippery construct to study. Simply by asking a teacher to state reasons for a particular teaching action, we risk changing the teacher's decision making process. As Kagan (1990) has suggested that many teachers have highly personalized perceptions of teaching that may be extremely difficult to communicate to an educational researcher. When teachers try to articulate the reasoning behind their instructional decisions, they may well tend to construct reasons that will sound "right" or logical to the researcher. The assessment of PCK is difficult and fraught with hazards, as it

requires a combination of approaches so that information can be gathered about what teachers know, what they believe, and the reasons for their actions. Assessment of any component of PCK in isolation of the other two incurs a significant risk of distorted meaning and interpretation. The situation is analogous to ecologists' reductionistic assessment of environmental factors prior to the popularity of systems thinking.

A Methodological Issue

One of the critical assumptions underlying the construct of PCK, that has influenced research, is that teachers' knowledge and beliefs influence classroom practice. Indeed, this assumed relationship between cognition and action has been consistently used to support the importance that many researchers have placed on assessment of teachers' subject matter and pedagogy knowledge structures. It is our contention that the relationship between cognition and action is highly complex and certainly not automatic. This point has significant implications for assessments of PCK that involve classroom observations. Researchers often precede classroom observations with some assessment of teachers' knowledge structures. Then, during observations, evidence of the previously assessed knowledge structures is noted. Such a research approach is subject to an expectancy bias. That is, the researcher is quite likely to see that for which he/she is looking.

Although we are quite aware that total objectivity is unattainable, it is an important ideal in research settings. There are several possible solutions, or at least moves in the right direction, to the problem of expectancy bias is for researchers to make classroom observations without knowledge of teachers' knowledge and beliefs. One approach would be to have different individuals assess teachers' knowledge structures from those completing classroom observations. In such a case, the different sources of data would initially be analyzed independently and then compared for consistency later. A second approach could be used in situations when there is only one researcher. The research could precede classroom observations with some type of paper and pencil assessment that involves no interviews, for it is the interview process that would convey biasing information to the researcher prior to classroom observations. Another approach, if a single researcher is to be involved, would be to withhold all assessments of knowledge structures until after classroom observations have been completed. One significant difference between this approach and the previous option involving only one researcher is the time of assessment. In the previous approach, the assessment is done prior to classroom observations and there is the possibility that the assessment will act as a treatment. In the latter approach, assessments are completed following observations and the possibility of a testing effect is removed. In our opinion, the use of multiple researchers is preferable because it allows the full range of data collection techniques (i.e., interviews as well as paper and pencil assessments) while minimizing expectancy bias. If one wishes to actually assess the amount of expectancy bias, assessment of teachers' knowledge and beliefs could be counterbalanced with classroom observations. It would be interesting to see if there is more consistency between cognition and action when the researcher has knowledge of teachers' knowledge and beliefs prior to classroom observation.

A Final Point and Call for Action

The empirical literature related to PCK is extensive and continues to grow. In the sciences the focus has been on assessments of knowledge structures and the relationships of knowledge structures to classroom practice: the critical relationship between PCK and student understanding has not been studied. In contrast, mathematics researchers have studied the impact of teachers' knowledge and instruction on student understanding (Carpenter, Fennema & Franke, 1996; Grant & Peterson, 1996). The mathematics research has been aided by two important developments: clearly articulated national standards and carefully designed assessments that reflect the national standards. Both goals and assessments are critical to research on PCK that seeks to incorporate student understanding.

The science education community has recently produced national standards that will substantially support efforts to design and implement studies of PCK and student understanding. The publication of national standards offers a clearly defined set of goals for teachers and students of science. These goals for science education create a common language for teachers, researchers, and students. In addition, psychometricians are developing assessments in science that go well beyond paper and pencil tests in reliably and validly measuring student understanding (website: http://www.tappedin.sri.com/pals/index.html). Shavelson and his colleagues have designed performance assessments that are closely linked to national standards and benchmarks (Baxter & Shavelson, 1994; Shavelson, Baxter, & Pine, 1991). In addition, they have translated their findings into manuals for teachers and administrators who are trying to use assessments that reflect the new science standards and benchmarks (Brown & Shavelson, 1996). The PALS website offers performance assessment tasks for many science concepts. By incorporating these types of assessments into studies of PCK, researchers can begin to trace how PCK affects student understanding.

Most likely relationships exist between knowledge structures, classroom practice and student achievement; however, the exact nature of these relationships in the sciences has not yet been investigated. For the PCK line of research to have a significant impact on classroom practice and teacher education the relationships of PCK to student understanding must be better understood. At this point in time, a focus on student achievement in science has been conspicuous in its absence.

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DEBORAH C. SMITH

7. CHANGING OUR TEACHING: THE ROLE OF PEDAGOGICAL CONTENT KNOWLEDGE IN ELEMENTARY SCIENCE

Thinking about and studying the uses of pedagogical content knowledge (abbreviated in this chapter as PCK) in teaching elementary science has been a personal as well as a professional journey for me. I have been monitoring and reflecting on my own teaching with children (Smith, 1993), and thinking about the ways that I re-work my knowledge of science content in order to design activities and respond to children's thinking. At the same time, I have been working with experienced teachers in their classrooms (Beasley, Christensen, Henriksen, Shank & Wesley, 1997; Eberhart, Philhower, Sabatino, Smith & Waterhouse, 1990; Smith & Neale, 1991) and with preservice teachers in science methods courses (Abell & Smith, 1994; D. Smith & C. Anderson, forthcoming; Smith, Levine-Rose, & Conway, 1995). Along with my personal experiences, the latter two situations have provided opportunities for learning about how other teachers, with different backgrounds and repertoires, construct and use PCK for elementary science teaching.

There have been various definitions and discussions of PCK (e.g., Grossman, 1990; McEwan & Bull, 1991; Raths, no date; Shulman, 1986; Strauss, 1993). In this chapter, the meaning of pedagogical content knowledge draws on that work, but is also drawn from my own understanding as it has grown in my teaching and in working with other teachers. First, I use PCK to mean knowledge of examples, analogies, and representations drawn from the scientific content, of two kinds: substantive knowledge and syntactical knowledge. Substantive content knowledge (see Schwab, 1978; Shulman, 1986) refers to the concepts, principles, laws, and models in particular content areas of science. For example, knowledge of particle and wave models of light would be substantive knowledge about light and its behavior. (I have combined what Grossman, Wilson, & Shulman, 1989, have called content knowledge and substantive structures, in this category.) Syntactical content knowledge refers to the agreements, norms, paradigms, and ways of establishing new knowledge that scientists in areas of science hold as currently acceptable. Kuhn's (1978) description of changing paradigms in the history of science is an example of syntactical knowledge.

Pedagogical content knowledge about teaching both substantive and syntactical aspects of scientific content is important for elementary teachers. For example, when teaching children about light and shadows, I may know about specific interesting shadows that pose central conceptual problems for children's explanations; I think of this kind of knowledge as substantive examples in the content. Or, I may know stories about important methodological issues in the history of this content area, for example, accepted ways of detecting and recording the presence of light. I think of this kind of knowledge as syntactical examples in the content area. I think of these kinds of knowledge as PCK and not pure content knowledge, because the examples are selected with a pedagogical purpose in mind.

A second aspect of PCK for me includes knowledge about how to design my teaching and classroom activities so as to facilitate children's understanding of that scientific topic. This category includes knowledge of children's naive explanations about light and shadows (e.g., DeVries, 1986; Guesne, 1995) as well as their ideas about the nature of scientific work (Driver, Leach, Millar & Scott, 1996; Varelas, 1996). Also included are knowledge of teaching strategies and curriculum materials and activities that work especially well in provoking change in children's ideas (e.g., Eberhart, Philhower, Sabatino, Smith & Waterhouse, 1990), and knowledge of ways to raise important methodological questions about recording the presence of light (see Figure 1).

As Figure 1 suggests, there are many connections and interactions among these different kinds of PCK. Knowledge about one kind of interesting shadow -- for example, shadows made by spoons with holes in them (PCK of examples from the substantive content) -- can suggest a curriculum activity (PCK of curriculum and materials) that is especially useful for children at a specific place in their development of understanding, e.g., those who are thinking of light as hanging in the air (PCK about children's naive ideas). Within that activity, there may be some teacher questions that are especially critical in provoking children's thinking about light traveling (PCK about effective teaching strategies) -- for example: What is this bright spot in the shadow? How did that get there? Why isn't this shadow all dark like the others? How could we make that bright spot go away? How could we make a bright spot in this shadow that's all dark? What could we do? Why would that work?

That activity may also present interesting syntactical issues, such as discrepancies in representations of the same event. For example, how do we represent a bright spot in the middle of a dark shadow? Draw around it? Color in the rest of the shadow? Does Jan's representation mean the same as Curtis'? Another use of the activity might be to focus on acceptable ways of argumentation about evidence and theories in science, another more general syntactical issue (e.g., Latour & Woolgar, 1979).

In this chapter, I describe and discuss examples of PCK under construction and in use in planning and teaching elementary science. I describe some ways in which PCK contributes to more effective science teaching and some barriers to its successful use in elementary science lessons in classrooms. Then, I raise some issues about related content-specific teacher knowledge. Finally, I consider some areas in which we need further research.

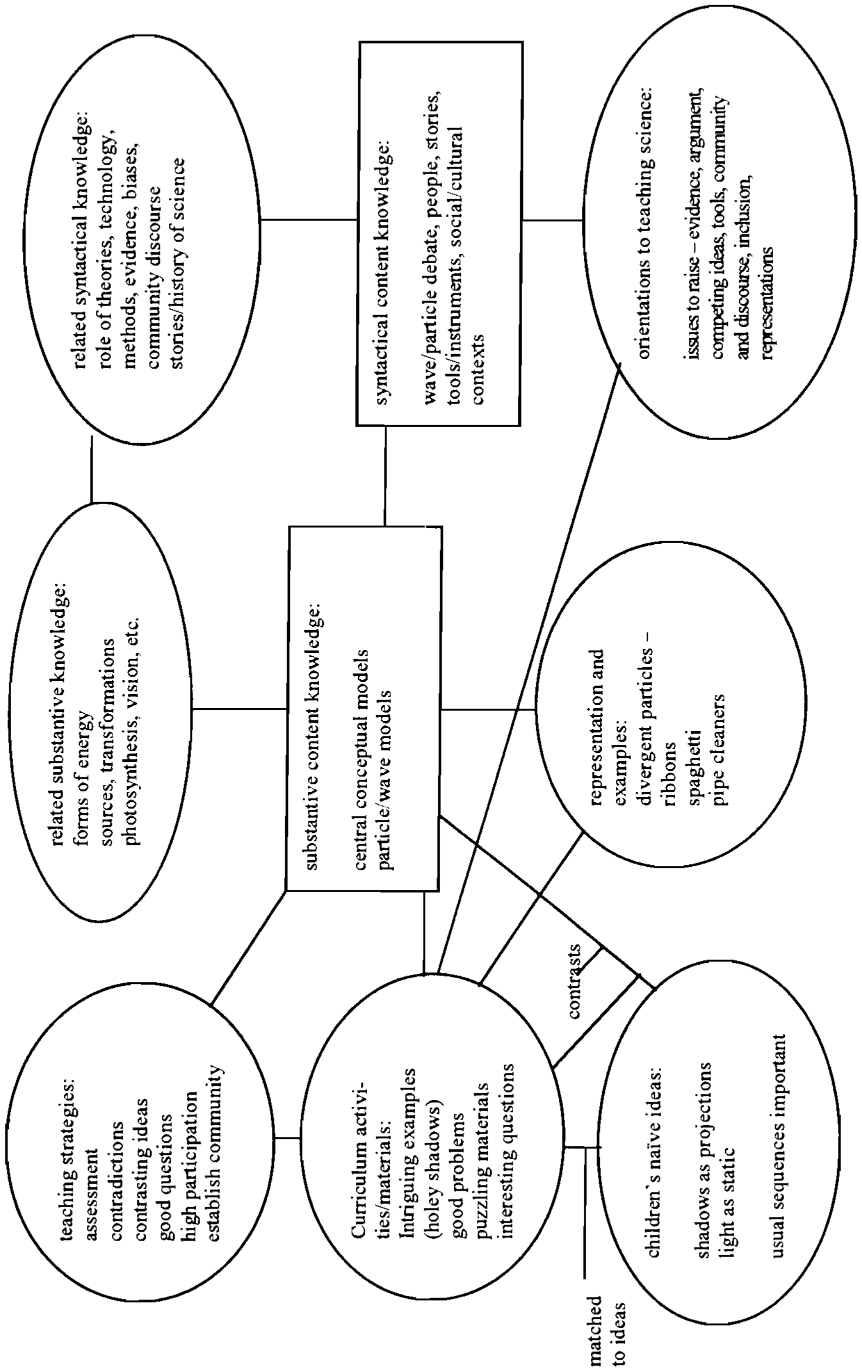

Figure 1

CONSTRUCTING AND USING PCK AS A RESEARCHER/TEACHER

Substantive Aspects of PCK for Elementary Science

I have been fortunate to have had the opportunity and the colleagues for studying my teaching with children. As a preschool and elementary teacher, I had done many science investigations with children in my classes, but with the usual limitations on my time for reflecting on and documenting what happened with children. In 1984, I began teaching science regularly to classes of elementary children from schools surrounding the University of Delaware, in a classroom at the Curriculum Development Laboratory (CDL). The CDL was housed first in the College of Education and later in a local public school classroom. The main idea behind the CDL was to take the recent studies of children's naive ideas in science (e.g., Driver, Guesne, & Tiberghien, 1985) and of classroom teaching aimed at learning with understanding (e.g., Anderson & Smith, 1985; Driver, Asoko, Leach, Mortimer & Scott, 1994), and to explore, with the collaboration of local teachers, how those ideas might work in practice in the primary grades.

Working with the teachers from one local public elementary school each year, we used the CDL classroom as a place to ask questions about how children thought about and came to understand important ideas in science. It was a place to design and try out activities and teaching strategies that might facilitate children's construction of understanding. It was also a place to talk about what we and the children were learning and what it meant for our teaching. Each class teacher worked with us for about four weeks and received release time for planning together, discussing the results of interviews with children, and debriefing about the teaching and learning in the classroom. In the classroom, the class teacher and I switched the roles of lead teacher and coach in the middle of the two-week unit (see Smith, 1992 for further details).

For me, the CDL classroom provided a place to think hard about what I planned and did with children, and how their learning and understanding changed over time. I had been thinking about the various roles that teachers' content knowledge played in elementary science teaching after reading Buchmann's (1983) thoughtful piece on that topic. But I didn't yet have a framework for making sense of the different kinds of knowledge I was finding useful in my own teaching.

As a graduate student, I found Andy Anderson and Ed Smith's (1983) work on teaching strategies for conceptual change and the Posner, Strike, Hewson and Gertzog (1982) framework for thinking about conceptual change in central ideas in the history of science. That work suggested some teaching strategies to try and we began exploring them in the CDL classroom. I began learning about what I later came to understand as pedagogical content knowledge.

At the start of my work in the CDL, I already had quite a bit of the aspect of PCK that Shulman (1986, p. 9) calls " 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." I had known about children's naive ideas about various natural phenomena from studying Piaget's work (e.g., Piaget, 1930) and from interviewing children while studying with Maurice Belanger, during my MAT work.

But my repertoire of teaching strategies (another aspect of pedagogical knowledge for teaching content, Shulman, 1986) was fairly limited. In my early teaching, like many other elementary teachers (e.g., Anderson & Smith, 1985; Smith & Neale, 1991), I had relied on a combination of "discovery" and "activities" orientations to teaching children science. I provided interesting activities and materials that I thought "showed" children clearly the correct scientific explanation for particular content areas. I listened carefully to children's ideas and talked with them about what they tried with the materials and what happened. And I was often frustrated when children didn't seem to "discover" what I had intended, in spite of my best efforts and materials.

With the recent studies in mind, I began my efforts at "teaching for conceptual change" in the CDL classroom. Looking back, it appears to me that I started out with a novice-like rule (Berliner, 1988) for change in children's ideas, somewhat along the lines of: "If you contradict them, they will change." So, in our lessons, I asked children to make predictions about the outcome of some action. Then we tried it, found that our predictions hadn't worked, and tried to figure out why.

This was an interesting interaction of the syntactical and substantive aspects of PCK. In some sense, I "knew" that explanations and their construction and revision were at the heart of conceptual change, both historically and developmentally in science. Yet, there was something about making the transition from other ways of teaching to these new ways that initially worked against taking the time for children's detailed explanations of their predictions during lessons. (This is also a pattern in other teachers' transitions, e.g., Smith, 1989.) I believe this was because my own conception of the role of explanatory frameworks in the interpretation of evidence (in this case "contradictory" evidence that children didn't always interpret as contradictory for their theories) was fairly novice-like, at the time.

For example, one of the children in a first grade class, Saul, had been able to predict the location of a shadow consistently in several lessons, and I had decided that he must have constructed accurately an idea of the role of light and its blockage in the formation of shadows. As his teacher, I thought to myself, "He's got it!" In the next lesson, my methods student took over the lessons and in her best constructivist style, asked each child what he/she now thought a shadow was. Saul replied, "It's black stuff that comes out of you from somewhere!" It turned out that his personal theory, which had resulted in accurate predictions so far, was that the light (or sun) pushed the black stuff out of you – thus the shadow was always opposite to the source of light and had the shape of whatever side of the object the sun was pushing on.

This episode (and others like it) provoked change in my own PCK in several ways. First, my repertoire of teaching strategies was modified to include asking children not only to predict what would happen, but also to explain to the rest of the class why they thought that. My own conception of how change would occur in children's ideas and, therefore, what I needed to know in order to help children change their ideas had undergone change itself. Knowing what children predicted was insufficient; I also needed to know why they thought that way. Asking for explanations enabled me to understand the current theory that each child held, enabled the child to formulate his/her thinking in words and consider what it was that she/he really meant, and enabled the other children to hear different ways of thinking about the same event, so that they could evaluate those viewpoints in comparison to their own. So, first, I had learned that I needed to ask for children's explanations, and why that was important.

Second, the act of including the request for explanations meant that my own questioning skills now had to be much more finely tuned. Clarifying children's predictions was fairly straightforward -- there would either be a shadow or not; it would be here or there; it would be round or square. But asking why the shadow would be here and not there opened up all the various models that children were using, from sun bouncing off objects to make the shadow, to black stuff being pushed out, to dark reflections. So, I needed to ask questions like, How did that happen? What made you think that? Why would it work at home but not here? Where did the black stuff come from? Did it weigh anything? Did you lose weight when it oozed out? All of these questions were now constructed and added to my content-specific pedagogical repertoire of questions for helping primary children learn about light and shadows. As a second change in my PCK, I had learned how to find out about children's explanations.

Third, understanding children's theories also provoked the design of different activities than we had planned previously. We had known about and planned for several common naive ideas about light and shadows (DeVries, 1986). For example, we knew that children often thought shadows were projections from their bodies, or were reflections from the sun bouncing off their bodies. But we were encountering new and creative variations that weren't addressed in the activities we had planned. So, we tried wrapping arms in plastic to see if that would prevent the "black stuff" from being pushed out. We tried weighing objects and their shadows to see if objects lost weight when the shadow showed up. A third aspect of my PCK was broadened to include a range of new curriculum activities for use in responding to children's explanations.

Finally, my own knowledge about and representation of common ideas children had about light and shadows became more detailed and ordered. The projection idea had several variations, such as Saul's, and so did the reflection idea. Over time, we found that the projection idea usually preceded the reflection explanation in a child's thinking. In fact, the move to a reflection model turned out to be a significant marker in a child's progress, because it meant he/she was considering the light and its action in relation to the object and the shadow. Thus, the reflection model was also "wrong," in terms of the scientific explanation, but in a "better" way, i.e., in the direction of a more sophisticated theory. My previously unordered list of common naive ideas about light and shadows now had the beginnings of a sequence, and several variations branching off each item. So, as a fourth change in my PCK, I had learned something about the usual sequences of ideas that children held, as they moved towards more sophisticated scientific understanding.

In describing this event, and how it provoked changes in my own PCK for teaching primary children about light and shadows, my purpose has been to show how the PCK one brings to a lesson, from whatever sources -- research on children's naive ideas, available curriculum activities, established teaching strategies -- is framed within assumptions about how teaching and learning occur in classroom lessons and is always being broadened, deepened, reorganized, and newly constructed. I have discussed these aspects primarily within the category of PCK concerned with what Shulman (1986; Schwab, 1978) calls substantive content knowledge. Next, I turn to issues of PCK within syntactical knowledge, not because these reside in two different places and are unconnected to each other, but simply for ease of discussion. Frameworks about teaching and learning science content are inextricably interwoven with frameworks about the nature of science itself (Tobin, Tippins, & Gallard, 1994).

Syntactical Aspects of PCK for Elementary Science

When I first began exploring "teaching for conceptual change," my own view of the nature of the scientific enterprise and how it might be represented in the classroom with children was focused on individual theory change and the role that contradictory evidence played in that change (e.g., Piaget, 1980). In my lessons, I asked questions of individual children, and tried to adapt my questions and suggestions to each child's personal theory, in a sort of tutorial. Although children worked in small groups to investigate their ideas, and talked as they worked, I saw my questions and the contradictory evidence of their activities as the primary source of change in their thinking. When that didn't work, I tried to think of additional activities and evidence that might be more compelling.

Teachers' conceptions of the nature of science carry with them assumptions about teaching and learning science, with implications for teachers' roles and the kinds of knowledge needed for teaching science (see Abell & Smith, 1994; Grossman, 1990; Lederman, 1992; Smith & Neale, 1991). For example, if scientific knowledge is "discovered" in the natural world, because it exists independently of human perception and interpretation, and is self-evident to all who observe the same phenomenon, then teachers need to provide activities that make discovery of such knowledge available for children. Because the knowledge is self-evident and inherent in the activity, teachers need not understand the content deeply themselves, nor do they need to know about children's own theories. Also, because the knowledge is self-evident in the observations of natural phenomena, the teacher need not consider how to have children share their ideas and evidence from the activities, except for making sure every child gets a turn and feels included in the class discussion.

However, if humans bring their own prior frameworks to the perception and interpretation of phenomena, and can disagree about the meaning and the explanation of observations, then teachers need different kinds of knowledge for teaching science with children. In Saul's case, I needed to know why he thought the shadow was black stuff that came out of you, so that I could think about what activities and evidence would provoke change in his thinking. Clearly, he was interpreting his observations of the same phenomenon in a different way than I had thought. In order to design those activities, I needed a robust understanding of the scientific explanations for light and shadows, so that I could choose among contrasting cases and examples, in order to highlight the discrepancies in his model (e.g., White, 1993).

But substantive knowledge and substantive PCK were not enough. If not everyone agreed about the interpretation of evidence, then, as a teacher, I needed knowledge of how to encourage the interplay of ideas and evidence in a social community, so that children could listen to each others' ideas and make progress in reaching agreement about the usefulness of different explanations (e.g., Driver et al., 1996; Lemke, 1990; Rosebery, Warren & Conant, 1990).

Gradually, through my own reading about the history and philosophy of science, attending the first conference on the History and Philosophy of Science and Science Teaching (Herget, 1989), reading studies describing the social interplay of ideas and discourse in classrooms (e.g., Ball, 1990; Cobb & Bauersfeld, 1995; Gallas, 1995), and talks with my colleagues, I came to see my lessons in a different way. I began to think more about establishing an arena for the class to engage with each other -- not just with me -- in talking about and investigating theories and evidence. Children's ideas and theories about events became public property -- considered by everyone, the evidence evaluated by everyone, questions raised by everyone, including myself (Chinn & Brewer, 1993; Pea, 1993). As Meichtry (1992, 1993) suggests, elementary children's understanding of the nature of science is a place where we need more attention and research (e.g., Carey & Smith, 1993; Songer & Linn, 1991; Schauble, Klopfer, & Raghavan, 1991). Teachers' knowledge about children's ideas in this syntactical area, and about ways to help them construct more sophisticated understandings of the nature of science, is an additional kind of PCK for teaching science.

Just as I had learned to recognize children's naive ideas in lessons and make strategic decisions about how to respond, I also began to recognize opportunities during lessons when syntactical issues could be raised and considered. For example, children in a second grade class were tracing and measuring the sizes of circles of light that appeared on a surface as they moved a shaded desk lamp closer or farther away from the wall. All the groups except one brought back results that were similar -- the diameter of the circle of light increased as the lamp was moved further away from the surface. Tena's group, however, presented results that were unusual. In their tracings, the diameter of the traced circles got bigger, then smaller, then bigger again.

In the class meeting, I asked the children if these results could also be possible. Could seven groups have similar patterns in their results, and another group get different results, yet all be "true?" The children were clear and quick in their responses -- something must be going wrong; these tracings should not be that different. So, we turned our attention to possible causes for the results. Children suggested the following possibilities: 1) the group was sloppy and didn't measure accurately; 2) they didn't really move the lamp and trace the circles of light -- they just drew whatever they wanted; 3) they got confused and made a mistake in labeling the corresponding circles and distances; and 4) they moved two things at once, the light and the distance. With these possibilities in mind, Tena's group went back to check their results and report to us.

The consideration of anomalous data and the search for alternative explanations for, and especially for possible errors in, results is a central problem in science (Chinn & Brewer, 1993). In this case, children revealed their expectations that results should be consistent across replications by different groups of investigators, and generated fairly sophisticated possibilities for the anomalous results. Yet, we as teachers rarely take the time to engage children in discussions about these syntactical norms for scientific work and to emphasize them, even in lessons designed to teach children about the nature of science (Meichtry, 1992, 1993).

There are several possible reasons for this. We may be focused on "covering" the substantive content and fail to consider the syntactical aspects of the lessons we do with children. Our own knowledge of the nature of scientific work may be incomplete (e.g., Lederman, 1995). We may know about current views of the nature of science, but value other aspects of classroom life (e.g., Lederman, 1994). Or, the demands of managing classroom discussions about disagreements, evidence, and differing theories may exceed what teachers feel they can tolerate (e.g., Smith & Sendelbach, 1982).

My decision to spend class time on this discussion arose from my own changing understanding of the nature of scientific work. Because of that discussion, I now have in my PCK repertoire the awareness to plan for activities that will also facilitate syntactical understanding with children. Sometimes these activities generate data that don't match and raise issues like: how much of a difference is acceptable among groups, when do we need to search for sources of error, and what is the role of the community in monitoring and providing feedback to investigators. These opportunities for learning the syntactical aspects of the content of science in classrooms often remain accidental or hidden in the curriculum, instead of explicit and planned.

Summary

In this section, I have described some examples of the ways that my own PCK -- of both the substantive and the syntactical aspects of science -- has changed and grown in my science teaching with elementary children. The PCK I've constructed about teaching light and shadows depends on and is derived from my own substantive and syntactical content knowledge. It is shaped and informed in classroom contexts, connected to particular naive explanations that children hold, and adapted to different developmental levels. It functions to meet changing goals.

In the next section, I describe my work with experienced teachers, their construction of PCK for teaching science, and the changes in their teaching that resulted.

WORKING ON PCK WITH EXPERIENCED TEACHERS

Knowledge about Teaching Substantive Content: Children's Ideas

In thinking about the changes I had made in my own teaching, there seemed to be several important factors -- knowledge about children's ideas that they brought with them to lessons, so that I could predict likely responses and plan for them; about teaching strategies that appeared to help children consider alternative views; about the design of classroom activities that enabled children to act on materials to produce contradictory effects, so they could control the investigation of their ideas; about ways to establish a community of validators in which ideas and evidence were interpreted and validated; and about related materials, such as children's storybooks and puzzles, that were relevant to the topic at hand. In my work with teachers over the last ten years, much of what we have done together in different topics and at different grade levels has been the investigation and construction of these kinds of PCK (Beasley et al., 1997).

Elementary teachers (as well as teachers at other grade levels, e.g., Berg & Brouwer, 1991; Hashweh, 1985; Sanders, 1993) rarely know about children's naive ideas in different areas of science (e.g., Smith, 1987). Teachers often hold orientations to the teaching and learning of science that focus on children's discovery and excitement in science lessons, or on following the steps of the "scientific method" (Anderson & Smith, 1985). Given those goals, teachers often don't ask the kinds of questions that would reveal the alternative conceptions that students hold. Often, it has only been after the initial construction of PCK about children's alternative frameworks and their persistence after science lessons as commonly taught, that teachers have had a reason to think that they needed to change their teaching. When I am working with teachers, we often start by interviewing children ourselves (see Bell, Osborne & Tasker, 1985), or watching videotapes of interviews, or viewing videotapes like "The Private Universe" (Schneps, 1989), or reading a short article describing children's ideas in a content area of interest to us. It is the firsthand evidence of children's own strongly held beliefs that makes an impact on elementary teachers, for two reasons.

First, lower elementary teachers often see themselves as more "child-centered" than upper grade level teachers (Book & Freeman, 1986). They see themselves as nurturing children's self-esteem and creativity, and encouraging children's expression of their ideas. So, knowing about and encouraging children to talk about their own ideas is a valued part of teaching.

Second, our discussion of children's ideas and their difficulties in understanding scientific views of natural phenomena, often provides teachers with an understanding of why they often came and went in science courses, and never felt they understood. Many elementary teachers lack confidence about their science content knowledge and about teaching science (e.g., Schmidt & Buchmann, 1983; Smith & Neale, 1987; Weiss, 1985). They often bring their own naive ideas about scientific content to their teaching with children (Smith & Neale, 1991). Putting their own histories of problems in learning science into the context of the international research on students' difficulties in understanding science (e.g., Driver, Guesne & Tilberghien, 1985; Tobias, 1990) is a source of relief and hope.

In focusing on children's thinking in our work with elementary teachers (see Neale, Smith & Johnson, 1990; Smith & Neale, 1991; Smith, 1992, for details), we look for ways to establish safety for exploring ideas and trust in others in the group, so that -- as adults -- teachers can re-kindle their curiosity about natural phenomena and ways to explain them. For example, teachers often think that they need to know the correct science content so that they can tell or show children the "right" answers. In the process of exploring children's ideas and their own, and coming to learn and understand something deeply themselves, teachers begin to think of learning and knowledge in different ways (e.g., Schommer, 1994). For example, one group of experienced elementary teachers reported that the biggest change in their teaching involved learning to listen carefully to children's ideas (Smith & Neale, 1991; see also Fennema, Franke, Carpenter & Carey, 1993; Simon & Schifter, 1991). This new view of science learning (as Richardson and her colleagues, 1991, have also found in reading), leads to the search for "What can we do now that we know this?" -- and the beginning of construction of another aspect of PCK, the particular teaching strategies that facilitate children's understanding of a scientific concept/model.

Knowledge about Teaching Substantive Content: Effective Teaching Strategies

For many teachers, the constructivist teaching strategies recommended in science education reform documents (e.g., Rutherford & Ahlgren, 1990; National Research Council, 1995) are very different from anything they themselves have experienced as learners, or have currently available in their teaching repertoires (Anderson & Smith, 1985; Duschl, personal communication, 1994; Smith & Neale, 1991; White, 1993). Teachers often ask me when we co-teach, "How do you know how to ask those questions?" -- referring to diagnostic questions that ask children to predict and explain some event. When teachers have a clear scheme for the continuum of children's ideas in learning about some topic in science, then they can plan for "those questions" and also recognize opportunities, while teaching, for responding to children's ideas in ways that provoke children's thinking.

For example, Nan, a third-grade teacher, knew the common naive ideas that children hold about light and shadows, and had planned her first lesson to evoke children's ideas (see Smith, 1989, for a detailed description). However, she was sure that because she had third graders, and several "gifted" children in her class, she would not encounter the "projection" model (DeVries, 1986), in which children think the shadow emanates from the front of the body. Thus, she had not planned any activity that would address or contradict that idea.

During her first lesson, Nan asked different children to predict where her own shadow would be, when she turned on a shaded light that was facing her. Jerry said it would be in front of Nan, towards the light source. Nan recognized this as possible evidence for a projection model of shadows, and revised her plans to allow for discussion and testing of Jerry's idea. Her comments while watching the videotape of this lesson reveal her PCK of children's ideas and its use in selecting teaching strategies during lessons.

> Jerry said, as soon as Jerry hit me with that, I said, this is a classic, you know, my shadow's always in front of me, so I said okay, I'll have to deal with this now, ... so I jumped on that to try and see if we could present graphically for him that that wasn't the way it was, that's why I had him come up and start standing there, and put the light in different places and everything, to see if, to let him see that it wasn't always going to be in front of him. (stimulated recall, 2/9/87, pp. 29-30)

Nan's PCK of teaching strategies for addressing children's different naive ideas enabled her to generate a way to test Jerry's idea, provide anomalous data about it (e.g., Anderson & Smith, 1983; Chinn & Brewer, 1993), and encourage a discussion about why the prediction didn't work. She had Jerry come up and make the shadow with his own body, with the light pointing at his face. When the light was first turned on, Jerry looked directly in front of him for his shadow (as did several other children). Then he turned around and noticed his shadow on the chalkboard behind him. He was puzzled and turned several times in the light, to see if the shadow would move around to the front, where he had predicted it would be. Nan then asked Jerry and the class for their ideas about why the shadow was on the chalkboard and not on the desk in front of Jerry. As a result, Jerry heard other children talk about the position of the light and its direction, and began to think about where the light was in relation to the shadow.

In the next day's lesson, with a different object and arrangement of the light, another child predicted that a shadow would appear in front of the object, again towards the light. Jerry immediately objected, "No, that won't work. You have to make the light point that way (pointing in the direction where the other child had predicted a shadow)!" Jerry had already made progress in his thinking about the relationships among the light source, object, and shadow, and was paying attention to the location and direction of the light, a significant step forward (DeVries, 1986).

In this example, we see how a teacher's newly constructed PCK -- about children's ideas and about teaching strategies -- enabled her not only to plan for, but also to recognize, and generate strategies for addressing, children's common ideas about this content area, while engaged in teaching.

The construction of this PCK about new teaching strategies was not easy for Nan or other teachers working with us. Changes in ideas and familiar ways of teaching are often unsettling and even frightening (Wandersee, Mintzes, & Novak, 1994). These changes are also not necessarily a first choice for teachers (see Berg & Brouwer, 1991). Nan reported that she had to monitor carefully as she taught, so that her old routines and teaching strategies did not intrude (Borko & Putnam, 1996). Some of her new teaching strategies were blends of old and new (Smith, 1989). Other teachers resorted to props like taping a card with the prompt, "Ask why!" to the sides of furniture in the room. But, once teachers saw how children responded and learned when the teachers tried out the new teaching strategies, they

reported that "I could never go back" to their old ways of teaching (Beasley, et al., 1997; Neale, Smith, & Johnson, 1990).

Knowledge of children's naive ideas and of new teaching strategies is, however, insufficient for changing what happens in classroom science. What teachers plan for and offer to children -- the curriculum materials and activities that Shulman (1986) calls the "materia medica" of teaching -- also changes. In the next section, I describe some examples of the construction of PCK for designing, selecting, evaluating and modifying curricular materials and representations of content.

Knowledge about Teaching Substantive Content: Curriculum Sequences, Materials and Representations

As Ed Smith and his colleagues suggest (E. Smith, Blakeslee, & Anderson, 1993), scaffolding teachers in changing their practice requires new curriculum materials, as well as other kinds of support. While some materials that address children's ideas are becoming available (e.g., Roth, 1987; Berkheimer, Anderson, Lee & Blakeslee, 1988), teachers who want to teach in constructivist ways often face the time-consuming (if not impossible) task of inventing the curriculum they need from scratch and throwing out or drastically revising familiar materials in their repertoires (Abell & Roth, 1994). As Nan remarked at one point in our work together,

> Then there will be the problem of either trying to do this with other areas of science throughout the year, and going crazy trying to keep up with the work, or teaching science the way we used to and having more time, but knowing that we are doing many of the wrong things as cited in the research. Aargh! (Log, 7/86, p 13).

In our work with teachers, we used grant money to provide them with release time for designing, trying out, and critiquing new curriculum materials and activities that were built around the naive ideas held by children in their classes. Building this knowledge of particular materials and activities that work well for helping children learn with understanding is an essential core in teaching science in new ways. For example, knowing that working with objects with holes in them almost always raises central questions for children about light going through things, is useful knowledge in teaching about light and shadows with children. It is information that we stumbled on while making "fooler" shadows with children (see Eberhart, Philhower, Sabatino, Smith, & Waterhouse, 1990).

For "fooler" shadows, children try to turn the object so that it makes a shadow that doesn't look like the object. Then, they present tracings of the shadows to the whole class and see if they can fool the other children. Some of the objects we had gathered from around the room and placed in the baskets for the small groups to use happened to have holes in them. Children's surprise at the resulting holes in the shadows and their discussion of possible reasons for those holes -- including their first comments about light "going through" the holes -- led us to include "holey" shadows in the unit from then on.

This PCK of materials and activities draws on and interacts with two other kinds of teachers' PCK. Their knowledge of children's naive ideas -- e.g., knowing that children often think of light as static (Guesne, 1985) -- leads to the decision to focus on the important idea that light moves. Their knowledge of the kinds of teaching strategies that promote change in those ideas -- e.g., knowing that providing discrepant evidence often provokes re-consideration of prior ideas -- leads to the search for activities that provide puzzling results and provoke children's thinking.

Similarly, a teacher's plans for the sequence of curricular activities in a unit draw on PCK about children's ideas and PCK about the kinds of materials and activities needed. In Nan's unit for her third-grade class, she had initially planned for a number of activities that would help children notice the path of light and construct the idea of light traveling. She also knew that when children do begin to think of light as traveling, they often have the idea that light travels in a straight "tunnel" (i.e., a beam of constant diameter) from the source, instead of diverging in all directions from the source (Guesne, 1985). So, she had planned activities to help the children notice the divergence of light for later in the unit, after children had constructed the idea of light traveling. Then, she had planned to have children make "monster shadows" -- the biggest shadows they could make of an object -- and see if they could use their new knowledge of the divergence of light to explain why the shadows got bigger and smaller as they moved the light towards the object or away from it.

In the first lesson, described earlier, Ronna noticed that Nan's shadow was bigger than her body was and commented on the size change. Nan thanked her for sharing what she had noticed with the class, but -- contrary to her response to Jerry's prediction -- decided not to follow it up with discussion of why the shadow had changed size. She asked Ronna to remind her to come back to that idea later in the unit, and promised that they would explore shadow sizes. After the lesson, she explained why she had made that decision.

I think once we do the things with putting the hands around the light and moving back (another planned activity), and do the thing with the pinhole and how much light is on the screen, we will start to see more about the spreading (of light) and maybe we can come back and do the shadow thing and get the idea that it is getting larger because of that... (stimulated recall, 2/12/87, p. 4)

We can see how Nan's knowledge of children's ideas and their usual development, and of the materials and activities she has designed to respond to those ideas, influences the sequence of lessons, as well as her decisions about what to follow up and what to leave for a later lesson, while teaching (Borko & Putnam, 1996).

Interactions among kinds of Pedagogical Content Knowledge: Syntactical and Substantive PCK at work

As I have suggested earlier, different aspects of teachers' pedagogical content knowledge for teaching particular science topics are not isolated, but rather connected to and interactive with other knowledge. In the following example, I first discuss how knowledge about children's ideas can be used to critique curricular representations and materials, and then how the resulting changes in the design of activities and materials can play syntactical roles in classroom lessons as well.

Karen, another third-grade teacher, used her knowledge about children's usual naive ideas to critique a representation I had used in one lesson. In this class, children had been playing with flashlights and looking for the light all over the room. As they talked about what they had done, they described the light as "going" over to the wall, or "starting" in the coat closet. In an attempt to represent this movement so that we could talk about it, I asked several children to be the light and show us where the light had "started" and "gone." As children walked forward across the center of the classroom meeting circle, I unrolled yellow ribbons behind them to mark their paths. The children walked in straight lines and parallel to each other across the room, and the ribbons represented that movement. Then the children discussed whether this model seemed to account for what they were finding out with their flashlights.

After the lesson, Karen came up to me and commented, "Aren't you worried that the straight paths of the ribbons will just reinforce any "tunnel" conceptions about how light travels?" Karen was aware that children commonly believe that light travels straight ahead from the source, in a tunnel with the same diameter at every distance (instead of diverging in all directions from the source -- see Guesne, 1985). She also had constructed for herself a more scientific model of light diverging from the source in all directions. So, she was able to point out the dangers in what I had done. As a result, we raised the issue with the children and asked them to critique "my" model and propose others. Over the next two and a half weeks, as we worked on different activities and investigated how light and shadows behaved, children proposed several other models, represented them with ribbons on paper and hung them around the room. We returned to them time and time again, to see if the different models were successful in explaining our results.

In the last week with Karen's class, children had traced the sizes of the circles of light found on a surface, as a shaded light was moved closer or farther away. Karen and I had not expected the children to be able to get as far as a 3-D model, so we had continued to use the 2-D models the children had suggested. But Kareem, who had worked very hard to understand what was going on, raised an objection. He didn't think the 2-D model that most of the class agreed worked best (a flat model in which ribbons traveled outward like a fan from the source), could account for the circles of light we had traced. I tried to clarify what Kareem meant, but most of the class and the teachers were puzzled. Then, Crystal said, "Oh, I see -- you mean it has to be like an ice cream cone!"

Crystal had recognized that the tracings, which enabled everyone to see the results that the different groups had presented, showed that the light arrived at the surface in a round shape, contrary to what the current models predicted (because they were flat, 2-D models, they predicted that the light would show up on the paper as a flat line). She had constructed, in her head, a model that would account for those tracings -- a cone of light coming from the shaded light source and making round circles of light on the surface. That evening, Karen and I sat in the classroom, trying to figure out how to attach ribbons to a hula hoop, to make a model of Crystal's idea of the light making a cone. Just as Ball (1990) describes ways of representing mathematical ideas with children, we were seeking ways of representing Crystal's scientific ideas for the class.

Karen's critique, and our subsequent design of ways to represent and consider alternative models and their adequacy, also provided opportunities for children to participate in an important syntactical construction in science -- the building, testing and revising of models (e.g., Carey & Smith, 1993; Grosslight, Unger, Jay & Smith, 1991) -- in addition to making substantive progress in constructing a workable conceptual model of light. Over the next two weeks, children became more and more comfortable asking questions about other children's models, offering comments and counter-evidence, and pointing out problems with both my model of light and children's models. For a short time, they became members of a community of investigators, and shared in the kind of discourse that characterizes the larger scientific community (e.g., Gallas, 1995; Lemke, 1990: Rosebery, Warren & Conant, 1990). It is this kind of specific, content-focused pedagogical knowledge -- of both substantive and syntactical aspects of the content -- that appears to make a critical difference in the opportunities that are provided for children and their consequent progress in understanding science.

This interweaving of PCK about ways to represent the syntactical nature of scientific investigations in classrooms is an aspect of the construction of knowledge for teaching science in new ways that deserves much more attention (Duschl, 1994). Teachers' orientations to teaching and learning science, and to the nature of science, have been documented at several grade levels (e.g., C. Anderson & E. Smith, 1985; Lederman, 1992; D. Smith & C. Anderson, forthcoming; D. Smith & Neale, 1991; see also Grossman, 1990). However, the process of coming to understand a different way of thinking about science, then of translating that new understanding into classroom discourse and opportunities, and of documenting what happens with children's understanding of both the substantive and syntactical content of science, has not been well studied (Grossman, 1990; Lederman, Gess-Newsome, & Latz, 1994).

Summary

In this section, I have described some of the ways that experienced teachers have constructed and used substantive PCK about content examples, about children's ideas in science, about teaching strategies that facilitate children's progress in their understanding, and about curriculum materials and representations that enable children to engage with important ideas. I have also described some ways in which PCK about syntactical aspects of science can be embedded in classroom events, and the need for further attention to this area.

As I watched these experienced teachers constructing and using PCK in changing their teaching, and observed what happened with the children in their classrooms, I found myself wondering what was possible with preservice teachers, in terms of

coming to appreciate and construct PCK for teaching science. Since then, I've had several opportunities to try out these ideas with preservice elementary teacher education students. In the next section, I describe and discuss some preliminary work with novice teachers along these same lines.

WORKING ON PCK FOR ELEMENTARY SCIENCE WITH NOVICE TEACHERS

In this section, I describe work with preservice elementary teachers at the University of Delaware and Michigan State University. In describing this work, I first address a key issue for both preservice and inservice elementary teachers – their own content knowledge of both substantive and syntactical aspects of science. As I have discussed earlier, this is a significant issue for elementary teachers (see Smith & Neale, 1987), but also for science teachers at all levels (e.g., Berg & Brouwer, 1991; Carlsen, 1993; Hashweh, 1985; Sanders, 1993). It is especially salient for preservice teachers who have just "finished" their science content courses and are preparing for their first teaching experiences (see McDiarmid, Ball & Anderson, 1989; Grossman, 1990). After a consideration of the substantive content underlying PCK, I will describe some of the problems and possibilities that the construction of PCK for teaching elementary science poses for preservice teachers. Then, I will turn to issues about preservice teachers' syntactical knowledge in science, and their construction of PCK in that area.

Substantive Issues in Constructing PCK: Some Examples involving Plant Growth

It is important that, in the focus on PCK in these chapters, we not lose sight of the critical dependence of PCK on accurate, rich, and flexible conceptual content knowledge. Research with both experienced (e.g., Carlsen, 1993; Hashweh, 1985; Krajcik, Layman, Starr & Magnusson, 1991; Leinhardt & D. A. Smith, 1985) and preservice teachers (e.g., Bendall, Goldberg, & Galili, 1993; Stofflet & Stoddardt, 1994) has revealed the misunderstandings in, and lack of confidence about, content knowledge that are all too common in science teaching, and not just at the elementary level (see also Wandersee, Mintzes & Novak, 1994). Preservice elementary teachers typically come to science teaching methods courses already apprehensive about teaching a subject they feel they know little about and, often, have had little success in understanding (Simpson, Koballa & Oliver, 1994; Smith, Levine-Rose, & Conway, 1995). Usually, they believe it is their fault that they don't understand science in college level courses, because they rarely question the quality of the teaching that they have encountered in those courses (see Anderson & Mitchener, 1994; McDiarmid, in press; Tobias, 1990).

In starting our work together one semester, I asked my elementary methods students to talk in small groups to design a way to carry the supplies for, and grow enough food to support, a crew on a space ship on a long journey. Prior to breaking into the groups, we talked about what we already knew about plant growth -- the factors involved and needed conditions -- which would help us design the system for the space ship. Students hesitantly began giving their own explanations for how plants get their food for growth. Many thought that plants got their food from the soil and/or the water, a common naive conception among children also (see Bell, 1985; Roth, Smith & Anderson, 1983). Some thought there was something in the air that was needed, and others thought the sun played a role, but weren't sure how. There were a few students who could provide the word "photosynthesis" or say "Plants make their own food," but almost none who could explain clearly what that meant. In all, about 11% of the 30 students could give an accurate scientific explanation -- approximately the same percentage of accurate explanations that learning science had been like throughout school, and whether we felt comfortable with the responsibility for teaching children science. Students wrote an autobiographical history of their experiences as learners in science, and we discussed in class the various kinds of science activities and science teaching they had seen in their careers as students. One student was convinced that no one had ever taught her about how plants get their food. She found an old copy of the science series used in her elementary school, and looked to see if the topic was included. To her amazement, she found that the topic had, indeed, been "covered" in her schooling.

Over the next few weeks, students worked in small groups to design ways of gathering evidence about the different views about plant growth. As a class, they critiqued each other's designs and suggested modifications. Some students thought the increasing temperature of the soil in the spring was the critical factor in plant growth, so they placed their seeds in the dark but on a heating pad. Others wanted to see if air was required for plant growth, so they sealed some seeds inside plastic bags and left others uncovered. Others were convinced that the soil was the source of the plant's food, so they investigated different soil conditions that might inhibit or encourage plant growth. They planted seeds in rocks, sand, and soil and noted how many sprouted and how well they thrived in the different media. Students kept detailed logs of their investigations and selected ways of representing their findings for the rest of the class. Other students raised questions about the investigations, findings, and the interpretations that groups had made.

As part of this content-focused investigation, I also asked students to critique my teaching with them and to identify features that seemed to work well to help them construct deeper understanding, as well as features that didn't seem to be working well. In this way, I hoped to contrast explicitly the kind of teaching I was doing with the ways they had previously been taught, and to help students to notice the features that differed among the models they had seen. For example, when students reflect, as future teachers, on what happened in their own recent classroom learning, they can notice things like: How did the teacher handle "wrong answers?" What were the effects, for the students? Would they have handled the "wrong" answers differently? Why? These discussions of my teaching also allowed me to talk about the different activities, content representations, and teaching strategies that I had considered, in planning for my lessons with them, and how I had decided which ones to use in my

lessons, thus modeling the "hidden" aspects of my teaching (See Grossman, 1991, for similar work with secondary English preservice teachers).

In addition to students' own investigations, I used activities from Roth's (1987) Power Plant unit with them. We worked through the activities in that unit, and discussed the evidence for different views of plant growth and how our ideas were changing. Students often commented on how counterintuitive the idea of photosynthesis was for them, and how appealing was the idea that plants got their food from the soil or water. These discussions led to the question: "If we have all these different views about how plants get their food, and it's difficult for us to understand, what do children think?" That question led naturally to the construction of PCK about children's thinking in this topic.

Before moving on to the preservice teachers' progress from more robust substantive content about photosynthesis to PCK for teaching, it is important to consider the implications of their own substantive understanding (or lack of it). When teachers hold some of the same naive ideas that the children in their classes hold, and in addition are not aware that those ideas are inaccurate, there are consequences for the quality of both their teaching and their children's learning. Teachers may not recognize children's misconceptions as inaccurate, and may reinforce those ideas (Hashweh, 1985; Smith, 1987). They may choose activities that do not address children's ideas, or limit discussion of the results of activities (Carlsen, 1993). They may misinterpret or modify activities, so that children have fewer opportunities to consider clear alternative explanations and the evidence for those explanations (e.g., Hollon & Anderson, 1987; Shapiro, 1994). Clearly, a strong and useful pedagogical content knowledge cannot be built on a shaky content foundation. In discussing my methods students' efforts to construct PCK for teaching children about plant growth, I will describe how these connections unfolded.

Constructing Substantive PCK for Teaching Science

Confronting our own fears and problems in understanding content in science and then learning together as a community investigating a science content topic provides both me and my students a way of connecting our personal experiences with our professional responsibilities. As I mentioned earlier, it also provides the opportunity for modeling a different image of teaching and different ways of learning and knowing in science, and for contrasting that explicitly with other kinds of science teaching they may have seen, as students.

When elementary teacher education (TE) students confront their own lack of understanding, and then begin to wonder about children's ideas, we work together as a class to construct and conduct interviews with children. Students read research articles describing children's naive ideas about plants and their growth (e.g., Bell, 1985), often recognizing some of their own prior conceptions. They use the information about children's thinking and the guidelines suggested by Bell, Osborne, & Tasker (1985) to construct interview questions. They also watch videotapes of my interviews with children and critique them. They role-play their interviews with other TE students (who respond to interview questions as if they hold a specific alternative conception), and critique the phrasing and focus of each other's questions. In this way, they practice asking good diagnostic questions, i.e., ones that will provide them with information about children's thinking. They also consider and receive feedback about their choices of tasks and materials, and whether they are effective in eliciting children's ideas.

This experience with interviewing children about their ideas is aimed at students' construction of three kinds of PCK. One is their knowledge that children have alternative conceptions and that these are important to know, as well as specific knowledge of the ideas that children of different ages bring with them to science lessons about plants and their growth (Wandersee, Mintzes & Novak, 1994). Reading articles that describe research on children's thinking about how plants get their food is interesting. Having real children describe in their own words that "trees have long branches that touch the ground so that they can get the food from the soil" is much more compelling.

The second kind of PCK students construct is the knowledge that they need the ability to generate good questions that can be used to find out what children are thinking, so that they can plan lessons to address those ideas. Their repertoire of effective questions about plants and their food, and of needed follow up questions for children's explanations, slowly expands, especially if they have the opportunity to interview the same children a second time. Experienced teachers with whom I have worked (see Smith, 1992) report that, over time, this ability to generate good diagnostic questions even begins to show up in their teaching in other subject areas (see also Ball & Lundquist, 1993; Tobin & Garnett, 1988).

The third kind of PCK that TE students construct while planning for and doing their interviews, and reflecting on what they found out, is knowledge about particular tasks and materials that provoke and reveal children's thinking about the topic. For example, are lima beans or sunflower seeds better at getting children to talk about what seeds are for? If children don't think of lima beans as seeds, then the question may not make much sense to them. Since these sorts of tasks and materials often show up in modified form as classroom activities, trying them out with individual children provides feedback about their usefulness.

The process of interviewing children often reveals interesting problems in future teachers' epistemological assumptions, as well. TE students' conceptions of what it means to know science, constructed during their own school careers, are often limited to knowing the "right answer (Raizen & Michelson, 1993; Schommer, 1994)." So, their initial drafts of interviews often consist largely of questions that can be answered by "Yes" or "No". Through the role-playing and critiquing process, students gradually revise questions so that they encourage children to elaborate on their answers.

In the interview, the TE student may ask a child: "How do plants get their food?" When the child responds, "Photosynthesis," sometimes the TE student accepts the answer, because it is the "right" one. She/he then continues with the next question, rather than probing to find out what the child means by "photosynthesis." It is only when we discuss the interview results as a class, and someone asks about what the child meant, that students realize that they have little basis for making a claim about the child's understanding of that word. In addition, the TE student's own understanding of the content may be limited or shaky. Even if she/he recognizes the need to probe the child's meaning for a word, she/he may not be able to generate the probing and clarifying questions that would reveal important differences between the child's understanding and the scientific explanation (as is also true for experienced teachers, Smith & Neale, 1991).

As in other methods courses, after interviewing children and interpreting their responses, students go on to plan and teach lessons, and reflect on their teaching and children's learning. I have described the interviewing process in detail, because it reveals some of the problems that TE students encounter in constructing the needed PCK -- about children's thinking, about effective tasks and materials, and about teaching strategies, in this case, asking good questions -- for their science teaching.

This section has also touched on the issue of TE students' conceptions of the nature of science and scientific knowledge. As suggested in the section on experienced teachers' construction of PCK for science teaching, these two aspects -- the substantive and syntactic -- are inextricably intertwined. In the next section, I consider the implications of TE students' knowledge of the syntactical aspects of science.

Syntactical Issues in Constructing PCK

Just as we spend time investigating preservice teachers' own substantive content understanding in science, we also ask them to write about what they think science is, about their own experiences with science teaching and learning, and about their vision/image of "ideal" science teaching and learning (Richardson, 1996). As with younger learners, we find that information about what future teachers bring with them to courses about teaching and learning science is critical for planning for and teaching them.

For example, just as with experienced teachers (Lederman, 1992), preservice teachers often have limited conceptions of the nature of science and scientific knowledge (Abell & Smith, 1994; Lederman, 1992; D. Smith & C. Anderson, forthcoming). They often view science as a set of procedural steps -- "the scientific method" -- that lead to unequivocal truth (Pomeroy, 1993; Strauss, 1993). Much like the children in Carey and Smith's (1993) study, scientific knowledge is viewed as emerging in a straightforward way from observations of natural phenomena (Boyes & Chandler, 1992; Smith, Levine-Rose, & Conway, 1995). Although preservice teachers use words like "theories" and "hypotheses," their writing reveals that these are thought to emerge unchallenged from the data as revealed in the natural world, not invented and constructed by humans seeking to make sense and understand events in the natural world (see also Driver, Millar, Leach & Scott, 1996).

Preservice teachers rarely mention the role of a community of scientists communicating with each other about ideas and evidence and constructing consensual agreement about changing theories and their usefulness. In their descriptions of scientific work, there are no disagreements or alternative explanations, no competing theories, no theoretical frameworks through which observations are interpreted. In fact, what is striking about preservice teachers' views is the lack of human participation in what gets constructed. Aside from being curious and "discovering" new scientific knowledge, scientists appear to be merely channels through which the observed truth is communicated (Abell & Smith, 1994).

Most TE students report that, in their previous experiences in science classrooms, they were the recipients of teachers' lectures about the "right answers" in science, or were allowed to perform "experiments" which confirmed what they had already been told (Anderson & Mitchener, 1994). Thus, in their careers as science learners, they have rarely encountered other images of science, of the construction of scientific knowledge, or of the work of scientists, a much-needed aspect of learning about science, as Duschl (1994) has noted. They have rarely participated in a community engaged in constructing scientific knowledge about some question (Borko & Putnam, 1996; D. Smith & C. Anderson, forthcoming; Smith, Levine-Rose & Conway, 1995).

In the work we do with preservice teachers, we offer a different way for them to learn and think about science, as a direct contrast to their previous "apprenticeship of observation" (Lortie, 1975). We ask students to make explicit their own naive theories, e.g., about the flow of electricity in a simple circuit (and these usually include the common naive ideas that children have, see Johsua & Dupin, 1987). They talk about, argue and debate the adequacy of the different theories to predict and explain events with batteries and bulbs. Students test out and collect evidence about their ideas, choose ways to represent their findings, and bring the evidence back to the whole class. They argue about the interpretations of evidence that different groups are making, disagree about the significance of differences in measurements, and struggle with evaluating the usefulness of the different theories in explaining phenomena.

In these discussions, students often express surprise at the differing interpretations of the same data that others in the class hold, and how those holding different theories are each convinced that the same data support their views. These events are contradictory evidence for their epistemological beliefs that observers of the same data will reach the same interpretations and conclusions (Boyes and Chandler, 1992). They also comment that no one has ever asked them to argue about theories and evidence before (Gallagher, 1991). They express discomfort and embarrassment in what Lemke (1990) calls "talking science (see also Gallas, 1995; Pea, 1993; Russell, 1982)."

It will probably come as no surprise to the reader that TE students often view these activities with considerable impatience and growing dismay. In most "methods" courses, TE students teach a series of lessons near the end of the course. Because they know they will soon be teaching their lessons, students struggle with feelings of anxiety about their own knowledge, and often ask me to "just tell us the right answer." This leads to class discussions about what it means to know in science, about teacher roles in the construction of deeper understanding in science, about their own personal histories in knowing science, and about the nature of knowledge construction in scientific communities.

Preservice teachers who have limited views of the nature of knowledge construction in science, and limited experiences in participating in that kind of endeavor, are likely to encounter difficulty in creating that kind of experience with the children in their classrooms (Anderson & Mitchener, 1994; Robinson, 1968). Reasoning about theories and evidence apparently does not come easily to children or to adults (Kuhn, Amsel & O'Loughlin, 1988). Teachers' abilities to provide opportunities for children to learn about syntactical ideas are critical. In the next section, I discuss some of the implications of preservice teachers' syntactical knowledge for their teaching and their students' learning.

Constructing PCK about Syntactical Aspects of Science

As I discussed with reference to my own teaching and that of other experienced teachers, teachers' views about the nature of the scientific endeavor carry with them implications for teaching and learning. One might expect that preservice teachers' syntactical knowledge and beliefs would influence their images of what good science teaching and learning should look like.

In the writing my students do at the beginning of the semester, their images of how teaching and learning science occur in classrooms usually involve "hands on activities," and "discovery" of scientific ideas through those activities. Often, in these descriptions of ideal science lessons, the teacher has an active role in planning the activities, but plays little role other than providing materials and then observing while children are engaged in the activities (L. Anderson, D. Smith, & Peasley, under review).

Some TE students include descriptions of "the scientific method" and words like "experiments" and "hypothesis" as valuable parts of science lessons, but fail to describe how these are linked to children's learning. If they mention any concern for children's difficulties in learning science (especially considering their own experiences as learners), they describe how demonstrations and activities will "show" the children how the scientific concept works. They rarely describe any role for the larger community in the classroom, as a forum for the exchange of ideas and the consideration of their usefulness in explaining phenomena. Sophisticated views of model-based reasoning (Driver et al. 1996; Lehrer, R. & Schauble, L., 1996) with its coordination of models, data, authoritative sources, and collective validation are missing from their initial conceptions (D. Smith & C. Anderson, forthcoming).

Constructing new images of the nature of science and then translating these into classroom contexts appears to be an area of great difficulty for preservice teachers and one worthy of further study. In order to make explicit the different orientations (or what Borko & Putnam, 1996, call "overarching conceptions") that teachers might hold about teaching and learning in science, students read about some common frameworks that experienced teachers take (e.g., Anderson & Smith, 1985). Then I divide the class into small groups with each group taking one of the different perspectives. We all critique the same videotape of an elementary teacher teaching science. Students listen to the very different evaluations of the teaching that the groups generate.

Often, the "discovery" group condemns the teacher for spending so much time on predictions and explanations and not letting the kids get right to work trying things out. The "direct instruction" group usually protests that the teacher never taught anything, because she never told the kids the right answer. The preservice teachers begin to comment on how one's perspective can influence both what one notices and how one interprets that information. They have earlier learned that, as learners of science, they held different theories and interpreted the same evidence in different ways. So too, as teachers of science, they begin thinking about the possible contrasting perspectives on teaching and learning science that they will choose and why (Grossman, 1990).

In spite of preservice teachers' child-centered descriptions of "good" science lessons and their best intentions to focus on creating opportunities for conceptual change in children's ideas, their plans (usually 3-5 lessons) and attempts to implement them sometimes fall back on identifying the factual content about a particular topic, and then "just telling them," as researchers in other areas and grade levels have also found (e.g., Borko et al., 1992; Richardson, Anders, Tidwell, & Lloyd, 1991; Wilcox, Lanier, Schram, & Lappan, 1992). If they plan for activities and succeed in implementing them, they sometimes still expect children to "discover" the content they had in mind, in spite of their knowledge about children's preconceptions and their experiences with their own preconceptions. When children don't discover the intended content in one lesson, TE students feel obligated to "just tell them," sometimes with exhortations to classroom observers -- "Don't tell Debbie!" (See also Black & Ammon, 1992; McDiarmid, 1990.)

There are several possible explanations. Preservice teachers may be looking for a feeling of efficacy in their teaching (J. Smith, 1994), and believe that -- in telling children the right answer -- they have at least met their obligations to "look and act like teachers" and "cover the content (Tobin, Tippins & Gallard, 1994)." Perhaps because of their own memories of uncomfortable and anxious moments in science classrooms and their beliefs that science knowledge is quick, obvious, and certain (Driver et al., 1996; Gallagher, 1991; Schommer, 1994; D. Smith & C. Anderson, forthcoming), they are reluctant to let children struggle with new ideas for very long (Civil, 1992). Or, because TE students typically have only limited experiences in classrooms in methods courses, they may not have the time to try out their ideas, notice problems with children's learning, realize the need to change their teaching, and test out contrasting ways of teaching (Richardson, 1996; Simon & Brobeck, 1993).

Clearly, the investigation, documentation, and explication of how preservice teachers construct both understanding about how scientific knowledge is generated and PCK for establishing the syntactical aspects of science in their classroom lessons is an area with much promise. Beyond the construction of adequate conceptual content knowledge, and its translation into PCK for teaching science, and beyond the practical issues of classroom management that interfere with

beginning teachers' intentions (e.g., Gess-Newsome & Lederman, 1993; Hollingsworth, 1989; Kagan, 1992; Stofflet & Stoddart, 1994), the construction of knowledge about embedding syntactical aspects of science in daily science lessons is a critically important piece of learning to teach science. The ways in which preservice teachers' conceptions of both the nature of science and of the nature of science teaching and learning affect their views about what they need to know (and therefore what they may select to attend to in teacher education programs) is an area in which we need much more research (Holt-Reynolds, 1992; D. Smith & C. Anderson, forthcoming; Tobin, Tippins & Gallard, 1994).

New teachers may come to know about children's ideas, and about new teaching strategies and curricular materials. However, it may be much harder to change the ways that they conceptualize the nature of science (Smith, Levine-Rose & Conway, 1995) and, thus, the opportunities that they provide for children to participate in science lessons, so that children can construct more complex views of the nature of scientific knowledge construction (e.g., Pea, 1993; Russell, 1982; Rosebery, Warren & Conant, 1990). Unless we can find ways to facilitate this change, we will continue to graduate future teachers whose views of the nature of science are limited, and who teach children science in ways that perpetuate those images.

Summary

In this section, I have described some of the ways that I have worked with preservice elementary teachers to focus on and facilitate their construction of science content knowledge -- both substantive and syntactical -- and of pedagogical content knowledge for teaching children in a way that facilitates their construction of both aspects of scientific knowledge. Preservice teacher education students come to our teacher education programs with significant problems in their scientific knowledge of both kinds. It takes considerable time and effort for them to change their own ideas about particular scientific content, and for them to construct a clear alternative of what understanding in science means. Translating these new ideas into plans and teaching poses even more difficulties. Likewise, changing their conceptions of the nature of science, and translating new ideas into plans and teaching, is a daunting task. I have suggested that this is an area in which we need much more research, and one that is critical for our understanding of what is possible and effective in teacher education programs.

I have described limited, anecdotal data about the success of my own attempts. Preservice teachers' essays, journals, and verbal reports need to be supplemented by individual interviews, videotape documentation of their planning and teaching, and an analysis of the ways in which their planning and teaching influence children's learning, in longitudinal studies (Anderson & Mitchener, 1994; Richardson, 1996; Zembal, Krajcik, Blumenfeld, & Palincsar, 1995).

I am optimistic about the potential that a focus on these kinds of knowledge for teaching holds for teacher education. Novice teachers often focus on themselves and their own teaching, and only later come to think about students and their learning

(Fuller, 1969; Lederman, Gess-Newsome, & Latz, 1994). Yet, many of the future teachers with whom I have worked appear to be constructing a framework for thinking about teaching and learning science that enables them to look for children's ideas in science, to think about teaching strategies that respond to children's thinking, and to begin to be critical of curriculum materials.

This kind of legacy from teacher education appears to be significant in other fields and at other grade levels (e.g., Grossman, 1990). Preservice elementary teachers' repertoires of the different kinds of PCK may not yet be broad enough to include several content topics in science, or deep enough to include many choices among strategies and representations. They may not be persuaded that the ways of teaching recommended by the reform movements are the most efficacious. Yet, there is at least an indication of a placeholder in their teaching knowledge for the kinds of PCK I have been describing (and that experienced teachers have found to be so useful). And while they may not yet be able to plan or teach in skillful ways, there are some rudimentary rough drafts that may someday be refined practice.

DISCUSSION

In this chapter on pedagogical content knowledge for elementary science teaching, I have chosen examples from my personal/professional journey into the territory of PCK, and from experienced teacher colleagues' and future teacher colleagues' journeys. I hope that the examples have helped the reader to get inside the teachers' thinking, planning, and classroom practices, and to examine how teachers' PCK can affect the opportunities that children encounter in science lessons.

The examples have raised issues about possibilities for changing elementary science teaching and learning, through teachers' construction of more sophisticated views of children's ideas and learning, curriculum activities, and teaching strategies, in both substantive and syntactical areas of PCK. Along the way, they have highlighted a number of problems we encounter in turning these possibilities into living, breathing classroom practices. For example, the very basis for teachers' PCK - their understanding of the substantive and syntactical science content - is at risk, given our current teacher education programs. We cannot assume that our pre-service teachers' experiences in high school and university science courses have been educational in ways that will support their sophisticated teaching with children.

There is need for different science courses, co-taught by science and education faculty, in which the focus is on conceptual model-making, collection and interpretation of data, critical evaluation of authoritative sources, and norms for establishing knowledge claims in the scientific community (McDiarmid, in press; D. Smith & C. Anderson, forthcoming). These courses would focus on teachers' understanding of substantive and syntactical aspects of scientific knowing, as well as connections between that knowledge and the PCK for teaching specific content with children. For example, at the University of Delaware, my colleague Elizabeth Wier and I designed courses for experienced elementary teachers that focused on specific grade levels and important conceptual models in areas like weather. The courses offered teachers opportunities to re-construct their own conceptual content understanding, in ways that embodied the reforms in science teaching. At the same time, teachers engaged in the construction of related PCK for teaching those ideas with children. Such courses tailored to teachers' needs for content-specific teaching knowledge could continue to support teachers across their careers.

A serious focus on teachers' content-specific knowledge would include curricular support systems, too. As Nan suggested, if each teacher must go through the construction of PCK for each science content area and grade level (as well as other subjects in the elementary curriculum), then teachers face an impossible task. Ed Smith and his colleagues at Michigan State University have been designing and implementing such a support system, the Michigan Science Curriculum Resources Network (MSCRN). The MSCRN is an Internet-accessible database of science curriculum units matched to state (Michigan Essential Goals and Objectives for Science Education, 1991) and national standards (e.g., American Association for the Advancement of Science, 1993; National Research Council, 1996). It provides teachers and other curriculum developers an environment for planning a unit, entering it onto the database, entering assessment tasks and children's responses, and downloading and revising other units. Eventually, it will include summaries of assessment data on the unit's effectiveness, video examples of lessons in the database and of interviews with children, and related resources such as children's books in the content area. This sort of curricular support offers teachers opportunities to design their own professional development opportunities, at their own pace, and to learn from other teachers who are involved in the same endeavor.

When these new opportunities to learn science content and related PCK are in place, teachers will need support in orchestrating new ways of teaching and learning science in their classrooms. National reforms call for sophisticated knowledge and practices. These visions of classrooms require knowledge for the design and nurturing of challenging classroom environments, in which children investigate questions and collect data, make claims and provide related evidence, and argue about models. Many teachers, both elementary and secondary (Gee, Sanchez-Saenz, Svec & Gabel, 1994) have not seen such classroom environments and have limited resources for creating them. In order for teachers' new PCK to have an influence, they will need support in learning to do so. While not specifically knowledge about teaching conceptual science content with children, this kind of teacher knowledge about environmental and interactional aspects acts to facilitate the path of teaching and learning, much as the sweeper with the broom does in curling.

Another important issue, given the reforms' emphasis on all children learning science successfully, is whether there is related content-specific knowledge that teachers need for making opportunities accessible for girls, minorities and poor children (Gardner, Mason & Matyas, 1989; Noordhoff, 1993; Watts & Bentley, 1994). For example, Keats' book *Dreams* (Keats, 1992) tells an intriguing story about shadows getting bigger, but also situates the story in an apartment building in the city, with children of different cultures and races. Finding books like these, using dolls of different races to make shadows, or telling stories of women in science who pursued interests in astronomy - all these appear to be content-specific in ways that connect to the more standard views of PCK. This sort of knowledge would be invaluable to teachers seriously committed to reform-minded practices.

Finally, given what we know about preservice and practicing teachers' construction of PCK, we need to understand what the developmental pathways can be for teachers at different places in their careers. While preservice teachers may embrace enthusiastically these new ideas and practices, we may be asking too much of them. The coordination of substantive, syntactical, and pedagogical content knowledge into sophisticated teaching practices (along with the classroom environment and equity issues), may simply be a bridge too far, even in one limited content area.

Likewise, for practicing teachers, new knowledge of this sort may mean risky upheavals in classroom practices, and in relationships with colleagues, principals, and parents. Teachers engaged in changing their knowledge and practices often realize that traditional assessment activities will not provide them the information about children's thinking that they need to plan, teach and evaluate lessons (Smith & Neale, 1991). Designing new kinds of assessments of children's understanding of science (e.g., National Research Council, 1996; White and Gunstone, 1992) is a daunting enough prospect. Accessible databases like the MSCRN, with examples of specific assessments, would mean that individual teachers need not invent these from scratch.

But using new kinds of assessments may also mean that teachers must construct PCK for helping parents and principals learn about what understanding in science entails, and how children learn. The sociocultural milieu in which teachers undertake more challenging and sophisticated ways of teaching and learning may also constitute a barrier to those changes.

Needed Research

Clearly, there are many opportunities for additional research in this area. We need to understand how teachers construct PCK in elementary science across their careers, and how this content-specific knowledge is related to opportunities offered to children and their subsequent substantive and syntactical understanding in science (R. Anderson & Mitchener, 1994; Borko & Putnam, 1996; Grossman, 1990). We need a clearer sense of the possible pathways to improved knowledge and practices that different teachers take, and what developmental sequences are most helpful. For example, is it more helpful to a beginning teacher to take on a particular science content topic and construct deep PCK related to that area, even though she/he is then not "prepared" to teach all the elementary science topics? Would more experienced teachers, with multiple such opportunities and a generalized schema for paying attention to children's ideas and constructing curriculum activities around them, be more likely to use and learn from a support system like the MSCRN? At what point does a focus on syntactical aspects of content-specific teaching and learning appear engaging, instead of intimidating, to teachers? Similarly, we need to understand much more specifically the key "hinges" in teacher education that work to swing new teachers' views and knowledge about elementary science teaching in promising directions that have long-lasting impact in their careers.

Research on science teacher educators' substantive and syntactical science content knowledge, as well as their PCK for teaching future teachers about those areas, is another area that offers potential for improving our elementary science teacher education programs (Abell, Magnusson, Schmidt & D. Smith, 1996). We need to understand the images of science and metaphors for science teaching that preservice teachers bring to our programs (Gurney, 1995; Milne & Taylor, 1995; Tobin, 1990) and how those entering conceptions interact with the features of the program (L. Anderson, D. Smith and Peasley, under review). Sharing the examples, metaphors and analogies we are using and how they enable future teachers to make progress in their thinking and practices, would contribute to the collective growth and knowledge of the larger community of teacher educators in elementary science. Documentation of particular curriculum activities that we use to address content-specific topics in learning to be an elementary science teacher would contribute to our understanding of the "hinges" and alternate pathways in learning to teach elementary science.

As elementary science teacher educators, we need to understand the views of substantive and syntactical science content, as well as the PCK for teaching undergraduates that content, that our university science colleagues bring to their teaching with preservice elementary teachers. In addition, we need to establish collaborative work that explores the constraints - both professional and institutional - that intrude on that work, as well as the imaginative possibilities that could support it. The construction of PCK about teaching future elementary science teachers must be a cross-cultural (as well as an intra-cultural, as above) project, if we are to move towards more supportive and effective ways of educating future elementary teachers in science.

I believe that we are just beginning to glimpse the power and usefulness of understanding elementary through postsecondary teachers' science content knowledge, how it is constructed and transformed for use in classroom teaching and learning, how it affects students' understanding in science, how it interacts with other kinds of knowledge for teaching, and how it functions in the broader political and sociological context of schools. It is fortunate for us that the investigation of these areas has been, and promises to continue to be, such a fascinating one.

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NORMAN G. LEDERMAN AND JULIE GESS-NEWSOME

8. RECONCEPTUALIZING SECONDARY SCIENCE TEACHER EDUCATION

Just as teachers should be reflective practitioners, science teacher educators should reflect on both current research as well as the research they pursue. With this in mind, we would like to describe how we first developed our interests in pedagogical content knowledge (PCK) and how this interest evolved into a line of research that culminated in the redesign of the teacher education program at Oregon State University (see Chapter XI this volume). It is our hope that this personal example will help clarify the implications of research on PCK for secondary science teacher education as well as provide insight into a particular line of research.

Both of us are successful former high school biology teachers who consciously chose to leave the classroom so that we could have more impact by preparing future science teachers. This story is a familiar one to many college level teacher educators. It seems that at some point in many teachers' careers there is a need to expand one's influence beyond the students with whom you have been fortunate enough to have contact. During the latter portion of the 1980s we both found ourselves at OSU team teaching a microteaching course. At that time, there was some discussion in the literature, and even more within the university department, about the contribution of microteaching to the preparation of preservice teachers. In particular, microteaching courses have been considered sterile and too contrived. After all, teaching to one's peers is not the same as facing a roomful of secondary students. We wondered whether there was any relevance of microteaching to the education of preservice teachers other than what we had convinced are ourselves to be the case. So, we began by investigating a sample of 17 preservice science and mathematics teachers within the context of a ten-week microteaching course (Gess-Newsome & Lederman, 1990). All students were satisfying the requirements for their initial secondary level (6-12) teaching certificate. Eleven of these students were completing requirements for a certificate in one or more of the sciences with the remaining five completing requirements for a mathematics certificate. This microteaching course was situated at the end of the campus-based portion of the teacher education program, just prior to student teaching. All students enrolled were required to plan and present four 15-20 minute lessons. Each presented lesson followed a different model/method of teaching: lecture/recitation, general inductive model, general deductive model, and a laboratory activity. Each lesson was videotaped and immediately followed by a class discussion evaluating the strengths and weaknesses of the lesson. Students were required to view their videotape and self-critique their lessons. Formal written feedback was provided by one of the course instructors following the submission of the self-critique.

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The primary purpose of this research was to investigate preservice science/math teachers' attitudes toward teaching and instructional decision making. The data sources were student self-critiques and a questionnaire completed prior to the first lesson presentation and following each of the lessons, for a total of five questionnaires. The questionnaires were identical and consisted of the following five open-ended items:

1. What have you learned, thus far, that will be of significant help to your student teaching? (For the questionnaire preceding the course, students were asked what they expected to learn).
2. Are those items discussed in #1 what you expected to learn?
3. Have you learned any instructional techniques that you initially did not anticipate as being important teaching skills? Explain your answer
4. What relationship, if any, exists between your ability to plan and the quality of your presentation?
5. Are there any comments that you would like to make concerning the value or content of this course?

Initial analysis of the questionnaires enabled one of the researchers to derive and operationally define 16 categories and/or trends of the preservice teachers' instructional concerns, attitudes, etc. These 16 categories were validated by the second researcher's independent qualitative analysis of the same data set. Self-critique comments were then compared with the derived categories in order to establish any discrepancies or congruence between these more open-ended data and that derived from the more structured questionnaires. Final data analysis allowed consolidation of the 16 categories into a final list of 12 areas of concern which were grouped under two major headings: Concerns for Self and Concerns for Students. Concerns for Self included: physical appearance and expression, speech, audio-visual mechanics, lesson plan access. Concerns for students included: reaction to and cognizance of students, student involvement, instructional sequencing, concrete and relevant instruction, use of questioning, audio-visual use, management, instructional planning.

Most of the aforementioned categories did not present a picture different than what had been identified in previous research on student teachers, beginning, and experienced teachers (Fuller, 1969). However, our findings did add microteaching students'concerns toward teaching to the literature. Furthermore, our investigation did not involve the imposition of an a priori set of categories (Fuller, 1969) into which teacher concerns were to be classified.

There were several interesting findings that had not been previously described in the research. Instructional planning was clearly viewed as a two phase process including both the physical act of planning and the mental rehearsal of the plan prior to teaching. The most significant finding related to the apparent shift of focus among the subjects from concerns for self to concerns for students, similar to the findings of Fuller (1969). However, the more detailed analysis allowed by our qualitative investigation showed that although the preservice teachers spoke about students, the students were really viewed as adversaries that could compromise the quality of lesson implementation. In short, concerns were still for self with the student added as a complicating variable to their lives as teachers.

It is interesting to note that our focus on preservice teachers' concerns prevented us from recognizing omissions in their thinking about teaching. For example, the teachers rarely talked about subject matter, their understanding subject matter, and the ability of students to learn from their classroom presentations. Even though prior research (Fuller, 1969) had indicated a consistent concern for subject matter by preservice teachers, an examination of that research revealed specific questions designed to prompt such a response. Our preservice teachers, given more open-ended prompts, failed to identify any concerns related to subject matter.

Given our concerns about the relevancy of microteaching to preservice teacher education, the natural extension of the first investigation was to continue collecting data on some of the teachers as they entered student teaching (Lederman & Gess-Newsome, 1991). A sample of six science student teachers was selected from the original 17 in the first investigation. Student teachers were required to complete a questionnaire prior to the beginning of student teaching and following each of the 15 weeks of their field experience. Each week, these individuals were observed, videotaped, and provided with written and verbal feedback in the same manner provided in the microteaching course. In addition, the student teachers attended a special weekly seminar in which the group systematically, but informally, discussed their videotaped lessons and concerns about teaching. The questionnaire consisted of the following eight open-ended items:

1. At this time, what specific teaching skills and/or techniques do you feel you are performing well? What evidence have you used to support this conclusion?
2. On which teaching skill/techniques do you need to improve? What evidence have you used to support this conclusion?
3. How do you plan to improve the items mentioned in question 2? Be specific. Did you develop these plans on you own? With the aid of your cooperating teacher? With the aid of your university supervisor? Others?
4. Have your previous plans to improve been successful? Why or why not?
5. What specific steps, in sequence, do you follow in preparation for teaching a lesson? A unit?
6. What specific skills/techniques that you learned and/or practiced in microteaching have helped you during student teaching? Which skills/techniques were irrelevant?
7. What teaching skills/techniques have been important for your success in student teaching but were not addressed in microteaching?
8. Do you have any additional comments or concerns?

Data were analyzed in the same manner as the previous study and yielded a total of 17 categories of perceptions and concerns, under the original two broad categories of Concerns for Self and Concerns for Students. Specific categories were the same as the original study with the following exception: Within Concerns for Self were added clerical/administrative skills and work load. Within Concerns for Students were added motivation, rapport, depth and breadth of material, time requirements for learning. Within Concerns for Students, audiovisual use did not appear in the second study. In general, there was a high level of consistency between the concerns expressed in microteaching and those during student teaching, serving to support the notion that microteaching contributes, in a relevant manner, to the preparation of preservice teachers.

In contrast to the findings of the previous investigation, and that of others, preservice teachers exhibited a sudden shift in concerns with students as the primary and overwhelming focus. We concluded that preservice teachers' shift in concerns from self to students was not developmental, but an artifact of the artificial nature of the campus-based microteaching course. The overwhelming presence of "real" students within the context of student teaching compels the student teacher to immediately and necessarily shift their concerns from self to students.

In retrospect, and related to the topic of this text, the most important finding of this investigation was the relative absence of concerns related to subject matter. Left to their own devices our subjects did not express any concerns about subject matter during either microteaching or student teaching. The only concerns possibly about subject matter were couched in terms of finding activities that matched their perceptions of teaching goals and realities. Although we did not recognize it at the time, current research has allowed us to note a different conclusion to this investigation. Our students' drive to find activities and quick teaching solutions was indicative of their own potentially weak subject matter understanding and the need to routinize classroom management prior to being able to attend to issues of student learning (Hollingsworth, 1989). At this time, the science education community strongly embraced the notion that beginning teachers possessed significant concerns about subject matter. This view, however, was derived from previous investigations that had used a quantitative and deductive approach that imposed prompts related to subject matter (Fuller, 1969). We approached the question of concerns in a more qualitative and inductive manner that did not impose any specific focus on preservice teachers' concerns. The bias of the educational community created some interesting problems as we attempted to publish the results of our second investigation. Specifically, more generic education journals viewed the research as specific to science education while science education journals viewed the research as more generic. The key point here is that we had unwittingly uncovered the same concerns about teacher education expressed in several publications by Shulman (1986a, 1986b, 1987). Specifically, he had asked about the absence of subject matter in the preparation of teachers and research on teaching.

As a consequence of our second study on concerns, we became concerned about the lack of emphasis on subject matter expressed by our secondary teachers. It could have been possible the preservice teachers at Oregon State University had a very strong understanding of subject matter and, therefore, had no concerns about subject matter. On the other hand, we knew from our experiences in supervision, methods courses and microteaching courses, that "all was not well in Mudville."

Consequently, we decided to investigate what our students knew about the subjects they were expected to teach. Because we were both former biology teachers, we decided to focus only on preservice biology teachers (Gess-Newsome & Lederman, 1993). Cognitive science clearly had influenced science education at this time, so assessments of subject matter knowledge were much more introspective than the usual paper and pencil test. However, we were concerned that card sort tasks (as used by Shulman and his colleagues) and concept maps imposed too many restrictions on respondents.

The purpose of the investigation was to answer the following questions:

1. What is the appearance/nature of preservice biology teachers' subject matter structures (SMS) during the final year of teacher preparation?
2. What is the source of preservice biology teachers' SMSs?
3. Are SMSs stable during the final year of teacher preparation?
4. What is the relationship between preservice biology teachers' subject matter structures and the act of teaching?

This investigation marked our first effort clearly couched within the framework of pedagogical content knowledge. Ten preservice biology teachers were selected and followed during their final year of course work leading to initial certification in secondary level biology. Eight of these individuals were completing a BS in science education and two already had degrees in biology. The first phase of the investigation focused on the nature of preservice teachers' SMSs. Each participant was given approximately 15 minutes at the end of the first day of the science methods course to answer the following questionnaire:

1. What topics make up your primary teaching area? If you were to use these topics to diagram your content area, what would it look like?
2. Have you ever thought about your content area in the way that you have been asked to do so above?

Students were assured that there was no correct answers and that they could feel free to format their response in whatever way they felt most comfortable (e.g., picture, words, concept map). Students were asked to answer question 1 again at mid-term and at the end of the course. For the second and third administrations of the questionnaire, the following questions replaced question 2: Have your views changed? If so, how and why?

Data were analyzed qualitatively in order to derive any evident patterns among and within the preservice teachers' stated SMSs. The second phase of the investigation focused on any changes that may have occurred in the preservice teachers' SMS. Mid-way through student teaching individuals were asked to complete the questionnaire a fourth time and participate in a 30-minute videotaped interview. In an effort to avoid any misinterpretation of how individuals represent their SMSs, individuals were given the opportunity to describe and clarify the meanings of their diagrams during the student teaching interview. The interviews were guided by a core of questions that focused upon the content and meaning of the final diagram, and whether their views had changed. Students were then asked to compare and contrast copies of their answers to the four questionnaire administrations. They were also asked if their SMSs were evident in their classroom teaching.

All individuals reported that they had never though of their subject matter in the manner that we had asked. Therefore, it is possible that assessments of SMSs are as much a treatment as they are an assessment. In general, the SMSs provided were primarily listings of discrete biology courses taken at the university. Though the formats that the students used varied (i.e., discrete topics, linear, hierarchical, and web-like), few connections or themes were evident between or within the list of topics. Thematic topics rarely occurred in the SMSs and the results called into question the findings of other research investigations that assumed preservice teachers possessed a coherent structure for their subject matter (Baxter, 1989). Participants overwhelmingly stated their conceptions of subject matter came directly from the biology courses they had taken at the university. Individuals also admitted that their SMSs were only tentatively delineated without any apparent rationale.

Changes in SMSs were evident by the third and fourth administrations of the questionnaire. As elucidated during interviews, actual changes had occurred in the preservice teachers' conceptualizations as opposed to individuals simply choosing to represent their SMSs in a different format. By the third administration of the questionnaire, the students felt that their SMSs were essentially the same in terms of content, but were now taking on new meanings in terms of how they viewed the subject matter in relation to teaching. In addition to conceptual changes, SMSs also changed with respect to an increased number of terms included and integration among topics. It became clear that during student teaching the preservice teachers began to structure their subject matter in terms of how they thought it should be taught. It appeared that the act of teaching and/or thinking about how one will teach biology had a significant impact on the way biology was perceived. Contrary to what Shulman (1987) advocated, the preservice teachers denied that their SMSs influenced their teaching. In essence, the preservice teachers felt that teaching was too complex a forum in which to focus on the portrayal of their subject matter beliefs. As beginning teachers, classroom management, the mastery of lesson dynamics, and day-to-day planning overwhelmed the preservice teachers to the point that planned or spontaneous incorporation of perceived themes or topic integration became virtually impossible. As a consequence of this investigation, we realized that repeated opportunities to reflect on one's SMS (as in repeated administrations of the questionnaire) may serve to provide preservice teachers with a coherent structure for their subject matter. Furthermore it may be the case that until a teacher has gained experience and mastered basic classroom skills it is inappropriate to expect readily accessible and useful SMSs to exist and/or to be translated into classroom practice.

At this point, we started to question the usefulness of the construct of pedagogical content knowledge for beginning teachers. In particular, the translation of one's SMS into classroom practice is one of the strongest arguments used in support of Shulman's conceptions of teacher knowledge. We began to wonder whether more important things (e.g., classroom management) inhibited such translation in the beginning teacher. Specifically, at this juncture it appeared to be important to investigate the knowledge, experience and teaching practices of experienced biology teachers in order to frame the goals and expectations held for teachers in our preservice programs (Gess-Newsome & Lederman, 1995).

The purpose of the investigation of experienced biology teachers was to assess the nature of SMSs and their relationship to teaching. Furthermore, this investigation involved actual classroom observations as opposed to the admittedly limited nature of self-reports of SMS impact. Five male teachers from five high schools in four school districts constituted the sample. Years of teaching experience ranged from 7 to 26 years. A semi-structured interview was conducted prior to the start of the school year in order to develop a profile for each teacher. This interview gathered information on the teachers' academic and professional backgrounds, teaching context, and the teachers' intentions and goals for teaching biology. SMSs were assessed in the same manner as in previous investigations. In an effort to assess the potential testing effect of the questionnaire, two of the five teachers were randomly selected to complete the questionnaire prior to classroom observations. The second phase of the investigation consisted of extensive classroom observations though the Fall semester. All observations were made without knowledge of the teachers' SMSs. The purpose of the classroom observations was to generate "inductively" the SMS of each teacher as portrayed in classroom behaviors. Three types of data were collected and analyzed: classroom observations, classroom documents, and anecdotal data. Weekly observations were performed in a single biology class of the teacher's selection.

Based on the classroom observations and documents, SMSs were generated by the researchers (see Gess-Newsome & Lederman, 1995 for details). These SMSs were compared to those found in the text used by each teacher, and to the SMSs described by each teacher in the final interview conducted after the analysis of all classroom data. The biology teachers in this study described their conceptions of SMS using content related terminology.

Typically, SMSs were described as an understanding that all biology content is interrelated and that a logical order of content presentation exists. Despite such descriptions, the teachers' SMSs consisted of fragmented concepts held together only by elusive threads that could be used to support conceptual integration. These findings call into question the ability of these teachers to successfully present biology as a conceptually integrated whole. SMS formation was attributed to early content experiences such as college courses, and are modified by the act of teaching and learning content. The SMSs of experienced teachers are dynamic in their format and structure over the course of their careers but were relatively stable within the context of a single semester of this investigation. Situations that allow teachers the opportunity to reflect on their SMSs, or reinforce the beliefs held, seem to be essential in the development of a coherent SMS. Interestingly, student reactions to the curriculum taught, influence the enhancement or removal of some topics from teachers' personal conceptions of SMS.

The translation of SMS into classroom practice was direct for one of the teachers and limited for the other four. The most obvious mechanisms of transfer included course scope, organization, sequence, and textbook selection. Teachers who had heavy course loads, poor pedagogical skills, and limited content experiences beyond those needed for certification did not have the time, or perceive the need, to reflect on the SMS of their content. SMS translation was also influenced by time, teacher autonomy, students, and teacher goals for classroom learning.

This investigation called into question the assumption that SMSs teachers possess are directly translated into classroom practice. Classroom complexity clearly mitigates the translation of SMS into classroom practice, reinforcing the necessity of studying teachers while in the classroom context. A simple correlation of years of experience to the degree of SMS articulation or the transfer of SMS into classroom practice did not exist. Opportunities for teachers to reflect on classroom practice and implement identified changes, however, greatly influenced teaching expertise. Opportunities to articulate beliefs about content and teaching appear to be critical factors in SMS formation and translation. It appears that experienced teachers, because they have resolved issues of management, are more likely to translate aspects of their SMS into classroom practice. However, such translation is not automatic and continues to be mitigated by the realities of classroom life. Without opportunities to systematically reflect on SMS and classroom practice the relationship between SMS and classroom practice is tenuous at best.

So what does this tell us about the preparation of preservice teachers? Preservice teachers can be provided with opportunities to develop and reinforce SMS, however, limited experience with classroom routines and management will foil the attempts of many to provide evidence of their beliefs in classroom practice. Additionally, the role of teachers' understadning and beliefs about pedagogy remains unclear to us. In addition, the intersection, or lack thereof, of such beliefs with teachers' views of content remain equally elusive. Consistent with Shulman's model of teaching and the key components of pedagogical content knowledge, we extended our investigations of subject matter structures to include structures of pedagogy.

Our return to the investigation of preservice teachers led us to a longitudinal investigation (Lederman, Gess-Newsome & Latz, 1994) that focused on the following questions:

1. What is the nature/appearance of preservice science teacher's subject matter and pedagogy structures?
2. What is the source(s) of these knowledge structures?
3. Are these knowledge structures stable during teacher preparation?
4. What is the relationship between these knowledge structures and how do they relate to the act of teaching?

Twelve preservice secondary science teachers were investigated as they proceeded (as a cohort group) throughout the totality of their subject-specific teacher education program. Similar data, though not longitudinal, were collected for six student teachers during the Fall term and 14 student teachers during the Winter term. These non-cohort groups were used to corroborate or call into question patterns or trends noted in the 12-member cohort group. The investigation was completed in two phases. Phase 1 primarily focused on whether preservice teachers possessed coherent conceptions/structures of subject matter and pedagogy. Phase 2 focused on the changes that occurred during the year of preparation and clarification of any patterns elucidated in phase 1. Each participant was given approximately 30 minutes on the first day of the Fall term to complete the SMS questionnaire used in previous investigations with the second question of "have you ever thought about your subject manner in this way." One day later, during the first meeting of the methods course, each participant was asked to answer the same questions, but with "important elements/concerns of teaching" substituted for the phrase related to primarily content area. Therefore, within a two-day period, participants supplied us with their knowledge structures for subject matter and for pedagogy. Participants were asked to complete the questionnaire at the end of the Fall term, Winter term, and five weeks into student teaching (Spring term). For the second, third and fourth questionnaire administrations, the second question was replaced with "have your views changed? If so, how and why?" Overall, Phase 1 involved the completion of four subject matter questionnaires and four pedagogy questionnaires. These assessments spanned the entirety of the subject-specific teacher preparation program. Phase 1 data were analyzed in the same manner as in our previous investigations with the only differences being the addition of pedagogy questionnaires and the services of a third researcher. All results were generated independently by the three researchers and then corroborated during subsequent discussions. Phase 2 began immediately following student teaching and involved a 45 minute videotaped interview conducted by one of the researchers. Questions guiding the interview focused on the same aspects of knowledge structures as in previous investigations. As mentioned previously, 20 non-cohort preservice teachers were also interviewed and administered one set of questionnaires. Analyses of these data provided information concerning the generalizability of the "final" conceptions/structures of the cohort group.

In general, subject matter structures were found to be listings of discrete topics/science courses taken at the university and pedagogy structures were primarily listings of the teacher oriented components of instruction with student oriented components, such as motivation, given little or peripheral emphasis. Integrative themes or connections between or within the components of either subject matter or pedagogy structures were not common.

Organizational patterns were quite traditional with respect to subject matter. In general, SMSs were presented in the same general formats we have found throughout our series of investigations: discrete, simple hierarchy, web-like. Pedagogy structures tended to be organized in a linear fashion coinciding with the temporal sequence of instruction, discrete listings of responsibilities, or web-like representations of activities preformed. Once again, the source of SMSs was identified as college courses and participants stated their representations were only tentatively delineated without conscious rationale.

Changes were clearly noted in each of the knowledge structures by the third and fourth questionnaire administration. SMSs generally became more consistent with how each respective content area would be presented to students in a secondary school, an organization that the participants reported to have found difficult to include in initial conceptualizations. Clearly, the planning and implementation of science lessons directly influenced preservice teachers SMSs. Overall, many individuals altered their representation into integrated and inter-related networks of topics. However, these representations were simplified in response to the needs of students (i.e., thinking skills, everyday experiences). With no exceptions, members of the non-cohort group provided SMSs consistent with those of the cohort group.

Pedagogy structures became increasingly more complex; clearly evident was a proliferating of student-focused components as well as additional teacher roles and responsibilities. Of major significance was a general shift away from linear representations of pedagogical knowledge to more web-like frameworks, which placed the students and their concerns at the center. As with SMSs, representations of pedagogy appeared to be influenced by the planning and implementation of actual lessons.

During interviews, participants clearly indicated a preference to conceptualize pedagogy and subject matter as separate entities. This finding stands in contrast to what one would have predicted from the literature on pedagogical content knowledge. However, it is important to note that this investigation was the first within the domain of pedagogical content knowledge that assessed knowledge structures of both subject matter and pedagogy.

In contrast to our previous investigations, the preservice teachers were confident that each of their knowledge structures was reflected in their teaching. It is important to note that the participants in our previous research included global, integrative curriculum themes such as the nature of science and science, technology, society (STS) interactions in their SMSs. Such themes were virtually absent from the representations of the cohort teachers in this investigation, rendering the knowledge structures to be relatively simple by comparison. Non-cohort participants in this investigation included integrative themes similar to those in the previous investigation. Interestingly, the non-cohort participants did not feel (as in our previous investigations) that their SMSs were reflected in classroom practice. Consequently, we began to consider the possibility that the ease with which a SMS affects classroom practice is significantly impacted by the relative complexity of the knowledge structure. Given that current national reforms would seem to require a complex knowledge structure with integrative themes (such as STS and nature of science), it may be inappropriate to expect anyone other than an expert teacher to translate the visions of the reform into classroom practice.

Following this study, the state of Oregon changed requirements for teacher licensure and there was a mandated change of the teacher preparation program to a Master of Arts in Teaching (MAT) program. Consequently, much of the knowledge gained through the series of studies presented thus far was incorporated into the development of the new MAT program. As you may have guessed, the following year provided an opportunity to assess the effects of the newly revised program relative to the literature base on pedagogical content knowledge (Lederman & Latz, 1995). The study of the MAT program was identical to the previously discussed study (Lederman, Gess-Newsome & Latz, 1994) with several exceptions. First, all students enrolled in the MAT program were required to have a minimum of a BS degree in their content area creating a sample of individuals with a greater degree of subject matter knowledge (as determined by course work) than those in our previous studies. Second, the pedagogy and subject matter questionnaires were administered

five times instead of four: at the beginning of the summer, end of summer, end of fall, end of winter, and end of spring following student teaching. A total of 12 preservice secondary science teachers comprised the sample for this investigation. Five possessed MS degrees and one had earned a Ph.D. with the remaining students having earned a BA/BS. All data were analyzed as in previous investigations.

Initially, subject matter structures, as usual, were commonly listings of discrete titles of courses taken during subject matter preparation at the university. Pedagogy structures were primarily listings of the teacher-oriented components of instruction with student-oriented components, such as motivation or prior knowledge given virtually no emphasis. The presence of integrated themes or connections within or between the components of either subject matter (with two notable exceptions) or pedagogy structures was not common. Subject mater structures were presented in three general formats: Discrete, simple hierarchy and web-like. Pedagogy structures tended to be organized as discrete listings of teacher-focused responsibilities and instructional approaches or web-like/interrelated representations of concerns, knowledge, and/or activities performed, with students conspicuously absent as a primarily focus for instruction. As in previous studies, students stated that their subject matter structures were derived from college science courses. With respect to changes in knowledge structures, no changes were noted with respect to subject matter in 11 of the 12 cases. This lack of change contradicted what we had found in previous investigations. It was eventually concluded that this lack of change was ironically the result of the more in-depth subject matter knowledge possessed by these individuals in comparison to previous study participants. Alternatively, preservice teachers' pedagogy structures were noted to become increasingly complex with time. Student-focused components, (e.g., motivation, learning styles) as well as additional teacher roles (e.g., friend, counselor) and responsibilities were more commonly noted. In addition, representations of pedagogy became more integrated with clear interactions among multiple aspects of the representations as the norm, and with a clear focus on students. These changes were reportedly influenced by the planning and implementation of actual lessons with real students. The preservice teachers, without exception, expressed the belief that both pedagogy and subject matter were distinct bodies of knowledge which, though both essential, were applied in an integrated manner during teaching. Inconsistent with previous research, the MAT students indicated that both pedagogy and subject matter structures were evidenced in their teaching. This result served to reinforce a significant finding from previous investigations. When subject matter structures remain simple and do not include unifying themes such as the nature of science and STS, preservice teachers report that these structures influence their teaching. As noted previously, there were two individuals in this study who had complex knowledge structures and rejected the idea that these structures would be evidenced in their teaching. In general, although the MAT program was informed by the results of our previous investigations, the evolution of the desired integration of pedagogy and subject matter was not noted, nor did we note that subject matter structures were integrated and consistent with the vision of national reforms in science education. This investigation made us aware, in a very real sense, that the nature and quality of instruction in college science courses was absolutely critical. Teacher education programs can only accomplish so much without the support of the total university educational system. Subject matter knowledge structures are largely determined in college science courses and it appears that these courses do not yield coherent and integrated subject matter structures. Further, it also appears that more extensive subject matter background may result in fragmented and less flexible SMSs, blocking the ability to create subject matter structures that are integrated.

The final study in our line of research was conducted in Taiwan (Lederman & Chang, 1997) and it presented the opportunity to study how robust our findings in the U.S. were and the opportunity to study knowledge structures within a very different culture and educational system. A sample of 12 MAT students from Oregon State University were investigated along with 14 preservice Taiwanese teachers from National Changhua University of Education. All students completed subject matter and pedagogy structure questionnaires prior to and following student teaching. All students were interviewed following their completion of the second set of questionnaires. The U.S. students yielded the same pattern of findings as their MAT counterparts in the previous investigation. That is, although they possessed extensive science background, their subject matter structures tended to be fragmented with virtually no coherent unifying themes. Once again, there was no change in their SMSs following student teaching. On the other hand, pedagogy structures were initially devoid of any focus on students but showed significant changes toward the student as the focus following student teaching. In short, the MAT students in this investigation replicated the results from our previous study. The Taiwanese students, alternatively, were completing programs analogous to what used to be called Normal School in the U.S. That is, they received their subject matter preparation within the context of ultimately planning to teach that subject matter. SMSs were quite similar to U.S. students in terms of their fragmented nature and lack of integrated and coherent themes. Interestingly, the Taiwanese students expressed extreme difficulty avoiding the inclusion of pedagogical concerns and components within their SMSs. For example, it was not uncommon to find such things as review, inquiry orientation, hands-on, etc, within the SMSs. With respect to pedagogy structures, the Taiwanese students consistently had students as a focal point. Taiwanese students exhibited no changes in either subject matter or pedagogy structures. On the surface, it appears that the Taiwanese fair no better on their SMSs than US students. However, their inclusion of teaching concerns within SMSs is of significance. In particular, it appears to indicate some combining of pedagogy and subject matter that we have never noted in any of our studies with U.S. students. The Taiwanese students possessed subject matter backgrounds that actually exceeded those of the MAT students, so, consistent with our previous conclusions, possessed subject matter knowledge at a level of depth that rendered SMSs inflexible to change. The Taiwanese students appeared to have internalized the importance of students well before their entrance into school settings. In our opinion, this international study indicates that the U.S. movement toward MAT programs and other formats that separate the development of pedagogy from the development of subject matter knowledge are ill advised. It may be that the better approach to achieving the integration of subject matter and pedagogy is a return to preparation programs that involve simultaneous and parallel development of pedagogy and subject matter knowledge.

Conclusions and Implications for Secondary Science Teacher Education

The research that has been conducted in the past has assumed that the SMSs that teachers possess are coherent during all phases of their teaching careers and directly translate into classroom practice. The results of our investigations show that this is not the case. We believe that when open-ended techniques are used, teachers are free to exhibit more valid representations of their subject matter conceptions. In general, we have not found that teachers have ever thought about the overall organization of their subject matter and assessment tasks, such as card sort tasks and concept maps, create as much as they assess teachers' conceptions.

The results of our investigations demonstrate that the translation of teachers' thoughts into action are much more complex than may have been previously realized. It appears that the level of complexity of one's subject matter structure is a critical factor in how easily knowledge structures influence classroom practice. Current reform efforts imply the possession of a subject matter structure that is highly integrated with coherent with unifying themes. And given that such a knowledge structure would be the most difficult to translate into classroom practice, it may be inappropriate to expect beginning teachers to implement reform efforts, let alone possess complex and integrated knowledge structures.

The SMSs reported by teachers across investigations and levels of teaching experience are content-oriented and the teachers claim such structures are initially formed as a result of college level content courses and then reinforced by the act of teaching. Such statements have two implications. First, teachers seem to be heavily influenced by the types of courses that they take in college, at least in terms of the scope of topics that should be taught in the high school context. Such an observation should place a renewed emphasis on the organization and breadth of content found in college level science programs. Programs that are skewed toward a narrow focus of content may inhibit teachers from offering well-rounded programs to their students. Second, the manner in which college courses are taught reinforce, or at least do not challenge, the fragmented nature of students' knowledge and their relative inability to apply that knowledge within the context of teaching.

Preservice education, particularly in the form of subject-specific methods classes, is the first opportunity that teachers have to reflect upon the actual use of their content knowledge within a specific context. Since the application of knowledge seems to be an essential step in the formation of a SMS that can be explicitly used in practice, the importance of such opportunities cannot be over emphasized. Specific opportunities for SMS formation should be provided, as well as the introduction of themes that may most appropriately guide instruction (e.g., process skills, nature of science, science-technology-society interactions). As suggested by

Gess-Newsome and Lederman (1993), SMSs utilizing such themes seem to be fostered through consistent reinforcement in science-specific methods courses. In addition, preservice teachers must be provided with specific opportunities to translate the SMSs they devise into classroom practice. Though many students at this stage in their careers find such a translation difficult to achieve, due to their concerns for classroom management, sensitization to the formats through which such translations can take place should occur, as well as the provision of systematic feedback concerning the effectiveness of such attempts.

Provision of similar opportunities would also need to occur early in one's teaching career. As previously noted, management concerns often overwhelm the novice teacher, suggesting that refinement of the teaching process in a manner that may effectively translate one's conceptions of subject matter and classroom goals may not be able to occur until management and classroom routines are mastered. In order to facilitate the transition from "survival teaching" to "reflective teaching," it may be necessary to provide novice teachers with a limited number of classroom preparations and with relatively greater amounts of time to design and evaluate their curricular programs in comparison with those of more experienced teachers. In addition, novice teachers should be given repeated opportunities to reflect on the effectiveness of their practice as fostered through formal feedback and critical examination of their instructional goals and the best means to achieve those goals. The provision of time and feedback may be adequate for reducing the time it takes for novice teachers to achieve a more expertise in implementing beliefs, ideas and goals into classroom practice through pedagogically effective techniques.

Let us now return to our original question: how should we reconceptualize the preservice preparation of secondary science teachers? From our line of research, it appears that conceptions of pedagogy can be easily changed within the context of teacher preparation courses as long as students are provided with ample opportunities to reflect upon instruction and experience quality field placements. Subject matter structures are a more difficult problem. Teacher preparation programs must work with the SMSs students possess upon entrance into programs. These knowledge structures are largely developed through prior experiences in K-16 science courses and activities. At present, these knowledge structures appear to be fragmented and can, ironically, become inflexible with greater exposure to science courses as they are currently taught. We are not advocating that teachers not have in-depth subject matter backgrounds, however, the subject matter backgrounds that they are currently getting by virtue of the instructional approach used in college courses is not acceptable. The problem with K-16 science instruction has been well recognized in the various reform documents. So, our conclusion is not new. What we are advocating, however, is that science teacher education be reconceptualized to include all aspects of our future teachers' education. Schools of education and teacher education programs, by themselves, cannot develop teachers of the quality demanded by the reforms. College science courses are as much a part of a teacher's preparation as subject-specific pedagogy courses. The recognition that teacher preparation is the responsibility of ALL represents a significant reconceptualization that teacher preparation. It is a reconceptualization that research on pedagogical content knowledge strongly implies. We are all well aware, however, of the inertia that exists among college science faculty, so is there really any hope? There is, it seems, one beacon of hope that can be derived from the investigation of preservice teachers in Taiwan. Returning to models of teacher preparation that integrate the learning of pedagogy and subject matter (e.g., normal schools, preparation programs similar to what elementary teachers receive) may create a culture that facilitates better cooperation between the parties responsible for teacher preparation

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KENNETH TOBIN AND CAMPBELL McROBBIE

9. PEDAGOGICAL CONTENT KNOWLEDGE AND CO-PARTICIPATION IN SCIENCE CLASSROOMS

Why do teachers do what they do when they teach science? This question has been the primary focus of a research program that commenced back in the mid 1980s and continues to the present time. Necessarily this research has been classroom based and over a period of a decade we have explored teaching and learning in a variety of settings in the United States and Australia (e.g., McRobbie & Tobin, 1995; Roth, Tobin & Shaw, 1997; Tobin & Gallagher, 1987; Tobin & LaMaster, 1995; Tobin & McRobbie, 1996; Tobin, Tippins, & Hook, 1994). Unraveling the complex social and cultural mazes of life in classrooms has been a challenge. Initially our explanations of what was happening were related to patterns that could be observed directly by members of our research team (Tobin & Gallagher, 1987). We identified numerous factors that shaped the enacted science curriculum, such as target students who monopolized interactions with the teacher, gender equity issues, and the nature of the assessment system (Tobin, Espinet, Byrd, & Adams, 1988). Gradually our foci shifted to patterns that related teacher beliefs to the manner in which the curriculum was enacted (Tobin & Espinet, 1989). The study of teacher beliefs then evolved to include the role of metaphor in constraining teacher and student actions (Briscoe, 1993; Tobin, Kahle, & Fraser, 1990; Tobin & LaMaster, 1995). As a landscape of understandings about teaching and learning emerged we began to examine the manner in which specific subject matter was taught in a context of social forces that distribute power and constrain actions throughout a social setting (Tobin, McRobbie, & Anderson, 1997).

The beliefs of a teacher are grounded in experience. Those beliefs that have proved to be viable, in the sense that they have enabled the teacher to meet his/her goals, are used as a guide for actions and those that are not viable in particular contexts are not used as referents for actions. To teach in ways that are consistent with particular beliefs about teaching and learning requires subject matter knowledge to support teaching roles. Thus a teacher might teach one way when s/he is in field and in a quite different manner when s/he is out-of-field. Shulman (1986) indicated that not only did a teacher have to know what to teach, but also how to teach in ways that facilitated students' learning. Shulman coined the phrase pedagogical content knowledge (PCK) to describe the professional knowledge of teachers. A teacher needed to know how to teach specific subject matter and what to do when students encountered difficulties in learning. Thus, for example, in the teaching of electrochemistry it is not sufficient to know only the subject matter of electrochemical cells, but the order in which topics should be presented, how to introduce them, what significant pieces of history to include, what demonstrations

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to employ, what questions to ask, how to respond to specific students' responses, what laboratory activities to adopt, how to assess what students learn, and how to apply the subject matter to the world outside of the classroom. In addition, a teacher ought to be familiar with the major research on teaching and learning the subject matter to be taught and learned, and the availability of learning resources, such as computer software, videodiscs, videotapes, and books.

The classroom is regarded as an evolving community of practice in which the discursive practices (e.g., talk, writing, cognition, argumentation and representation) of participants are constantly changing in response to the actions and interactions of a teacher and students, not only with one another, but also with social structures, such as conventions and norms (e.g., McGinn, Roth, Boutonné, & Woszczyna, 1995). Discursive practices involve text production, reproduction and consumption, where text is broadly defined as any written or spoken product (Fairclough, 1992). Learning occurs within a constantly evolving community that involves dialectical struggles in which "members' practices are shaped in ways of which they usually are unaware by social structures, relations of power, and the nature of the social practice they are engaged in whose stakes go always beyond producing meanings" (Fairclough, 1992, p. 72). Within a classroom community it is essential to consider what has been negotiated as viable against other knowledge claims and build consensus around what is agreed to be satisfactory ways to understand given phenomena. Eventually, negotiated consensus needs to be compared with the official knowledge of science.

If science is viewed as a form of discourse then learning science can be considered as learning a new way to make sense of experience. Discourse as it is used here refers to a "social activity of making meanings with language and other symbolic systems in some particular kind of situation or setting" (Lemke, 1995, p. 8). Lemke also noted that:

> Instead of talking about meaning making as something that is done by minds, I prefer to talk about it as a *social practice* in a community. It is a kind of *doing* that is done in ways that are characteristic of a community, and its occurrence is part of what binds the community together and helps to constitute it as a community. In this sense we can speak of a community, not as a collection of interacting individuals, but as a system of doings, rather than a system of doers (p. 9).

In a school science community one might expect to see students engage in ways such that, over a period of time, the discourse of a class would become more science-like. If the essence of science is to examine the coherence of evidence and knowledge claims then one might expect a form of discourse in science classrooms that involves students routinely in arguments over the efficacy of the warrants for knowledge claims. As has been advocated by Kuhn (1993), science could be regarded as a form of argument in which emerging conceptual understandings are related to evidence and the extent of the fit with canonical science.

If students are to learn science as a form of discourse it seems imperative that they are able to adapt their language resources as they practice science in settings in which others who know science assist them to learn by engaging activities in which co-participation occurs (Schön, 1985). As it is used here co-participation implies

the presence of a shared but constantly evolving language that can be accessed and appropriated by all participants to communicate with one another such that meaningful learning occurs. The shared language must be negotiated and would enable all participants to engage the activities of the community. Students receive opportunities to practice and observe others practice such that at any time a person might be both a co-teacher and a co-learner with respect to others in the community. Co-participation implies a concern for facilitating one another's learning and peer teaching is a critical constituent of such an environment. During interactions among participants respect would be shown for the knowledge of others and efforts would be made to find out why particular claims were regarded as viable. There would be concern for knowing in a way that is scientific and the knowledge that is learned within the community would be consistent with canonical science. Within this evolving knowledge community, concern would be shown for what is known by learners at any given time and how they can re-present what they know.

Power, which is constituted in the discourse, would be equitably distributed among the teacher and students such that knowledge claims that made no sense would be clarified and discussion would occur until such time that a learner was satisfied that s/he now understood. In a setting in which co-participation was occurring students would have the autonomy to ask when they did not understand and the focus always would be on what students know and how they can re-present what they know. Students would not feel that they could not understand and that their only recourse was to accept what was being said as an article of truth based on faith that other authoritative sources understand the warrants for the viability of a claim. Thus, co-participation would involve discussions in which participants tested one another's understandings and were sensitive to their roles as both teachers and learners.

As a teacher seeks to teach specific subject matter it is necessary for him/her to identify and retrieve relevant knowledge, re-construct it in his/her mind, and then re-present the knowledge in actions that are embodied in his/her perceived context and goals. Pedagogical content knowledge is involved in knowing what knowledge is relevant, re-constructing the knowledge in pedagogically appropriate ways, and re-presenting the knowledge in ways that effectively mediate the learning of all students in the class. That is, all learners must be able to access and appropriate the teacher's discourse. Thus, PCK involves knowledge of the subject matter, knowledge of the students and how they learn, and knowledge of the resources that can appropriately mediate learning. Being an effective teacher necessitates the teacher interacting in a community in ways that promote active involvement of others and change the discourse of the classroom to follow a trajectory of becoming more science-like.

This chapter describes science teaching in terms of the PCK teachers need in order to promote the learning of their students. We begin with an analysis of the teaching and learning of science from the perspective of the social construction of knowledge and the use of language to make sense of science. Then we present a case study that explores the teaching and learning of electrochemistry in a grade 11 class. The activities described in this case study do not feature co-participation and the discourses of the teacher and students are sufficiently different as to limit the extent to which students can learn with understanding. A second case study of a science teacher and his grade 8 class, show how the teacher and students co-participate in a range of activities in which they negotiate meaning and build consensus on what they have learned about oxidation. The teacher and the class are fictional and represent a composite of what we have learned in our histories as science teachers, teacher educators, and researchers.

UNDERSTANDING SCIENCE

To understand can be thought of in at least three senses. First, and in the most trivial meaning of understanding, one can know in a limited way, in which links with other science knowledge are not extensive. Examples of limited understanding include knowing the names of objects, facts, and definitions. Linkages between what is known might not be solely within a domain of science. For example, a link might be from something scientific to something non-scientific as occurs when students remember the colors of the spectrum of sunlight by remembering the name, Roy G. Biv. As well as memorizing the name, a learner must remember a one to one correspondence between the letters of the name and the first letter of a color. If these links are recalled an individual is able to re-construct the order of the colors when white light is dispersed.

Having re-constructed the colors to describe a spectrum this knowledge can be related to dispersion, diffraction and refraction to form a semantic web that can then be expanded to include properties of electromagnetic radiation such as wavelength, frequency, and velocity. New knowledge can be connected into the semantic web as a learner postulates a connection and then examines the extent to which the new knowledge coheres with existing knowledge. With some conceptual re-organization learners can develop relational understandings by constructing webs of relationships for given scientific subject matter. Relational understanding and limited understanding are parts of a continuum that differ in the number and quality of the linkages formed within a domain of knowledge. At some stage in the process of learning an individual might link scientific knowledge to his/her actions in the world outside of the classroom, to create patterns of understanding from everyday life experiences. Transformational understanding occurs when scientific knowledge, connected to cohere with the beliefs of an individual's lifeworld, is used as a basis for actions and interactions in communities that are not directly science-related.

A community of learners has its own ways of making sense and an associated language that enables participants to meet the goals of their everyday lives. When learners come together in a science classroom they bring with them their own languages as a diverse form of capital that can be used to form connections with the language of science. This process is fraught with difficulties because everyday language is often inconsistent with the discourse of science. Accordingly, it is imperative that students have opportunities to identify when and how their everyday discourse is compatible with the discourse of science and to figure out ways to resolve inconsistencies.

In their efforts to learn, science students can observe members of a scientific community, study what they do, and come to understand their goals. An essential part of beginning a journey from one discourse community to another is to build an understanding of the participants, the goals they seek to accomplish, the methods associated with the manner in which they construct meaning, the products associated with successful attainment of goals, and the review process employed in coming to a decision on whether or not goals were accomplished. A learner would examine the tasks in which scientists engage, how they go about participating in those tasks, and what they regard to be the products of their work. What are their goals and how do they know when they meet them? Who decides whether or not a participant has achieved in a satisfactory manner? Observing participants is one way to learn, but it is clearly desirable for students to extend their roles beyond being spectators. There are many ways of engaging, such as working at the side of a scientist and learning in much the same way as an apprentice might learn from a master tradesman. Alternatively, or as well, a learner might read accounts of famous scientists, watch videotapes of scientists in action, or participate in laboratory activities with peers. Having repeated experiences such as these an individual can come to know what participants in a discourse community do, how they make sense, what they come to know, and what they do with their knowledge.

Ideally students ought to engage in intellectual activities that are similar to those in which scientists engage. Learners need to practice the use of semantic tools to engage specific tasks related to the attainment of given scientific goals. In so doing they ought to employ written and oral discourse, symbolic reasoning involving expressions such as equations, and inscriptions such as sketches, diagrams, tables, graphs, and mathematical calculations. Thus, in the process of coming to know the students ought to have chances to describe, elaborate, clarify, review, change, question, and argue. By engaging these processes students build domain-specific understandings that make sense to them, however an issue that must be resolved is whether their knowledge fits with other knowledge they have and whether it can be used predictively to solve novel problems. Students need opportunities to fully test the adequacy of knowledge claims, to explain why given knowledge claims are viable, and identify warrants for those claims being considered viable. Are claims for viability based on internal sources such as tests of coherence or are they justified in terms of external sources in which one has faith, such as a deity, a textbook, a scientist, a teacher, a parent, or a peer? Rather than defer to the authority of experts it seems desirable that learners are able to relate their theories to evidence and examine those theories in relation to the canons of science.

The roles of the teacher are to practice science in ways that are within the reach of students and provide feedback on the adequacy of their students' science-related practices. If the teacher is to do this successfully it is essential that s/he use considerably more than subject matter knowledge of science, or more than the mechanics of when and how to pose questions and react to student responses. The what, how, and when come together in a package that is irreducible. The teacher has to make sense of student discourse in terms of the community of the student and then determine what to do to promote the learning of that individual.

When teachers teach they need to have a good grasp of the subject matter knowledge in two senses. First, they need to understand the science subject matter and re-present it in ways that are personally meaningful. That is, they will know some aspect of science in relation to other concepts of science, or they will relate science concepts to the knowledge used to meet the goals of everyday life. Second they need to know how to re-present their knowledge in ways that are potentially accessible to students, and how to mediate in the processes in which students engage the re-presentations of teacher knowledge and make sense of them in their own terms. In the process of trying to teach another, it seems imperative that the teacher is conscious of the manner in which knowledge can be constructed and re-presented in ways that are potentially meaningful to learners. Thus, effective teaching is not just a case of being able to re-present given scientific knowledge. An effective teacher also must know how to re-present a discourse that it is accessible to students and allow them to appropriate that discourse while co-participating in the processes of making sense of their learning environments and building understandings of science.

How can learners construct meanings from learning environments that are perturbed by the presence of a teacher and peers? What sense is made of the oral texts of the teacher and peers, of inscriptions on the chalkboard and in textbooks, and of the gestures made by the teacher in an endeavor to bring extra meaning to a lesson? Learning in a classroom can be thought of in terms of an individual re-presenting what is known and using language to make sense of the re-presentations of others and interactions with phenomena (such as manipulating a pendulum bob). The dynamic interactions between participants in a classroom environment are mutually constraining and facilitative of learning. Within the classroom community learners ought to co-participate in an evolving discourse in which the teacher and students engage. Most learners will need opportunities to use their discursive tools in ways that make their knowledge visible to themselves and to others, including the teacher.

All attempts at communication are imprecise and this creates a challenge for learners. Because they are building new discursive tools students ought to have opportunities to make mistakes and learn in a process of dialogue with others that include teachers and peers. Also there ought to be contexts in which learners would re-present their knowledge in activities in which they teach others. In the processes of negotiation and consensus building the teacher and learners communicate and test the extent of the fit of the re-presentations of one another. When the fit gets to an acceptable level it is concluded that a consensus has been reached, at least at the level that one feels that personal constructions bear a family resemblance to the constructions of the others with whom negotiation has been occurring. Students can reflect on the adequacy of their re-presentations and consider feedback from others while considering the efficacy of what they know. To what extent do given re-presentations fit with knowledge considered by scientists to be, for the moment at least, adequate re-presentations of reality? Characteristics of coming to know are the use of tests of the viability of knowledge claims and comparisons of the viability of alternative knowledge claims. What is the evidence for knowledge claims? To what extent are knowledge claims coherent with one another? Which re-presentations are of most value for the attainment of goals that are pertinent to a learner at a particular stage in the process of coming to know science? Seeking answers to such questions reflects not only an individual's struggle to make sense but also an effort to locate that individual's place in a community of learners.

AN ABSENCE OF CO-PARTICIPATION

Prior to commencing a demonstration with his class, Jacobs checked on the homework done the previous night. During this initial homework review Jacobs spoke 551 words compared to 6 words from students. His oral text did not permit co-participation nor provide insights into what students knew. There were few opportunities for students to show what they knew and to test the viability of their understandings. The emphasis was on the coverage and transmission of subject matter. Jacobs signaled to students that he was in charge when he called on them to look to the front to "get this right," and used questions to highlight salient points as he proceeded to review the main differences between electrochemical and electrolytic cells. The first part of the review focused on how students could remember the anode and the cathode in a particular electrochemical cell and a convention for drawing the symbol for a cell, the short stroke being negative and the long stroke being positive.

The lesson continued with Jacobs speaking. "Just quickly recap the important differences between an electrochemical and an electrolytic cell. Do you remember the two important things?" Jacobs established the significance of the content but did not complete his sentence, an intentional strategy to prompt Steve who had been talking with a peer for most of the early part of the lesson. Steve did not respond and Jacobs did not probe to identify reasons for his failure to respond. "The reaction occurs spontaneously. Good. And in an electrolytic cell, the reaction is forced. The way it is forced is by, applying ...?" Once again Jacobs directed his incomplete question in the direction of Steve. "Applying..." Steve repeated the final word uttered by Jacobs and was silent. He could not understand electrochemistry and had not completed the homework. Jacobs provided the correct answer. "An external source of energy. In this case it's electrical energy. Everyone look at question 10 at the bottom of page 103. We'll complete this really quickly then get on to experiment 1.7.2."

Jacobs was concerned about time. He wanted to show the students a demonstration of electrolysis and had not expected the homework review to take so long. Jacobs focused the class's attention on a diagram showing the difference between a lead acid battery during use and recharging. "What's the difference Suzie?" Suzie's response employed her everyday language and did not incorporate any of the principles discussed earlier in the review. Jacobs was agitated as he paraphrased her response, re-phrased the question, and directed it to another student. "One's got a light and one's got a battery. And the light is not only a light but it's a light that is working. And which one of those is the electrochemical cell and which one is the cell being recharged. Kim?" A satisfactory answer to the re-phrased question required a dichotomous choice. Although Kim did not respond Suzie made the right choice and Jacobs explained why the response was correct. Finally he could commence the demonstration.

Although students were not comfortable with the ideas associated with electrochemical and electrolytic cells Jacobs commenced a demonstration associated with electrolysis immediately after the homework review. The chemistry associated with the demonstration was much easier for students to grasp than the subject matter of the homework review. Jacobs' monologue during the demonstration was oriented toward providing students with an account of what he was doing and student participation was restricted to individuals assisting him to set up the apparatus, watching him, and listening to his oral text.

Jacobs performed the demonstration twice. First, he inserted the electrodes and increased the voltage. No current registered on the ammeter and there was no evidence of activity at either electrode. "Let me add some brine solution," Jacobs remarked. This time there was evidence of gases produced at both electrodes. Although Jacobs explained what he was doing he did not explain why he was doing it or require explanations from students. Why did he first apply an external voltage to electrodes immersed in distilled water? Was this designed for students to learn about the role of electrolytes? If so some discussion about electrolytes and the nature of the ions present in distilled water may have been beneficial. Were students aware that a small current was flowing through the distilled water? What difference to the electrolytic cell was made by the addition of brine? The failure of students to discuss the chemistry of what was happening may have reduced their opportunities to build relational and transformational understandings.

In the following excerpt from a transcript of the demonstration limited verbal interaction occurred when Jacobs asked the students to identify the gases produced at each electrode.

S: Hydrogen.
Jacobs: Hydrogen?
S: Chlorine.
Jacobs: Chlorine? Now that's interesting. Someone says hydrogen, H_2 (writes on board). What's the formula for chlorine?
(Several students say Cl_2 simultaneously.)
Jacobs: Cl_2 (writes on board). That was another suggestion. Anyone got another suggestion?
S: Oxygen
Jacobs: Oxygen. Okay. O_2. (writes on board) Well why on earth did you predict those? If you said hydrogen were you thinking that there must be hydrogen ions in there?
S: Yeah
Jacobs: Hydrogen ions present in the water. Well that could be a possibility. Okay why did you predict chlorine?
S: ... sodium chloride.
Jacobs: We had sodium chloride so that tells us?
S: Chloride
Jacobs: Chloride ions, good. Okay. Whoever predicted oxygen?
A student points to Michael, saying "Michael" (Teacher laughs)

Jacobs: Well in sodium chloride solution okay we're going to have sodium ion and (writing on board) chloride ion. Why did you predict oxygen Michael? Well why not? I don't blame you because oxygen is a gas that we can frequently get associated with water. But what ion could it come from? Well we might think about that soon. Now let's get back to the real thing, if there is hydrogen in there how could you test it to prove that it's there?
(Several students respond simultaneously, answers indistinguishable.)
Jacobs: You know about that, don't you? We can do a pop test in a moment and see whether or not. How can you test for the presence of chlorine?
S: Smell it and see.
Jacobs: Smell it is right. Do you know the smell of chlorine? Anyone here has got chlorine pool disinfectant, chlorinators at home that have a distinct smell? ... Okay. Donna, you're the one who's standing in the firing line there. Can you smell chlorine?
(Teacher and students laugh.)
Jacobs: Poor Donna! ......Can anyone smell chlorine? No obvious evidence of chlorine. Okay. Did you smell hydrogen or oxygen? (pointing to some writing on the board) These two gases are interesting to distinguish. Chlorine is a slightly yellow-colored gas, yellowish green. You know chlorophyll, that's the green part of the plant cell so the chlorine would be slightly green. Now there's a white backing, any greenness in either of those test tubes? No smell. No greenness. Doesn't look ... I've forgotten the ... Does anyone know the test for oxygen?
(Several students respond simultaneously.)
Jacobs: You need a lighted match. A match goes out when you put it in oxygen.
(Several students answer together.)
No.....
Jacobs: The match keeps burning?
S: For a little while, not long.
Jacobs: Tell me more. someone else?
S: ... Re-light ...
Jacobs: Well if you put a match in that's already lit, it's, what do you mean by re-light?
S: .....still coals there ...
S: It's red.
S: Yeah
Jacobs: If you put it in as it glows. Okay. Well Donna let's hope that some of those gases have accumulated in there now. Let's test the one which seems to be producing the most gas first. Which one is that? This one. What could that be, that's connected to the negative? This is an electrolytic cell. The negative in the electrolytic cell would be the ...? Cathode. Donna can you please just take your, if I grab this and put my finger over, then (actions not visible) ... (Teacher then lights a match.) light the match. Can't see anything, didn't hear any (Teacher blows out match.) evidence of a pop ... Result ... I was expecting a pop...
(Inaudible exchange between teacher and students. Some laughing.)
Jacobs: What's more, I know that the gas is hydrogen (laughing) but there's a bit of a problem with this apparatus isn't there. When I asked for the experiment to be set up by the lab assistants this is what they supplied me (holding up a piece of apparatus) but they didn't supply a vessel for it to go with. Now I discovered that about 5 minutes before the lesson. So very quickly at the end we've just substituted a U-tube for it. There's only one problem. How good a collection mechanism have we got? It doesn't look to be too satisfactory to me ... it's a windy day. I can feel the drift of air coming through this room on that side. Can you feel it? ... And here we've got a light gas, hydrogen, coming out of this electrode and when it gets here it's just getting blown away. It's not getting into this tube at all. And in fact let's take the other tube, thanks Donna, where I believe we're supposed to have oxygen. According to theory, if this is a glowing splint, when a glowing splint, and that's still glowing (Actions not visible) goes into oxygen it re-lights.
S: Is that staying alight?
Jacobs: You thought it continued to glow a bit. Look (picking up the splint from the desk). It's glowing still. Why's that? It's because of the wind in here today. It's replenishing the oxygen.

Throughout the interaction Jacobs accepted students' answers and elaborated on them, providing students with opportunities to revise their knowledge of gases and explain how to test for the presence of particular gases. There was minimal involvement from the students and few of their responses related to electrochemistry. Although the conversation was about descriptive chemistry studied in the previous year, students did not get involved substantively to make sense of the demonstration, predict what would happen, and test to see whether or not their predictions were viable. Jacobs endeavored to model good science by providing multiple explanations for the results of the demonstration. He did not try to fake a result, but stated that he was expecting a pop because his prediction was that the gas at one electrode was hydrogen. He also provided an explanation for the continued glowing of a splint in terms of air being blown onto the splint. Finally he reflected on the design of the apparatus and whether or not it was suitable for collecting a sufficient concentration of gas.

What Jacobs did not do in the interactions was to deal with unacceptable responses from students. Neither did he require students to produce oral or written texts to make their extant knowledge visible. In essence, Jacobs presented a script and student participation was minimal. That the demonstration did not work out as planned was not an issue for either Jacobs or the students. The demonstration was not an event from which students were expected to build understandings. Instead it appeared to be an opportunity for Jacobs to contextualize an oral text that contained subject matter to be accepted as fact. With just a few adjustments the demonstration could have been a rich context for co-participation. As it was Jacobs' discourse did not assist students to build mental models for electrolysis or to connect the demonstration to the subject matter dealt with in previous lessons on electrochemistry. Discussions about ion movement, energy transformations, oxidation, and reduction were absent even though the demonstration was an ideal context for such discussions.

Garnett and Treagust (1992) described a misconception as conceptual and propositional knowledge that is inconsistent or different from the commonly accepted scientific consensus. They listed a number of misconceptions about electric circuits and oxidation-reduction equations in electrochemistry (p. 1087) in terms of four categories: charge laws, electric current, potential difference and e.m.f., and oxidation-reduction. Jacobs did not engage learners around any of these areas to ascertain whether their understandings might be impeded by the occurrence of some of these misconceptions. During the lesson Jacobs employed 19 scientific terms associated with electrochemistry (e.g., half reaction, ions, negative electrode). In the same segment students employed only 5 of those terms. Only three students engaged overtly and there was no effort on Jacobs' part to ascertain whether or not the students had some of the pervasive misunderstandings of electrochemistry, misunderstandings that might prove to be a problem in making sense of the demonstration on electrolytic cells. There is no evidence that the students could understand these terms and make the connections necessary to make sense of the oral text. In fact, a lack of responses to several questions suggests that students were not making sense of the discourse. If there had been a greater degree of co-participation Jacobs could have checked for the presence of these misconceptions and assisted students to understand the science. He narrowed the focus of the lesson to the distinction between electrochemical and electrolytic cells. This focus on selected subject matter made it easier for him to complete the activity in time to commence a demonstration but created an environment in which students were not provided with opportunities to connect difficult concepts into a coherent array. Failure to encourage co-participation made it difficult for Jacobs to ascertain the extent to which students were constructing the relationships needed to make sense of electrochemistry. Opportunities were not provided in class for students to build a conceptual array, to test the coherence of the identified components of that array, and to test the viability of their knowledge of electrochemical and electrolytic cells. Furthermore, there was no discussion of the wider relevance of knowing the differences or understanding about either type of cell. For example, there were no discussions about corrosion of metals and industrial applications such as electrorefining and electroplating.

Garnett and Treagust list more than 50 propositions they regard as the foundational scientific knowledge about electrochemical and electrolytic cells. Many of these build upon knowledge of conceptually challenging areas of chemistry such as oxidation and reduction (e.g., the oxidation-reduction reaction that takes place is controlled and the oxidation and reduction half-reactions usually occur in separate compartments called half-cells). Jacobs was unaware of the research undertaken by Garnett and Treagust. Had he known about it there is no doubt that the lesson could have been planned to address a larger number of salient points about electrochemistry and he might have understood the need to examine the ideas that students bring with them to class. In fact, as the lesson was implemented there is a danger that some of the student misconceptions may have been reinforced. For example, Jacobs' comment that "the anode's negative" might reinforce a belief that the anode is charged. Even though he previously mentioned that it was a convention to regard the anode as negative he did not go on to say that neither electrode is charged and that the convention in chemistry is to describe the anode as negative because it is a source of electrons. Jacobs' failure to emphasize that the anode was not charged but was a source of electrons when the two electrodes were connected may have led to students to accept the viability of claims that the electrodes of an electrochemical cell are charged.

Jacobs' beliefs about the transmission of knowledge, teaching efficiently, and maintaining rigor comprised a coherent set that influenced the manner in which he planned and enacted the curriculum. The transmission myth views the teacher as a principal source and the students as receivers of knowledge. The myth was supported by three dimensions, an objectivist view of knowledge (Johnson, 1987), a mental model for teaching and learning that is characterized by memorization (Pitts, 1994), and a belief that the teacher should have power over students in most classroom situations. Jacobs also believed he had the responsibility to ensure that students learn at a level that is consistent from one set of students to another and from one year to the next. As guardian of the standards he believed his job was to maintain the rigor of the chemistry course by covering the prescribed subject matter, maintaining high standards, preparing students for the next educational level, and recognizing that the specification of the curriculum was the prerogative of external agencies.

Because of his beliefs about transmission, efficiency and rigor Jacobs made few efforts to elicit student re-presentations and usually was unaware of how they were making sense of what they were to learn. Similarly, because of his beliefs about learning he did not perceive a role for himself in mediating the construction of linkages within semantic webs of understanding. Even though Jacobs knew his electrochemistry thoroughly, his knowledge probably was based on his extensive teaching experience and did not seem to extend beyond the knowledge needed to transmit certain facts and perform particular demonstrations. Jacobs did not believe in an interactive model of learning and for that reason did not encourage co-participation. By maintaining a distance from his students and relying on transmission of facts he was not conscious about his failure to anticipate probable misconceptions and to address them during his activities. In addition, he did not encourage student interaction to facilitate their learning because he believed that he needed to have control over subject matter coverage to ensure efficient learning and maintain high standards. Thus, there is an interaction between the subject matter that needs to be known and beliefs about teaching and learning. With few exceptions Jacobs' PCK seemed adequate for the restricted roles he enacted while teaching. However, from a perspective of the roles he might have enacted as a mediator of understanding his PCK can be seen as limited. Not only did he need to know his facts about electrochemistry but also how to assist students to re-present what they know and how to constrain the experiences of students such that they build particular canonical understandings.

AN EMPHASIS ON CO-PARTICIPATION

Jasper's physical science class was focusing on chemical reactions and recently had studied oxidation reactions. "Today we will look at an interesting demonstration," said Jasper. "Watch carefully for the next 10 minutes and write down what you observe and why you think it happens the way it does." The students moved to the front of the room, organized themselves into groups of two, and began to make notes as Jasper lit a candle that was standing vertically in about two inches of water in an aluminum dish. The party candle was burning vigorously as he carefully placed a gas jar, mouth downward, over the burning candle. The candle continued to burn brightly for a time before flickering and gradually extinguishing.

"Are those bubbles?" asked Jason.

Sherry, nodded, "I think it is air from the jar. The air will expand because it is heated. The pressure might have forced some bubbles through the water."

"The candle went out because the oxygen is all used up," noted Jason.

"The class became quiet. Is the level of the water in the jar rising?" Sherry was enjoying this activity because it required her to keep a sharp watch for changes and she was good at doing that. Slowly the water edged its way higher in the jar. "How high do you think it will go?" Sherry asked Jason.

"If all of the oxygen was used up I would expect it to go up by about 20 percent of the way because the oxygen is used up. Get it? The oxygen isn't there any more so the pressure is less on the inside and the water is pushed up from the outside."

Sherry looked dubious. "There's smoke on the side of the jar and the glass looks moist," she noted. "Perhaps the water put the candle out."

"What water?" challenged Jason.

"Well. I think I can see some condensation on the sides of the container. Lets think about what is going on."

"I'd like you back in your seats now." said Jasper. See if you can write a description of what happened and reach an agreement. Try to explain the changes you observed in terms of physical and chemical principles.

"First the candle began to smoke..." said Sherry, reading from her detailed notes. Jason had relied on his memory to a greater extent and readily accepted Sherry's observations.

Jasper moved around the room and thought about the demonstration. He was pleased with the conversations he had heard and also he was pleasantly surprised at the quality of the cooperation and the notes that were being taken. Furthermore, he had introduced this activity at just the right time. Because the students had been looking at oxidation as a class of chemical reactions the group was on the lookout for oxidation and immediately associated the burning candle with the formation of oxides. Not only was the oxygen being used up, but also there were oxides being produced. Not every one was on to it, but at least four groups had discussed water and carbon dioxide as products of the burning candle. In addition, some of the students had noted carbon deposits on the collection jar. Jasper was confident that in the class as a whole about everything of importance that he wanted the students to observe had been noticed. Perhaps I will organize two groups to consolidate their results, thought Jasper. "Can I have your attention?" he requested. The noise dropped at once. "Within each group each person will take a number, 1 or 2. The ones can meet with Sherry at the front of the room and the twos can meet with Jason at the back. Your task is to reach consensus on what happened and the reasons for what happened."

As the students discussed their results and negotiated a consensus Jasper went to the whiteboard at the side of the room and began to list a number of concepts: expansion of gases; pressure; yellow flame; black smoke; condensation; bubbles; water rising; pressure on outside surface of water; extinguished candle; chemical reactions; oxidation; water; carbon dioxide; composition of air; nitrogen; oxygen. He would ask the students to place these terms in a concept map with any others they might want to add. "Now," he said, "Return to your initial groups. Check out the consensus you reached and resolve any differences. Work together to build a concept map containing these terms on the board and add any others you like. When you feel good about your concept map enter it into C-Map. This can be a part of your portfolio."

Jasper had a vast array of PCK, but to make it apparent to readers of this chapter we need to consider what he did from the two perspectives developed earlier. First, to consider how he went about trying to facilitate understanding we consider a which the students are prepared and able to maintain a high self-esteem with respect to the learning of science.

CONCLUSIONS

Within the classroom the teacher adopts a mediational role, demonstrating his/her discourse and providing cues to assist students to practice and build their knowledge of science. Three areas of engagement are of most importance in a classroom: dealing with the extant knowledge of students; providing opportunities for students to experience and in the process build new discursive resources; and establishing a climate in which knowledge claims are related to overt warrants for their viability. As long as the students are engaging in ways that make it possible for the teacher to see what they can do, there are many options for the teacher. The teacher can speak to students about their performance or s/he can show them how to improve their performance. Co-participation in the community is an essential requisite for effective mediation of learning. Schön (1985) described the type of situation that might evolve within a community in which a teacher is mediating the learning of students in the following way:

> As the two persons approach convergence of meaning, their speech becomes more elliptical, they use shorthand in word and gesture to convey ideas that might seem complex to an outsider; they communicate with greater confidence; they finish one another's sentences, or leave sentences unfinished. (p. 64)

When students endeavor to learn something new they need to re-construct relevant prior knowledge. Two challenges confront learners, how to decide what is and is not relevant and how to re-present what is known in ways that best lend themselves to making sense of what they need to learn. Through conversations in which co-participation occurs the teacher can have a role in assisting students to identify and re-present relevant prior knowledge. Such conversations would focus on the knowledge of students and the appropriateness of different re-presentations for learning given science subject matter. A teacher can establish a climate in which students are expected to test the viability of their knowledge. Thus, when students participate in the community this expectation can be observed in their efforts to provide evidence for knowledge claims in all written and oral texts. If such evidence was not volunteered a characteristic of a scientific community is that others would request it. Within the community of classroom science concern can be directed toward the extent of the fit between personal understandings, classroom consensus, and canonical science. The class goal would be to attain a level of understanding that would be consistent with the understandings of scientists.

An initial first step in establishing an environment conducive to learning is to enable students to make their knowledge and thinking processes visible to others. Conversations can take account of what is known by learners and efforts can be made to negotiate and build consensus around goals that are of significance to a community. Although it is common for teachers to analyze the goals of a community and determine instructional paths based on hierarchies of prior knowledge

needed to attain the goals, the ideal trajectory commences with the extant knowledge of each participant in a community and emphasizes interactions that incorporate negotiation of meaning and building of consensus. The teacher, who knows the subject matter to be learned, will recognize that a logical breakdown from the perspective of one who knows, may not be perceived as logical by those reconciling the extent of the fit of given teacher re-presentations with their own re-constructions. Accordingly, it is imperative that co-participation facilitates conversations about the extent of the fit between the re-presentations of participants in a community.

In Jacobs' class failure of a student to respond, or an incorrect response, was a signal to the teacher to provide a correct response. Students were expected to memorize the correct response and were not required to reconcile the difference between their response and what was asserted as correct. An alternative that is consistent with the concept of co-participation was evident in Jasper's teaching. Jasper asked students to provide evidence for understandings they have and, when there was an inconsistency, he initiated a conversation about that inconsistency. Conversations about the viability of knowledge can occur routinely and involve a teacher with students, students with students, and the self talk of students as they reflect on the adequacy of their own understandings. If these conversations are to occur and be productive it is imperative that teachers plan sufficient time for them to occur.

Because students have a greater likelihood of making sense of the discourse of peers it is important to provide opportunities for student-student interaction in which the written and oral texts of the students are used as bases for interaction. During such interactions there are opportunities for negotiation of meaning in which students clarify what they mean, elaborate on findings, and compare knowledge claims against evidence such as other knowledge claims or data from an investigation. If students share a discourse the power differentials can be less significant than often occur in teacher-student interactions. If student-student interactions are to be productive it is important that students are clear about their goals and are committed to building relational and transformational understandings.

Although Jacobs was concerned that students understand canonical science he did not assist them to compare the claims of canonical science with their own understandings. When errors occurred he was inclined to provide correct answers to questions but did not challenge the answers of students or require them to provide evidence for their answers. Failure to do so led to an environment in which student re-presentations were visible, usually as short oral responses, but the frameworks supporting those responses were invisible and often intuitive. Assisting students to make their own frameworks visible allows them to reflect on those frameworks and put them to the test. Accordingly, an important part of the mediational role of the teacher is to create conversations around the knowledge assertions of students. These conversations can then link to canonical understandings via a chain of small group and whole-class consensus that is established within the course of a lesson.

An important part of students being aware of the limitations of their own understandings is being able to compare what they know to common misconceptions. For example, in Jasper's class a common misconception is that the water moves up the jar because the oxygen is consumed. No attention is given to the products of the chemical reaction in which oxides are produced. Similarly, it is common for learners to regard the electrodes of an electrochemical cell as being charged. If teachers are aware of the common misconceptions about given subject matter and bring these to the attention of the participants in a community then there are opportunities for them to relate their own understandings not only to canonical science but also to these pervasive misunderstandings.

Two forms of discourse were apparent in Jacobs' class, one associated with students and one with Jacobs' voice and canonical science. The extent to which the two forms of discourse overlapped was negligible even though Jacobs made some efforts to paraphrase and elaborate on student responses to his questions. Jacobs' concern was to progress through the subject matter, interacting with students to the extent that at least the correct understandings could be provided, and ensuring that he completed most of the work planned for the lesson. The main goal of the lesson was to present correct answers and cover the content rather than to ensure that students understood the subject matter. The understanding of subject matter was left to students to accomplish either as a result of their own thinking during the class or in out-of-class settings. Although there are many types of activity that would enable students and the teacher to forge a new discourse, each of them would involve students being able to create written and oral texts around which interactions, negotiation and consensus building would occur. It is assumed that all participants would, over time, acquire a discourse that was more science-like.

The two separate discourses that were so evident in Jacobs' class were not apparent in Jasper's class. By focusing on the re-presentations of learners Jasper was able to facilitate the development of a shared language that formed a bridge between the languages of science and the students. The formation of a shared language and an ever-present concern that all students would access and appropriate a shared language is the essence of PCK. Evidence of Jasper's success as a teacher is the varied texts produced by each student in his class and the extent to which conversations about them were inclusive of all learners. That Jasper could build and sustain such an environment in his class reflected strength in his knowledge of science, his beliefs about teaching, learning and the nature of science, and an unwavering commitment to all of his students learning with understanding.

Power within a community needs to be distributed such that all students have equitable access to resources to enhance their learning. In essence this means that all participants have the autonomy to co-participate in the discourse of the community. If someone speaks then an individual has the freedom to comment on what was said or to ask questions. Of course, after another person has spoken, many verbal moves are possible. At issue is whether a person is able to participate verbally in the practices of the community. There are several scenarios in which co-participation does not occur. For example, perhaps a teacher is using a form of discourse that is inaccessible to the learners. If that is the case they might not raise questions because of a fear that they do not know enough to ask a question, or they might not co-participate because the teacher does not provide the opportunities for

them to participate. In each instance the teacher engages in a form of monologue and the students do not interrupt the flow of that monologue. The power of the teacher is constituted in a form of discourse that cannot be appropriated by the students, leaving them with little recourse other than rote learning. How then can a teacher avoid monologues that disempower learners? It seems apparent that the critical element of an instructional strategy is to allow students to practice in a co-participatory way using their discursive tools, and thereby render their performance visible to themselves and others. What form of autonomy is this? It seems essential that through gestures and writing at least students can communicate what they do and do not understand. Students also could write questions that need to be answered and when necessary interrupt the flow of delivery by asking questions orally. Within each classroom the conditions under which co-participation is possible and encouraged needs to be negotiated and enacted such that learning can be optimized for all students.

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SECTION IV

IMPACTS OF PCK ON THE DEVELOPMENT OF SCIENCE TEACHER EDUCATION PROGRAMS

CARLA ZEMBAL-SAUL, MARY L. STARR AND JOSEPH S. KRAJCIK

10. CONSTRUCTING A FRAMEWORK FOR ELEMENTARY SCIENCE TEACHING USING PEDAGOGICAL CONTENT KNOWLEDGE

Reform efforts in science education have emphasized the increasing importance of preparing effective teachers. In *The Future of Science in Elementary Schools: Educating Prospective Teachers,* Raizen and Michelsohn (1994) stress a number of qualities associated with effective science teachers. Among them are:

- an appreciation of scientific reasoning skills (e.g., posing questions, designing investigations) and "habits of mind" (e.g., desire for knowledge, skepticism), as well as an understanding of how to foster them among students;
- a specialized knowledge of appropriate ways to represent science to children (e.g., analogies, experiments, demonstrations);
- an awareness of children's informal ideas, prior knowledge and experience, especially as it relates to science concepts with which they are likely to experience difficulty; and
- the ability to orchestrate science learning through the use of various organization structures, including cooperative groups.

In a review of Raizen and Michelsohn's work, Penick (1994) suggests that these recommendations fall short of what needs to be done. He asserts:

> (Raizen and Michelsohn) should advocate a real program, one with cohorts of students who stay together for years, long enough to really form a cohort. Within those cohorts, weave modeling of desired instruction, science and education, all within a research-based rationale and framework. Rather than merely praising reflective teaching, why not discuss theory and goal driven reflections. We rarely see what we are not looking for. Our teacher education programs must make clear the roles and goals of students as well as teachers. Without specific understanding and awareness, our teachers will see little when they look at their own teaching.

In this chapter, we will describe a program that implemented several of Penick's suggestions. This elementary science teacher preparation program[1] was crafted using the various components of pedagogical content knowledge (PCK) as guide-posts to coursework, assignments, field placement experiences, and program structure while attempting to meet the professional development needs of preservice teachers. We begin by establishing the context for the chapter with an overview of the teacher preparation program. Next, we look specifically at program components and correlate them with the knowledge bases for teaching, particularly PCK. This is followed by a review of recent research findings that report the impact of the teacher preparation program on preservice teachers' first experiences teaching

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science to elementary school children. Finally, we draw on the apparent successes and challenges of the teacher preparation program to make suggestions regarding further applications of the construct of PCK in science teacher preparation.

OVERVIEW OF PROGRAM

The two-year teacher preparation program described here was funded by a grant from the National Science Foundation. In this chapter we provide an overview of the program; however, more information about the program is available elsewhere (see Krajcik, Blumenfeld, Starr, Palincsar, Coppola & Soloway, 1993; Krajcik, Starr & Zembal-Saul, 1997). In general, elementary education majors entered the program in their junior year at the university and complete the program with student teaching four semesters later. The preservice teachers progressed through the program as a cohort, taking the majority of their classes together. In this chapter we will focus on the first two semesters of the preservice teachers' coursework and teaching experiences. The data that are included here were drawn from two consecutive cohorts of preservice teachers, those who began their preparation in the fall of 1991 and those who began in the fall of 1992.

Program Features

The elementary science teacher preparation program was organized around several key features -- (1) integrated coursework in science content, science methods, educational foundations, and practicum; (2) assignments and experiences designed to integrate key concepts from coursework, and (3) multiple opportunities to teach. Each of these features was situated in a consisted framework of inquiry-based science teaching and learning (Magnusson, Krajcik, Borko, this volume).

Coursework. Program coursework was highly integrated in an effort to help the preservice teachers synthesize their developing understanding of teaching science. The preservice teachers were enrolled in a chemistry course during the first semester of the program and a physics course in the second semester. Both were closely coordinated with a year-long science methods course in which they were concurrently enrolled. The science methods course helped the preservice teachers represent concepts that they were learning in chemistry and physics in ways that were meaningful to elementary school children. The preservice teachers were also enrolled in foundation courses -- Educational Psychology and Introduction to the Elementary Classroom. Educational Psychology emphasized instruction, learning, and assessment, while Introduction to the Elementary Classroom focused on classroom operation, management of various participation structures, individual differences among learners, and general issues associated with education.

The coursework also was connected with a year-long practicum experience. Students spent one day each week in their placement classrooms. The cooperating teachers were volunteers who taught science regularly. Program staff and cooperating teachers met as a group on several occasions to discuss program philosophy, operation, and expectations for preservice teachers. Together the cooperating teachers and program staff generated a list of desired practicum experiences for preservice teachers. These experiences included working with individual students (e.g., tutoring, enrichment activities), small groups (e.g., coordinating a reading group), and whole groups.

Unit Design. Another important feature of the program was that it involved assignments and experiences designed to integrate key concepts from content, methods, and educational foundations coursework. During the first year of the program, the central assignment was the unit design. Each semester, the preservice teachers worked in pairs to develop a fifteen-day science unit. The subject matter of the units typically paralleled that of the content courses.

The units were created using a computer program called Instruction by Design (IByD).[2] This technological tool facilitated the preservice teachers' development of units that included a concept map, unit goals, and teacher and student activities (see next section), as well as the integration of these components. A unit design graphic (see Figure 1), was used to organize these three unit components. Each component was assigned a graphic symbol (e.g., student activities = rectangles; teacher activities = parallelograms). These symbols could then be connected to illustrate more specifically how concepts, goals and activities were related. This graphic provided both the preservice teachers and the program instructors with a concise overview of the content and the planned goals and activities of the unit.

As mentioned above, IByD included an integrated concept mapping program. This feature assisted the preservice teachers in developing a concept map of the content they planned to teach. In many instances, the development of the concept maps created dissonance for the preservice teachers between what they thought they knew about the topic and what they actually understood. They were then forced to further investigate their topic to clarify and refine the maps and their understanding. An example of a concept map is included in Figure 2.

Based on the maps, the preservice teachers created unit goals. These goals and the teaching and learning activities that were chosen to meet them, were developed through a recursive process. The preservice teachers were encouraged to question the connections between their chosen activities and their written goals throughout the development process. Considerations, which are described below, were used to assist the preservice teachers in this process.

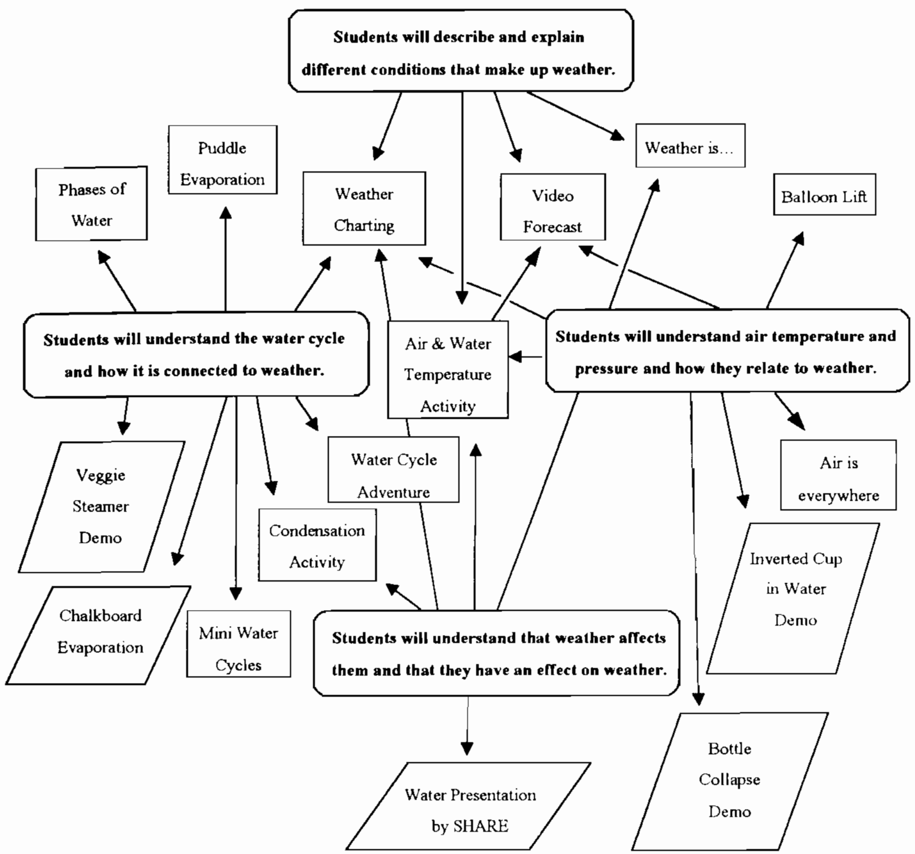

Figure 1. Unit design graphic for Water, Weather & Air unit.

With the selection of each activity during the planning process, the preservice teachers were asked to respond in writing to a structured set of *considerations.* The purpose of the considerations was two-fold. First, they were intended to provide preservice teachers with a series of general questions to guide their thinking during planning. More specifically, the preservice teachers were asked to attend to representing concepts accurately, addressing the needs of learners in terms of prior knowledge and cognitive engagement, and anticipating contextual issues, such as managing participation, resources, and time. Second, the considerations provided preservice teachers with a way to evaluate their own plans prior to receiving feedback from program staff. For each broad area, the preservice teachers generated more specific questions. With regard to management, for instance, a more

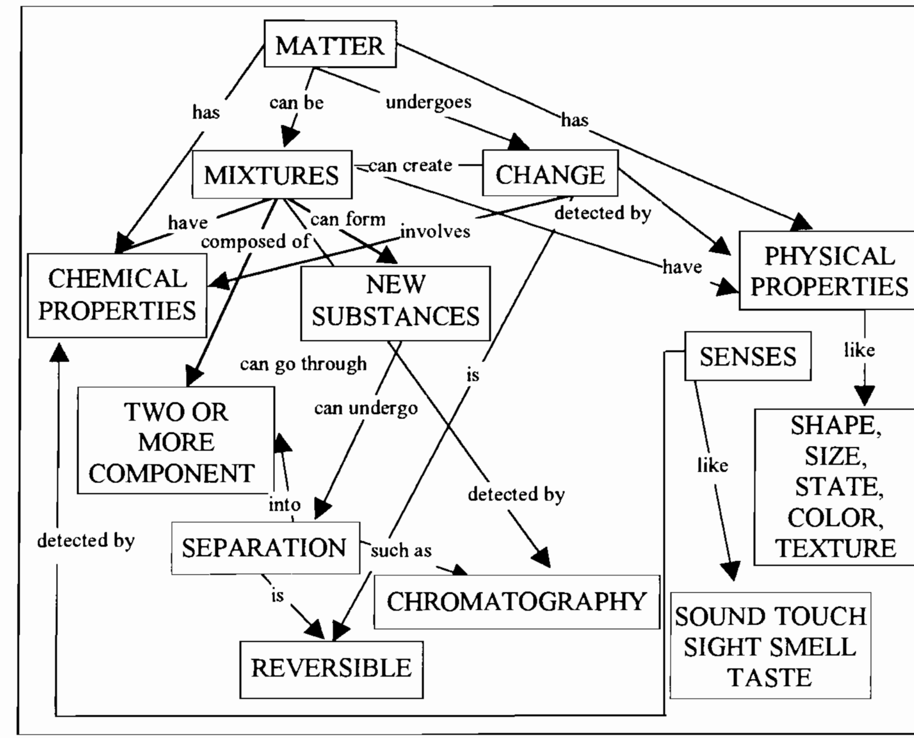

Figure 2. Concept map created for a three day teaching experience.[3]

specific question might be, "If students are working together during a scientific investigation, how will I monitor them for engagement?" Moreover, in each program course, the preservice teachers learned strategies for dealing with various considerations. For example, in science methods, they explored developing multiple, accurate, and concrete representations of science concepts.

Opportunities To Teach. The program also provided preservice teachers with multiple opportunities to engage in cycles of planning, teaching and reflection. The first of these was Apprenticeship Teaching, which took place during the first eight weeks of the program (Zembal, Blumenfeld, Krajcik & Palincsar, 1994). This early peer teaching situation required the preservice teachers to plan and teach lessons developed from a modified version of the *What's in Our Water?* unit (National Geographic Kids Network, 1991). As opposed to discrete lessons, a unit provided more opportunities to create links among concepts and develop a particular set of concepts over time. Whole group reflection sessions for each lesson were structured around the previously described considerations, introducing the preservice teachers to issues of representing content, attending to the needs of learners, and managing participation, resources and time. Emphasizing these issues while engaging preservice teachers in planning, teaching and reflection over time, was intended to assist them in developing an initial way of thinking and talking about content representation. This experience served to prepare preservice teachers for subsequent teaching experiences.

During each semester of the first year, the preservice teachers worked in pairs to teach three consecutive lessons from their fifteen-day unit plan in their practicum classrooms. There were many program supports in place to assist the pairs in planning for their three-day teaching experience. In addition to receiving guidance from their cooperating teachers, the preservice teachers initially met with their university supervisor to discuss content ideas and potential resources. The pairs then planned their lessons using the structured planning considerations to guide them through the process. Each lesson plan included an overview, goals, a materials list, and elaborated introduction, development, and closure sections. In addition, the preservice teachers were required to prepare written justifications of their plans based on the considerations.

Prior to teaching, the preservice teachers met with their university supervisor at least once to review their plans. During these meetings, the preservice teachers were asked to use the considerations to justify their plans. The purpose of this meeting was two-fold. First, it served as an opportunity for the preservice teachers to articulate and clarify their teaching plans. Second, it allowed program staff to provide suggestions and to point out any critical issues or potential problems that were not adequately addressed in the plan. In other words, it was a way to strengthen the plan and avert potential difficulties in the classroom.

Next, the teaching pairs enacted their instructional plans in the context of their practicum placements. All teaching sessions were videotaped by program staff. Finally, the preservice teachers were required to watch their videotaped instruction and generate written reflections regarding the strengths and weaknesses of their content representations. Their reflections were guided by the same questions used for planning. These considerations prompted preservice teachers to address the strengths and weaknesses of how science concepts were represented, how the needs of learners were met, and how participation, resources and time were managed. The pairs then met with a university supervisor to debrief their teaching.

INTEGRATING KNOWLEDGE BASES

Shulman's research (1986, 1987) points to helping preservice teachers integrate knowledge bases in planning for instruction as a primary purpose of teacher preparation. This knowledge, however, cannot be communicated as a fixed set of rules or information; teachers must construct their understandings. Shulman and his colleagues (Grossman, 1991; Shulman 1986, 1987; Wilson, Shulman & Richert, 1987) have described the diverse sources of knowledge -- of content, representations of content, pedagogy, curriculum and learners -- that teachers draw on in teaching. Their work points to the important role of subject matter knowledge in effective science teaching; however, subject matter knowledge in and of itself is not sufficient. New teachers must also develop pedagogical content knowledge -- knowledge of the most effective ways to teach various concepts, and knowledge of curriculum, learners/learning and instruction. Novices need to develop representations (e.g., examples, explanations, metaphors, investigations) that can be adapted to diverse interests and abilities of learners. This capacity to transform subject matter knowledge into forms that are pedagogically powerful and adaptive to particular groups of students is at the core of successful science teaching. Work by Krajcik, Layman, Starr and Magnusson (1991) indicates that pedagogical content knowledge in science develops slowly.

In the next section, we highlight the ways in which this teacher preparation program attempted to address and integrate Shulman's knowledge bases for teaching. We begin with subject matter knowledge, proceed to general pedagogical knowledge and knowledge of context. We conclude this section with an in-depth discussion of how pedagogical content knowledge informed various program components.

Subject Matter Knowledge

There is strong evidence of a critical relationship between subject matter knowledge and effective science teaching. McDiarmid, Ball and Anderson (1989) suggest that prospective teachers must develop flexible, thoughtful and conceptual understanding of the subject matter if they are to create and/or select representations of content that are appropriate and meaningful to learners (see McDiarmid, et al., 1989 for elaboration and examples). There is considerable evidence, however, that elementary and secondary preservice teachers do not have adequate knowledge of the key ideas in their disciplines (Ball & McDiarmid, 1990; Grossman, Wilson & Shulman, 1989; McDiarmid et al., 1989; Wilson & Wineburg, 1988). In addition, they typically lack understanding of the organization and connectedness of topics in their discipline. Both of these factors interfere with their ability to develop powerful content representations.

In this teacher preparation program, we attempted to meet the subject matter knowledge needs of the preservice teachers in a variety of ways. First, as mentioned previously, the preservice teachers were required to take two content courses, one in chemistry and one in physics. Enrollment in these courses was limited to students in the program. In addition, the content courses were developed specifically for prospective elementary teachers. That is, they were designed around the science concepts and representations that are typically introduced at the elementary level. The courses also included a laboratory section for the purpose of engaging preservice teachers in developing an understanding of the process of science. The instruction in these courses, particularly the laboratory, paralleled the inquiry-based instructional orientation that was the focus of the program. For example, the physics course included an extended investigation of batteries and bulbs following an inquiry approach. This approach was adopted so that preservice teachers could experience, as learners, the types of science instruction promoted by the teacher preparation program and expected in their teaching.

The program also addressed the subject matter knowledge needs of preservice teachers through the use of concept maps. As mentioned previously, concept maps were used to assist the preservice teachers in identifying and developing relationships among critical concepts in each of the units they taught. The preservice teachers were required to create a concept map prior to planning for instruction. These concept maps assisted the preservice teachers in developing an understanding of the content and applying that understanding to the selection and modification of learning tasks. After completing a draft of their maps, the preservice teachers were given feedback on the concepts and connections included in the map. This feedback was provided to facilitate the revision process.

General Pedagogical Knowledge

Another knowledge base transformed in the development of PCK is general pedagogical knowledge. Although the program described here focused on science teaching in the elementary school, the importance of general pedagogical knowledge in teaching was not minimized. General pedagogical knowledge was addressed through several courses. Instructional principles, classroom management, topics of learners and learning, and the goals of education in the United States were discussed both in the general methods course and in educational psychology. These courses were taught in the first semester of the preservice teachers' preparation. The general methods class included consideration of many types of organizational structures in which different roles and responsibilities of teachers and students were examined. In educational psychology, the preservice teachers were introduced to learning theories, educational aims in American schools, and the identification and development of educational objectives.

As discussed previously, considerations guided the preservice teachers in the selection, critique, and modification of teaching and learning activities. General pedagogical knowledge was very important in the development and use of the considerations. The preservice teachers were encouraged to develop some considerations that would be useful in all of their lesson planning, not strictly their science teaching. For example, the preservice teachers were expected to consider, "How will you organize the students to achieve understanding of the key ideas? If students are to work together, how will you help them?"

Finally, the preservice teachers put into practice their emerging understanding of general pedagogical knowledge through three authentic planning and/or teaching experiences -- apprenticeship teaching, three-day teaching, and the fifteen-day unit design. These authentic activities will be discussed more fully as they apply to PCK later in this chapter.

Knowledge of Context

Knowledge of the context of teaching is critical to teaching success. Preservice teachers' limited practical knowledge of classrooms, however, has been implicated as an underlying reason for difficulties preparing and implementing powerful representations of content (Borko & Livingston, 1989; Kagan, 1992). While they have a wealth of experience as learners in classrooms, preservice teachers have minimal experience orchestrating classroom activities. This leads to unrealistic expectations regarding what they can do in terms of content, organization, and time. Therefore, preservice teachers tend to create plans that attempt to accomplish too much, and often undertake activities that are not feasible because they are too complex. It has also been reported that because preservice teachers have limited practical knowledge of classrooms, they tend to become preoccupied with management issues and control. This remains a salient feature of their instructional experiences throughout their teacher preparation programs and often into their first years of teaching (Kagan, 1992).

In this program, we attempted to assist preservice teachers in dealing with the complexities of the classroom in a more systematic manner in several ways. First, the preservice teachers were involved in a year-long practicum that connected university coursework to practical experience. Practicum experiences have been identified as a potentially powerful approach to helping preservice teachers improve their ability to carry out planned representations of content. Such experiences can help preservice teachers learn more about students' ideas, abilities, and interests and about what is feasible to accomplish in the context of the classroom (Kagan, 1992). In terms of this program, the integration between the university coursework and practicum placements was critical in assisting preservice teachers in connecting theory with practice when attempting to make sense of the complexities of classroom context.

Second, research suggests that the cooperating teacher can strongly influence beginning teachers in terms of what and how they teach (Borko & Mayfield, 1995). In this program the cooperating teachers were selected because they valued the teaching of science and modeled effective science teaching in their classrooms. In addition, the cooperating teachers were introduced to the philosophy of the teacher preparation program through meetings with program staff. There was also frequent contact among the cooperating teachers, preservice teachers, and program staff throughout the school year. As a result, preservice teachers learned about classrooms while being immersed in contexts that supported and modeled effective science teaching.

Third, the preservice teachers maintained the same practicum placement for the entire academic year. This provided the preservice teachers with a consistent situated experience in which they could consider, apply, and test some of the ideas that were presented in the coursework. This extended experience also gave the preservice teachers a chance to learn about the classroom environment, develop meaningful relationships with students, and see the progression of student learning throughout the entire academic year.

Finally, the preservice teachers were assisted in understanding the complexities of elementary classrooms through a structured set of program assignments. These assignments began with guided observations of classroom activities and moved the preservice teachers toward whole group instruction. Pre-classroom teaching experiences, such as Apprenticeship Teaching, were also used to scaffold the preservice teachers' development. More specifically, Apprenticeship Teaching provided an opportunity for preservice teachers to grapple with issues of representing content, attending to the needs of learners, and managing participation, resources, and time while minimizing the often overwhelming complexities associated with elementary classrooms.

PEDAGOGICAL CONTENT KNOWLEDGE FOR ELEMENTARY SCIENCE TEACHING AND LEARNING

The construct of pedagogical content knowledge guided the teacher preparation program in assisting preservice elementary teachers in planning and enacting effective inquiry-based science instruction. In what follows, we describe the program features that focused on orientations toward teaching science, curricular knowledge of science, knowledge of specific science curricular programs, and knowledge of instructional strategies useful in science teaching.

Orientations Towards Elementary Science Teaching

Much has been written about orientations toward teaching and the impact a teachers' orientation toward teaching a specific content area has on their effectiveness. It has been suggested that a teacher's orientation to teaching science creates a 'conceptual map' that can be used to critique, develop, modify, and enact specific teaching and learning activities (Borko & Putnam, 1996). Magnusson and colleagues (this volume) suggest that there are several orientations to teaching science. Within an inquiry orientation, the teacher "supports students in defining and investigating problems, drawing conclusions, and assessing the validity of knowledge from their conclusions" (Magnusson et al., this volume, p. 101). This orientation toward teaching science provided a framework for the program and for guiding the preservice teachers' thinking about science teaching. Previous research suggests that promoting a framework within a teacher preparation program has the potential to influence preservice teachers' understanding of teaching and learning and their ability to use the framework in their own teaching (Hollon, Roth & Anderson, 1991; Zembal, 1996; Zembal, Krajcik & Blumenfeld, 1996).

The teacher preparation program attempted to understand the preservice teachers' incoming knowledge and beliefs and consistently model an inquiry-based orientation in several ways. First, as mentioned previously, the preservice teachers' science learning experiences in the content and methods courses followed the inquiry model. Second, the preservice teachers' experiences learning about teaching and learning were inquiry-based. For example, the preservice teachers were expected to engage in defining problems which they investigated and from which they drew conclusions about teaching science for understanding. In addition, the considerations challenged the preservice teachers to assess the validity of the knowledge they used to answer questions about teaching and learning. Third, the preservice teachers were expected to develop inquiry-based instruction for their classroom teaching experiences.

Curricular Knowledge of Elementary Science

Knowledge of Goals and Objectives. Within the context of teaching, it is important for teachers to identify what they want students to learn and how the students should go about learning it. Explicit goals and objectives provide teachers with a set of guidelines for what students should learn. As mentioned previously, considerable time was spent in educational psychology assisting the preservice teachers in developing clear, concise and assessable goals and objectives. Unlike behavioral objectives, these were focused on the learning outcomes of students and answered the question, "What do you want students to know/understand by the end of the lesson?" The preservice teachers were expected to use these objectives in developing their teaching experiences. The preservice teachers were encouraged to draw on their practicum experiences to develop the goals, objectives, and teaching and learning activities.

Practicum seminar provided a vehicle for discussing goals and objectives at particular grade levels and across the curriculum. Several pairs of preservice teachers in each cohort were assigned to the same grade level in the same school district. During the practicum seminar, these preservice teachers were able to share their ideas and understanding of the goals and objectives of science teaching at specific grade levels and develop an understanding of the longitudinal progression of science concepts throughout the school year. In addition, the preservice teachers were assigned to all elementary grades. As a result, the preservice teachers were able to consult with their peers regarding the goals and objectives for science teaching across grade levels as they discussed practicum experiences and their plans for teaching. In doing so, they developed a notion of the vertical elementary science curriculum.

Knowledge of Specific Elementary Science Curricula. Reform movements in science education have produced many curricular programs over the years (e.g., Elementary Science Study, Full Option Science System, Science: A Process Approach, Insights, Science - Technology - Children). In addition, it is currently common for individual school districts to create curricular programs to meet the needs of their students. A plethora of elementary science teaching resources also exist. Knowledge of these programs and resources, as well as how they can be incorporated into elementary science programs, is an important aspect of PCK for the developing science teacher that the program attempted to address.

The preservice teachers, for instance, had a wide variety of curricular resources available to them as they developed their teaching plans. Sets of the curriculum for the district in which they were assigned to practicum sites provided the most substantive guidelines as they prepared to teach. The preservice teachers also had a wide assortment of elementary science textbooks and science methods books, as well as recognized science activities from some of the programs cited above. From these resources, the preservice teachers were asked to identify activities that might be age and content appropriate and complemented the district curriculum and/or the teaching experience they were developing. Although the preservice teachers were given, and used, many activities from these resources, they were encouraged to develop inquiry-oriented, rather than activity-driven units. The preservice teachers used their considerations when selecting and modifying the activities to meet this goal.

Knowledge of Instructional Strategies for Science Teaching

Magnusson, Krajcik, and Borko (this volume) discuss knowledge of instructional strategies in terms of subject-specific strategies and topic-specific strategies, including topic-specific representations and topic-specific activities. The emphasis of this program, however, was on content representation, which includes many of these components but differs in organizational structure. Recent research indicates that preservice teachers have difficulty developing content representations that promote meaningful learning (Borko & Livingston, 1989; Borko & Putnam, 1996; McDiarmid, et al., 1989; Wilson, et al., 1987; Zembal, 1996). Such representations include topic-specific examples, metaphors, demonstrations, activities and explanations (Shulman, 1986, 1987). In order to make representations powerful, or more comprehensible to others, one must know learners' existing conceptions and interests related to particular concepts, as well as the possible problems they are likely to experience with the content. In addition, representations should be explicitly linked and relationships among concepts must be clear. The ordering and number of concepts is also very important. In science teaching particularly, hierarchy of concepts is critical to learning (Novak, 1977). Moreover, the inclusion of too many concepts often results in rote memorization of terms (Novak, 1977). In this section, we address the ways in which the preservice teachers were assisted in developing appropriate content representations for elementary science teaching.

Several aspects of the teacher preparation program specifically focused on assisting the preservice teachers in identifying and implementing accurate, appropriate and connected representations. First, the preservice teachers were provided with at least two avenues through which they received assistance in determining the accuracy of their representations. The science content courses and the representations included in those courses provided one route. That is, the preservice teachers were encouraged to plan and teach content that was addressed through the chemistry and physics courses. Another way in which preservice teachers were assisted in determining the accuracy of their content representations was through feedback from program staff on their planned representations. This feedback stressed appropriateness and accuracy, as well as adherence to an inquiry approach.

Second, by engaging in cycles of instruction within the context of their practicum placements, the preservice teachers gained perspective on the teaching task and became better able to understand the appropriateness of potential representations for the learners in their classrooms. More specifically, comprehensive planning provided preservice teachers with opportunities to think about issues of content, learners, and management. In particular, they were encouraged to develop multiple representations that were accurate, appropriate, and connected. Planning provided preservice teachers with a chance to anticipate potential problems and consider alternatives, especially with regard to creating and maintaining participation. Enactment provided preservice teachers with opportunities to put their plans into action. By engaging in interactive teaching, preservice teachers had the potential to learn more about what students already know, what topics they find difficult, and what questions they tend to ask. Finally, guided reflection allowed preservice teachers to analyze and evaluate the strengths and weaknesses of planned content representations. Moreover, reflection served as the vital link between cycles, informing subsequent attempts to plan and teach content representations by making them more realistic and feasible (Zembal, 1996).

Third, the use of the planning tool, IByD, forced the preservice teachers to link, at least in their planning, the various representations both to each other and to the concepts and goals of the unit. The planning tool also allowed the teachers to create and share topic-specific activity libraries. These libraries served as a resource file for a variety of activities that were directly related to unit content. Activities could then be drawn upon to complement various goals and contexts. Finally, as mentioned previously, the preservice teachers used considerations as a vehicle through which to think about representations and evaluate their appropriateness. The considerations may have assisted the preservice teachers in modifying potentially inappropriate or inaccurate representations.

Knowledge of Students' Understanding Of Science Topics

Knowledge of Requirements for Learning and Areas of Student Difficulty. Another issue associated with preservice teachers' difficulties representing content is their limited understanding of learners (Civil, 1992; Grossman, 1989). Because they are unable to anticipate what students already know, what topics they find difficult, how they might respond to instruction, and what questions they might ask, preservice teachers encounter difficulty tailoring representations to meet the needs of learners. This difficulty has been attributed to preservice teachers' lack of extensive experience interacting with children in formal learning situations.

Within the teacher preparation program, several specific attempts were made to assist the preservice teachers in bridging the gap between their understanding of the requirements for learning and the needs of their students. First, the preservice teachers met with the program staff during the planning stage of each of their teaching experiences. In these meetings, program staff assisted the preservice teachers in identifying students' needs and finding ways to meet those needs. Second, prior to each teaching experience in the practicum classroom, the preservice teachers met with the cooperating teacher and discussed these same issues.

With regard to assisting preservice teachers in considering the important role of prior knowledge in new learning experiences, explicit attempts were made during coursework to assist the preservice teachers in understanding documented areas of student difficulty. The pre-teaching meetings also assisted preservice teachers in identifying students' learning difficulties for specific science topics. In addition, the preservice teachers were expected to independently investigate their students' understanding of the content they were going to teach through a topic-specific interview. The preservice teachers interviewed their students prior to teaching and were expected to use the information from these interviews to modify the learning tasks. These interviews served to assist the preservice teachers in extending their knowledge of students' thinking and concretizing the importance of prior knowledge in learning.

Knowledge of Science Assessments. Various methods of assessment are being developed to meet the changing needs presented by the increasingly varied and complex expectations of science teaching and learning (National Research Council, 1996). Through integrated coursework and assignments, the preservice teachers were introduced to a variety of authentic assessment techniques. However, given the program's emphasis on content representation, formative rather than summative assessment was stressed. For instance, within lessons, the preservice teachers were assisted in developing and implementing probing questions to monitor students' understanding during instruction. These questioning strategies focused on assessing students' thinking processes rather than looking for the 'right' answer. In addition to the emphasis on formative evaluation, the preservice teachers were encouraged to include a summative evaluation as part of their unit designs.

Knowledge Of Dimensions Of Scientific Literacy

Currently there is a growing emphasis on developing 'habits of mind' (Rutherford & Ahlgren, 1990) and an understanding of the way in which science and scientists work (National Research Council, 1996). As stated earlier, the laboratory components of the content courses revolved around the investigation of topics commonly included in elementary science curricula. As part of the content courses, the preservice teachers were engaged in problem solving activities meant to uncover the "way science works" (Rutherford & Ahlgren, 1989, p. 25). The science methods course, along with the teaching, planning and debriefing sessions, also stressed representations of the nature of science and scientists work. For example, the preservice teachers were challenged through questioning to consider the effects of teaching process skills without content and teaching the scientific method without application (Starr, 1996).

LESSONS LEARNED: CONSTRUCTING A FRAMEWORK FOR ELEMENTARY SCIENCE TEACHING & LEARNING

In this section, we provide an overview of how the teacher preparation program assisted preservice teachers in learning to teach science in the elementary school. Several studies have examined changes in preservice teachers' science instruction during their first year in the program (Krajcik et al., 1993; Krajcik et al., 1997; Starr, 1996; Starr, Krajcik & Blumenfeld, 1993; Zembal, 1996; Zembal, et al., 1994; Zembal, et. al., 1996; Zembal, Blumenfeld, Krajcik & Palincsar, 1995). These research projects implemented an analysis framework that examined three main aspects of preservice teachers' science content representations -- how they represented concepts, how those representations reflected the needs of learners, and how they managed participation, resources, and time in the service of content representation. The key issues in considering content representations were multiplicity, accuracy and connectedness. With regard to the learner, analysis emphasized the preservice teachers' ability to assess students' prior knowledge and tailor learning experiences to promote cognitive engagement. Management of participation, resources, and time were also considered to the extent that they either facilitated or inhibited content representation.

Although this work does not examine PCK specifically, the analyses address a number of aspects associated with the various domains of teacher knowledge, including PCK. For example, the emphasis on preservice teachers developing multiple, accurate and linked content representations reflects the consideration of subject matter knowledge and PCK in terms of knowledge of instructional strategies, curricular knowledge, knowledge of the dimensions of scientific literacy, and knowledge of orientations to teaching science. Similarly, issues related to attending to the needs of learners encompass aspects of general pedagogical knowledge, knowledge of context, and knowledge of PCK with regard to student understanding, assessment (i.e., formative), and knowledge of orientations to teaching science. Finally, management of participation, resources and time primarily addresses general pedagogical knowledge and knowledge of context. Therefore, this research has the potential to inform our understanding regarding how the program assisted preservice teachers in developing and integrating the knowledge bases, including PCK.

The findings of the aforementioned studies indicate that, within the context of an integrated program, preservice teachers can make a great deal of progress, prior to student teaching, in terms of developing and integrating the domains of teacher knowledge, including PCK, necessary for effective science teaching (Krajcik et al., 1997; Starr, 1996; Zembal, 1996). Using the previously described analysis framework, the following improvements were noted over the course of the preservice teachers' first year in the program. First, the preservice teachers were able to develop accurate representations of science content, such as the water cycle, as early as the first semester. With time, the preservice teachers developed and implemented multiple, high quality representations. Among these representations were demonstrations, many student-centered activities, and several analogies. With regard to the learner, the preservice teachers shifted emphasis from teacher-centered to student-centered representations. Moreover, they demonstrated their developing understanding of the importance of cognitive engagement through the use of strategies, such as prediction, discussion, inquiry activities and questioning. With more teaching experience, the preservice teachers began to implement a greater variety of organizational structures and became more adept at managing participation, resources and time in the service of content representation.

Although the preservice teachers were able to make these advances, they nevertheless encountered challenges and difficulties during classroom teaching. These challenges included linking, assessing students' prior knowledge and incorporating it into instruction, and improvising during interactive teaching. Given that the preservice teachers were still in the very early stages of their development, such issues are not surprising. In particular, others have noted prospective teachers' difficulties with improvisation during interactive teaching (Borko & Livingston, 1989). Such skills are developed over time and with a great deal of classroom experience, both of which preservice teachers lack.

Starr (1996) and Zembal (1996) conclude that various aspects of the program assisted preservice teachers in developing a framework for thinking about and evaluating their teaching by considering how they portrayed science concepts, responded to learners, and anticipated contextual issues. Given this approach, the preservice teachers had a way in which to incorporate the variety of new experiences they encountered in practicum in a systematic manner, rather than as discrete events. In particular, the authors assert that engaging preservice teachers in an integrated program with early teaching experiences can assist them in developing a conceptual approach to teaching science. In addition, a variety of other elements need to be in place in order to provide the structure and support necessary to assist preservice teachers in teaching science more effectively. For instance, integrated coursework and assignments are needed to help preservice teachers synthesize their developing understanding of the various aspects of content representation. Connecting university coursework to a year-long practicum supported by experienced cooperating teachers is also crucial. Furthermore, the preservice teachers must be provided with an initial set of considerations, drawn from both theory and practice, that guide them to plan multiple and accurate content representations while keeping the learner and the context in mind. Similarly, they need to evaluate their lessons according to these considerations in order to avoid planning and reflecting on a superficial level. Finally, structured feedback is necessary, especially during planning and reflection.

Clearly, the preservice teachers that emerged from this program are not experts. In fact, they experienced many of the same successes and difficulties associated with preservice teachers in the literature. However, having developed a thoughtful approach to considering issues of content, learners, and management, the preservice teachers appear to be well-started beginners (see Hollon et al., 1991).

CONCLUSION

In this chapter we have described a teacher preparation program that applied the construct of PCK in developing an integrated theoretical framework for coursework and field experiences. Many of the features of the program have been advocated as necessary for preparing "well-started beginners" to meet the standards of current reform efforts in science education (Penick, 1994). By addressing knowledge and beliefs in other domains, such as subject matter and general pedagogy, preservice teachers were relieved of some of the usual limitations associated with the development of PCK. The teacher preparation program also assisted the preservice teachers in learning about teaching science through a consistent frame -- one that they adopted as a means to consider their decision-making in planning, teaching and reflection. In this chapter, and in other work (Hollon et al., 1991; Krajcik et al., 1997; Starr, 1996; Zembal, 1996), such a framework has been shown to serve as a powerful tool in structuring the ways in which preservice teachers continue to think about teaching, learning and classroom contexts.

Although this program applied the PCK heuristic and met many of the challenges suggested by reformers (National Research Council, 1996; Penick, 1994; Raizen & Michelsohn, 1994), the implementation of this teacher preparation program raises several critical questions for teacher educators, particularly those interested in preparing elementary science teachers. First, we need to reconsider, *What are effective ways through which to integrate coursework?* The solutions we found to integrating coursework are but one example of the possibilities. Our research suggests that the integration between the content courses and the science methods course, as well as the scaffolding within the content courses, might have been stronger. Although the preservice teachers had access to many supplies and ideas in the content courses, they appeared to have difficulty translating the information and activities to their elementary science teaching experiences. Without strong connections between content courses and methods courses, the transformation of subject matter knowledge necessary for teaching cannot occur.

Second, as teacher educators, we must ask, *What are the long-term implications of providing a consistent theoretical frame for the purpose of planning, teaching and reflection, throughout teacher preparation?* In this program we focused on one theoretical framework throughout the courses. Further research is necessary to understand how a frame is applied by beginning teachers in their independent teaching. This research must include following beginning teachers into the field, observing their planning, teaching and reflection, probing their decision-making, and determining how their framework for thinking about teaching is translated into the everyday world of teaching elementary school science. It is the application of these thought processes that generate expertise in teaching and assist in further developing pedagogical content knowledge.

Third, *What are the factors that delineate excellent field experiences for preservice teachers? What abilities make a classroom teacher an "expert teacher" and a role model for preservice teachers?* In developing the field component for this teacher preparation program, we had difficulty finding teachers that met the minimum criteria of "valuing the teaching of science" at the elementary level. When we were able to find these teachers, a number of factors resulted in them teaching science less often than we had hoped. This issue raises a final question -- *What alternatives exist to school-based field work?* Alternatives such as hypermedia practicum experiences (Lampert & Ball, 1990) are being developed and used with preservice teachers in elementary math methods. These types of experiences might maximize the quality of preservice teachers' observations of expert teacher. Some type of field experiences in which the preservice teacher begins to take the role of teacher rather than student are critical in transforming and contextualizing knowledge gained in university coursework.

As teacher educators, the work reported in this chapter extends our understanding of the types of experiences that benefit preservice teachers in learning to teach. As a community of teacher educators and researchers, we must persist in identifying and applying the types of guiding heuristics, activities, experiences, and thinking that assist preservice teachers in developing pedagogical content knowledge. We must also pursue mechanisms through which we might disseminate our growing comprehension of preservice teachers' development and application of pedagogical content knowledge.

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[1] National Science Foundation Grant TPE9150020

[2] The use of IByD in this program has been documented elsewhere (Starr, 1993). IByD was a prototype for a current Macintoch and IBM version of the planning tool PIViT. The use of this tool has also been documented (Marx, Bllumenfeld, Krajcik, Soloway, Cox & Breen, 1995). Further information about either of these tools can be obtained from the third author.

[3] Two changes were made to the map when including it in this chapter. Each change was made to minimize space taken up by the diagram. First, the concept rectangles giving examples of senses (sight, sound...) and physical properties (shape, size...) were consolidated and appear as one rather than five. Second, the link between mixtures and change was left without a directional arrow because the proposition the preservice teachers' chose made the directionality uncertain.

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MARGARET L. NIESS AND JANET SCHOLZ

11. INCORPORATING SUBJECT MATTER SPECIFIC TEACHING STRATEGIES INTO SECONDARY SCIENCE TEACHER PREPARATION

Oregon's teacher preparation has significantly changed since 1987, partially in response to national calls for reform in teacher education (Holmes Group, 1986) and partially in response to legislative funding. The Oregon State System of Higher Education directed its teacher preparation programs to move to a fifth year model and to significantly increase the standards while reducing the number of newly prepared teachers.

In response to this call, the faculty of all preservice teacher preparation programs at Oregon State University engaged in discussions to determine the conceptual framework to direct the redesign effort. At that time, the agreement was to focus on the "teacher as decision maker." From this common understanding, the individual programs developed differing conceptual frameworks to specifically direct their redesign efforts.

The faculty of the Department of Science and Mathematics Education used the overall organizational framework of *knowledge growth in teaching* with an ultimate focus on *teachers as transformers of subject matter* to guide the development of the program for the preparation of secondary (grades 5-12) science (integrated science, biology, chemistry, physics and mathematics) teachers. At an operational level, the program was designed to focus upon the development, revision, and elaboration of the six primary domains of knowledge that both theory and research indicated as essential to effective instruction (Shulman, 1986; Shulman, 1987; Wilson, Shulman & Richert, 1987): subject matter knowledge, pedagogical knowledge, knowledge of schools, knowledge of learners, curricular knowledge, and pedagogical content knowledge.

The goal of the new program is to prepare science teachers with the ability to respond in a variety of ways to the instructional decisions they may face in the process of transforming and representing subject matter so that it is comprehensible to their students in grades 5-12. The faculty envision the domains of knowledge as having a high degree of interaction, a fluid relationship with no one domain totally distinct or separate from another. From this perspective, the science teacher must possess knowledge in each of these areas; however, the ultimate measure of a teacher's effectiveness is in the ability to transform the content into a form accessible to learners. The science teacher preparation program at Oregon State University thus was conceived within a framework emphasizing the development of a teacher's ability to transform what he or she knows to

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teaching strategies that make that knowledge accessible to learners, in Shulman's words, pedagogical content knowledge.

THE SCIENCE TEACHER PREPARATION PROGRAM

Given this understanding, the science teacher preparation program initiated in 1991 is a challenging full-time, graduate-level program leading to a Master of Arts in Teaching (MAT) degree and an Oregon teaching license. The program is a twelve month, cohort group model that includes 63 quarter hours of upper division and graduate course work.

Entrance Requirements

In order to facilitate the development of a preservice science teacher's knowledge, certain requirements are needed prior to admission to the teacher preparation program, a fifth-year, graduate program. A candidate for admission must have completed a Bachelor's degree in an appropriate field of study such as mathematics, biology, chemistry, physics, or general science. Competence in the specific subject area (integrated science, biology, chemistry, physics, mathematics) is assessed through transcript analysis with respect to specific competency areas (see Figure 1 for example of biology competency areas). In addition to academic course work, a candidate for admission to the teacher preparation program must have at least a 3.0 (based on a 4.0 scale) grade point average in the last 90 hours of

Competency Areas	Lower Division Quarter Hrs.	Upper Division Quarter Hrs.
Biological Science Sequence	12	
Genetics	4	
Evolution		3
Microbiology		5
Ecology		3
Basic Chemistry Sequence	15	
Basic Physics	10	
Earth Science	8	
Anatomy & Physiology		6
Upper Division Biological Science Electives (must be in Botany if none elsewhere; must be in Zoology if none elsewhere)		

Figure 1. Biology Competency Areas Required for Admission

undergraduate course work. Candidates are also expected to present a passing score on an approved test of basic skills, a passing score(s) on the Oregon approved National Teacher Exam (NTE) Test(s) of Subject Matter, and verification of successful experience working with youth in a school setting. Finally, each candidate must meet admission requirements for the Graduate School at Oregon State University.

Candidate applications must include a written statement of the candidate's professional goals specifically addressing how these goals emerged and are envisioned in the public school experience. Annually, candidates who have met all requirements are interviewed by the faculty in the Department of Science and Mathematics Education; a cohort group of 24 students representing a cross section of the subject areas is chosen to begin the twelve-month program each June.

The Twelve-Month Program

A four-part model delineates the major factors of the program: purposes, processes, outcomes and evaluation (see Figure 2). The program is designed to have the students examine their initial pedagogical beliefs, gain insight into the influences that have shaped their beliefs, acquire knowledge of classical and contemporary pedagogical perspectives, and examine the viability of alternative perspectives. The primary objective guiding the development of the program toward these purposes is to provide for the development of professional knowledge ability and competence essential to successful teaching. Based on this understanding, a carefully planned sequence of courses, participation and internships is provided. However, an important consideration is the thoroughly integrated view of the six domains of knowledge held by the faculty in the development of the program. Any delineation of which courses address which domains of knowledge is conceptually complex and realistically each course addresses each of the domains to a significant degree in an integrated manner. Appendix A provides a summary of the courses (including their relationship to the knowledge domains) that students complete each term of the program.

Overall the courses are divided into three areas, professional core courses, subject matter teaching specialty courses and field experiences. Knowledge of schools and knowledge of learners are addressed in the professional core courses. Knowledge of subject matter is primarily dealt with in the nine graduate hours of graduate level subject matter students are required to take in addition to the subject matter included in their bachelor's degree. Continuing with this line of thinking, the primary focus of the subject matter teaching specialty courses is upon pedagogy, curriculum, and pedagogical content knowledge. The program specifically addresses the development of pedagogical content knowledge in the Science/Mathematics Pedagogy courses (SED 582/3) taught Summer and Spring terms. These courses directly attend to helping the student interns develop a variety of representations of subject matter within instructional context. Another important factor concerning the subject matter teaching specialty courses is the

Teacher Education Program	Agricultural Education Health Education Language Arts Education Mathematics Education Music Education Physical Education Science Education Technology Education
Purpose	***To enable preservice teachers to ...*** • Explore their initial pedagogical beliefs • Gain insight into influences shaping their beliefs • Acquire knowledge of classical and contemporary pedagogical perspectives • Examine the viability of alternative perspectives
Processes	***Professional Core*** • Educational Psychology • Educational Foundations • Multicultural Perspectives • Legal Perspectives Counseling ***Field Experiences*** • Extended field work • Structured, field-based projects ***Subject Matter Teaching Specialty*** • Subject specific pedagogy • Research methods • Microteaching • Extended subject matter • Subject specific methods • Subject specific curriculum • Technology • Teaching and Learning Seminars
Outcomes	***Teachers who have ...*** • In-depth content knowledge • In-depth knowledge of learners, pedagogy and curriculum • In-depth content specific pedagogical skills • Knowledge of curriculum frameworks • Competence in a variety of evaluation techniques • research-based understanding of teaching and learning • Integrated schemas with respect to the six knowledge domains • Appreciation and sensitivity to diversity issues
Evaluation	• Portfolio of readiness for beginning teaching • Assessment of extended field experience • Ongoing student and faculty program reflection • Continued professional growth following graduation

Figure 2. Teacher Education Program Model for Oregon State University

focus on the nature of the subject matter, i.e., science and mathematics and the teaching of the nature of the subject matter. Teachers need to have a firm understanding of the epistemological basis of their subjects in order to adequately transmit that subject into a form accessible to learners. In turn, this understanding forms a guiding framework for the development of instructional activities as well as varied instructional decisions, such as planning and assessment. Throughout the program, students are consistently asked to evaluate instructional and curriculum materials with respect to their consistency with the nature and structure of science/mathematics. In addition to receiving direct instruction on the nature and structure of science/mathematics, students are expected to utilize this knowledge when they develop and implement instructional activities in their field experiences.

The primary focus of the field experiences is upon the integration of all six domains of knowledge, for it is that integration that is required for successful teaching. Early in the program, the students are prepared as researchers through an emphasis on observation, reflection and the development of a repertoire of skills during their field experiences. Students conduct mini-research projects that require both quantitative and qualitative techniques. Through this research, they investigate the complexity of the classroom, how the teacher notices that complexity, and how the teacher guides learning in that complex environment (Good & Brophy, 1994). Students learn to be good observers, well-versed in research on teaching, and learn the necessary skills to actually plan and implement action research in their own classrooms.

In essence then, the outcomes for the program are for teachers to have in-depth content knowledge, in-depth knowledge of learners, pedagogy and curriculum, in-depth content specific pedagogical skills, knowledge of curriculum frameworks, competence in a variety of evaluation techniques, research-based understanding of teaching and learning, integrated schemas with respect to the six knowledge base domains, and an appreciation and sensitivity to diversity issues. These outcomes are assessed through a variety means throughout the program and through a summative evaluation provided by a portfolio and an oral examination. The student's portfolio is an indication of the quality of work completed by the prospective teacher. The various components of the portfolio serve as a reflection of the individual's knowledge of the six domains of knowledge: subject matter (mathematics, physics, biology, chemistry, integrated science), pedagogy, secondary school (grades 5-12) students, curriculum, schools and pedagogical content knowledge. The purpose of the portfolio is to help the students integrate what they have learned and to display their work in a manner that best represents their growing abilities as a science or mathematics teacher. The contents of the portfolio includes revised papers and projects completed as part of the course work. It also includes the intern's work samples, videotapes of teaching, a video summary, and materials documenting additional professional activities in science or mathematics education. It is expected that students demonstrate consistency between their statements of philosophy and goals and their practical applications of this understanding. As part of the Master's degree requirements, each student completes a two hour oral examination, presenting and defending the portfolio. During these examinations, questions from the faculty specifically target the students' understanding of the individual domains of knowledge as well as their integration of the domains of knowledge. Upon successful completion of all course work, presentation and defense of the portfolio, and the final oral examination, students are recommended for the Oregon Standard Teaching License and the Master of Arts in Teaching (MAT).

PROGRAM EVALUATION

The MAT program has been significantly different from the previous teacher preparation program at Oregon State University. The change to this program was made after considerable investigation of Shulman's model requiring considerable decision making as to an appropriate practical application of the model. Because of the extensive nature of the changes in the program, faculty focused on continuous program evaluation. Since 1991, the faculty and doctoral students have conducted formal research efforts documenting the program effectiveness. In addition, the faculty have surveyed the graduates from 1992 through 1995, mentor teachers who worked with these students during their program, and principals of these graduates. Finally, based on the analysis of these data, the faculty have continually used the information to revise and direct the program for each succeeding year.

Research Documenting the MAT Program Effectiveness

In the field of education, developments and advancements that extend knowledge are based on empirical research. Shulman's (1986) delineation of the domains of teachers' knowledge also provided the framework for research on the development of teachers' knowledge. Given that the MAT program at Oregon State University was designed with both national educational reforms and Shulman's model of teacher's knowledge as guiding frameworks, there was a clear need to assess whether the students developed the type of knowledge desired. Furthermore, the program was revised and strengthened based on empirical research conducted within the department itself.

The program is based on a constructivist epistemology that claims that individuals are continually structuring knowledge and revising their structures of knowledge. As participants in the program students enter with preconceived ideas about their subject matter and its teaching. What conceptions do they bring of their subject matter and its teaching? What is the nature of this knowledge and what role does subject matter knowledge play in their conceptions of teaching that subject matter? These questions, and many more, are central to establishing an effective teacher preparation program. Consequently, it is important to assess these structures and determine how they change over the course of the program.

Several studies have been conducted that attempt to identify the preservice teachers' conceptions of subject matter and pedagogy prior to the MAT program and how these conceptions change throughout the program. Lederman and Latz (1995) implemented a research project to assess the nature, development, and changes in preservice secondary science teachers' conceptions/knowledge structures of subject matter and pedagogy as they proceeded through the twelve-month program. Twelve preservice secondary science teachers (seven biology, three general science, one chemistry, one physics) were participants in the study. These preservice teachers were part of a cohort group of 16 students enrolled in the program (four mathematics; 12 science). Data were collected and analyzed in two phases. In the first phase, the participants were to respond to the following questions:

1. What topics make up your primary teaching content area? If you were to use these topics to diagram your content area, what would it look like?
2. Have you ever thought about your content area in the way you have been asked to do so above?

One day later, each participant was asked to answer the same questions but with "important elements/concerns of teaching" substituted for "primary teaching content area." The participants were asked to complete Question 1 again at the end of Summer, Fall, Winter and Spring terms. Question 2 for these administrations was replaced with "Have your views changed? If so, how and why?" The second phase was conducted at the end of Spring Term. Each preservice teacher was asked to participate in a 45-60 minute videotaped interview conducted by the primary researcher in an attempt to assess changes and clarify the preservice teachers' knowledge structures.

The preservice teachers, the students, indicated that they understood the questions, but were hesitant about the content and quality of their responses. Results indicated that initial knowledge structures were typically linear and commonly listed the discrete science or pedagogy topics. The presence of integrative themes or connections between or within the components of either subject matter or pedagogy structures was not common. "The preservice teachers, without exception, expressed the belief that pedagogy and subject matter knowledge were distinct bodies of knowledge which, although both essential, were applied in an integrated manner during teaching," stated Lederman and Latz.

Although Lederman and Latz noted changes in the preservice teachers' pedagogical knowledge structures by the third administration of the questionnaire, subject matter knowledge structures remained relatively stable. The preservice teachers felt that their subject matter representations were not influenced by the act of teaching. The preservice teachers' representations of pedagogy had become more complex throughout the program. Students became the focus of their structures, where previously the students had not been considered. The researchers offered several implications for science education including revising college level science instruction in such a manner that the integrative themes and issues become clearer to students. They also recommended the science educator become more active in providing opportunities for preservice teachers to reflect on their own conceptions in light of the current reforms.

Lederman and Latz also presented ideas for future research and concluded by stating "It seems clear that additional research which includes direct classroom observations should focus on the relationship between knowledge structure complexity and classroom practices." Based on this recommendation, another study was conducted by Scholz (1996) to determine the relationships among preservice teachers' conceptions of geometry, conceptions of teaching geometry and classroom practices.

The sample for this study consisted of 10 preservice secondary mathematics teachers who were enrolled in the MAT program the following year. These preservice teachers represented the mathematics students of the 22 science/mathematics student cohort enrolled in the program. Each preservice teacher completed a card sort task with an interview and a videotape task which consisted of viewing three experienced geometry teachers on videotape. Four of these preservice teachers were observed eight times each during their professional internship experience in a high school geometry classroom. Work samples, informal interviews, and additional documents such as lesson plans and worksheets were also used as data sources.

Results of this study indicated the relationship between the preservice teachers' conceptions of geometry and conceptions of teaching geometry was complex. It was clear the preservice teachers' conceptions of geometry influenced their conceptions of teaching geometry. Directly, the preservice teachers made errors with the content and were unable to provide answers to students' questions. The preservice teachers' knowledge of geometry also had indirect consequences in their classroom practices. They often could not answer questions about the content from assigned homework problems. They could only provide one procedure to solve a problem and often regarded students' suggestions as insignificant.

The preservice teachers demonstrated a limited, ordered view of geometry. Their conceptions of geometry were linear and textbook-bound. Most stated their conceptions of geometry were based on the order they had learned geometry in high school. Clearly, the textbook had influenced the preservice teachers' conceptions of geometry. Furthermore, what they did in the classroom was from the textbooks they used. The classroom observations of the four preservice teachers' lessons confirmed this "book-bound" conception. The four preservice teachers observed followed the order of the textbook and made direct references to the textbook when teaching.

Several conceptions of geometry teaching emerged in this study including the importance of using "real world" problems to teach the content. The preservice teachers believed it was essential for teachers to relate geometry to students' interests or that which they could relate to in their lives. The preservice teachers also stated their beliefs about how students learn geometry. They stated that students should not have to memorize formulas or algorithms, rather students learned best by discovering the content for themselves through hands-on explora-

tions. The preservice teachers also believed it was essential to present lessons in an inductive manner and involve students in learning the content.

Results indicated that the preservice teachers' conceptions of geometry and its teaching were not always consistent with the preservice teachers' classroom practices. Interestingly, none of the preservice teachers observed used real world problems to teach the content, related the content to the students' interests, or presented their lessons in an inductive manner.

Scholz concluded, "Changes in the instruction of mathematics at all levels will be enhanced with more emphasis on the teacher's conceptions of mathematics, its teaching and the effect of these conceptions on classroom practices. Although preservice teachers are just beginning to learn about teaching mathematics and have some preconceived ideas about teaching, a concerted effort on the part of teacher preparation programs is needed so that preservice teachers learn the type of teaching envisioned by the reform movement."

Consistent with previous research (Gess-Newsome & Lederman, 1993; Hauslein et al., 1992; Lederman, 1994), preservice teachers completing the MAT program may not possess well-formed or highly integrated subject matter or pedagogy knowledge structures. The idea that teachers' conceptions of subject matter and pedagogy directly influence classroom practice has served as the foundation for the continued interest and research related to teachers' thinking. In order to gain a better understanding of the relationship between preservice teachers' conceptions of their subject matter and its teaching much more remains to be learned about such conceptions and the role these conceptions play in instructional practice. Future research must also focus on questions related to the relationship of teachers' conceptions on student learning.

Voices of Graduates, Mentors and Principals

Since the inception of the MAT program, faculty have surveyed the graduates asking them to reflect on their teacher preparation program and their preparation for entering the teaching field. At the end of each year, graduates are asked for recommendations for programmatic changes. The recommendations of the 1994-95 group are representative of the types of recommendations that have been used to revise the program annually:

1. The professional core courses need to be reconsidered; the counseling course needs to be integrated in the first term's work. The graduates consistently have difficulty in merging pedagogy courses that are not science-content specific into useful information for their preparation for teaching science.
2. Continue to integrate the science/mathematics education courses. Graduates continuously find the science-content specific pedagogy courses to be of the most value for preparing them to teach. They find the specific examples to have more meaning for their professional growth.

3. Internship experiences (part-time and full-time) should remain as they are. Graduates recognize the value of campus-based courses taught concurrently with a part-time internship; they feel these subject specific pedagogy courses directly relate to their growth in teaching in the internships.
4. Spring science/mathematics education courses need more integration and pedagogy needs to be adjusted to be different from summer pedagogy. These Spring term courses do not have any accompanying internship in the schools. As a result, the graduates find them to be less integrated. However, based on this recommendation, faculty reviewed the pedagogy courses and revised them to more closely fit the pedagogical content knowledge emphasis, encouraging more connection with current secondary science teachers forming the bridging the connections to actual practice.

At the end of the first three years of the program, a comprehensive survey was sent to all graduates. Graduates reported they felt (1) ready to assume the responsibility (with no additional assistance) for planning for instruction, implementing plans for instruction and evaluating pupil achievement and (2) ready to assume the position (with a minimum of assistance) of establishing a classroom climate conducive to learning. They reported that they were well prepared for dealing with national and statewide reforms in science and/or mathematics. They indicated that the internship, microteaching and methods courses benefited them most for their teaching position while the professional core courses (primarily the summer core courses) were least beneficial. When asked about the strengths of the program, they typically identified aspects as described in the following quotes:

The <u>intensity</u> - this really helped prepare me for the <u>rigors</u> of that first year.

Work sample, resource cards, rigidity of program - <u>discipline</u>.

Emphasis on advanced planning during the internship - my school requires two weeks; emphasis on timeliness of completing projects/working on several projects simultaneously; emphasis on "reflection" section of lesson plans; emphasis on self-appraisals for evaluation during the internship; emphasis on the development of critical appraisals during microteaching; pedagogy classes of practicing teachers.

Preparation For The Real Thing. As I see now, teachers come into our school with no training, they have no experience with classroom management, learning style differences, teaching methods, etc. Their single focus is on the lecture approach.

With respect to their recommendations for improving the program, the graduates focused on a request for specific techniques (for classroom management and for teaching specific topics or lessons) and a request for more internship and microteaching work. The graduates' concern for classroom management and discipline is consistent with their feelings of readiness for their first position for establishing a classroom climate conducive to learning.

Mentor teachers worked with the students throughout their internships, collaborating with the university supervisors to coordinate the activities of teaching in the public school with the campus-based course work. The faculty also were interested in the mentor teachers' perspective of the readiness of the graduates for their first position. Thus, mentor teachers for the first three years of the program were

also surveyed at the same time the graduates were. Interestingly, they perceived the graduates as ready to assume their first teaching positions <u>with a minimum of assistance</u> with respect to planning for instruction, establishing a classroom climate conducive to learning, implementing plans for instruction and evaluating pupil achievement.

The mentors reported that the graduates were well prepared for dealing with national and statewide reforms in science and/or mathematics. Concerning the subject matter preparation of the graduates (their interns), the mentors believed that their preparation was "solid" and was "a good basis for beginning teaching." When asked about the strengths of the program, the mentors focused on aspects concerning the internship:

The length and depth of the "at school" portion of the internship. The amount of monitoring - inclusive of video monitoring - was very valuable.

Interns are strong in subject matter; interns are trained in behavior and learning evaluation procedures; interns are trained in complete lesson planning; interns are expected to find out about wider functions of the school through contact with principals and board meetings.

Lots of feedback. Good emphasis on preparation.

The strength of the program was the high involvement of mentor teachers and supervisors in the evaluation program. It was a very comfortable, supportive and competent environment.

The strong emphasis on lesson preparation. The expectations are very clear. The basic elements of good teaching are thoroughly covered.

With respect to their recommendations for improving the program, the mentors also identified classroom management and discipline techniques and requested more internship time. The mentors consistently felt that time spent teaching was more valuable than campus-based course work.

To balance the perspectives of the graduates and the mentors, the faculty also surveyed the current principals supervising the graduates. Consistent with the mentor teachers, the principals reported the graduates ready to assume their first teaching positions <u>with a minimum of assistance</u> with respect to planning for instruction, establishing a classroom climate conducive to learning, implementing plans for instruction and evaluating pupil achievement. When asked to compare the graduate with other novice teachers, they reported the graduates "As good to superior to other novice teachers." When asked about the teacher's (our graduate) strengths as a novice teacher, the principals reported strengths as follows:

Excellent content knowledge, good people skills, good organizational skills, high intellect, hard worker.

Organization skills, subject area preparation, team collaboration.

Academic background/preparation; commitment to science education and to the teaching profession; research orientation.

Ability to communicate and interact on a positive level with all students. Flexibility and willingness to try different things. Openness to students' culture.

The principals were also asked about the teacher's weaknesses as a novice teacher. They reported:

Working with special education students.

Lack of skills and understanding when dealing with "at-risk" students - a common problem with education as a whole but an area we must address.

Had a small problem adjusting to ability, interest and performance levels of ninth graders.

No real weakness other than those that are common to all new teachers.

Makes the rest of us look silly on occasion!

Taking high energy and translating it into a "teaching form."

Behavior management, classroom discipline.

Based on their experience with their particular novice teachers, the principals were asked for suggestions to help improve the teacher preparation program. Comments received are reflected by the following:

Additional training in effective classroom strategies for working with learning disabilities, students with reading comprehension problems.

No! Send me more! Clone him!

None at all; you've done a great job as far as I can tell.

More experience and practical training in motivating the at-risk students.

Courses in classroom management.

Finally, principals, asked to share any other information, responded:

I appreciate your follow-up of your graduates.

Include some special ed stuff.

Great staff member. Mature, hard worker. Hope we're able to retain based on financial situation.

In general, spend lots more time working with classroom management including but not limited to discipline.

Students come prepared academically; however, some of them have not made that transition between the theoretical material (teaching philosophies and techniques) presented in the classroom and the practicality of implementing it in the real world setting of a high school. Anything that could be done to help a teacher make that transition smoother would help novice teachers to become more successful.

Comparison of these various voices identifies the consistent theme of a concern for classroom management and discipline, possibly suggesting a weakness in the graduates' facility in the pedagogy domain. Initially, the faculty perceive growth in this domain to require more time than a twelve month program allows; also, growth in this domain requires experience different from the internship where the student generally operates within the classroom management organization of the mentor teacher. Another piece may be explained by the comment from the

principals concerning the "transition between the theoretical material ... and the practicality of implementing in the real work setting."

However, based on these surveys, the faculty have continued to try different approaches to teaching classroom management and discipline. The faculty have focused on classroom management from a preventative perspective, emphasizing that "classroom management is a process of establishing and maintaining effective learning environments" (Good & Brophy, 1994). With this perspective, the faculty insist on detailed planning of lessons and that interns be appropriately planned five instructional hours in advance of teaching for every class taught. If the intern is not prepared, the faculty require that the intern not be allowed to teach until achieving this level of planning. Interns are also expected to develop a classroom management plan. This plan is to be reviewed and changed over the year as the intern gains more experience in the classroom.

Another point highlighted in these surveys is the importance of providing subject specific pedagogy classes. Graduates consistently found the core courses (general in nature) to be of the least value for their professional growth. They also requested more subject specific lessons and activities. This perception is sensible in that the students are novice teachers with little experience. What is concrete to them is couched in terms of their subject matter. Translating the salient features of a language arts activity requires an abstraction of the ideas, an ability that also requires more expertise and experience.

CONTINUED PROGRAM REVISION

Naturally, the program is in a constant state of evaluation as the faculty continue to collect data on the needs and concerns of faculty, students, mentors, and principals. While the information of the various voices have assisted in making changes in the program, the process of the National Council for the Accreditation of Teacher Education (NCATE) review during 1995-96 provided another perspective of program assessment. From the NCATE Board of Examiners visit, the faculty received an external assessment of the program directly related to the identified knowledge base. The examiners asked the question, "What do you do in your program to directly assess the growth of your students specifically with respect to your knowledge base, *knowledge growth in teaching*?" While the response referred to the portfolio, the examiners were unable to identify specific directions to assure this assessment was completed. Following this concern, the faculty revised the requirements for the portfolio. Prior to this point, students were given specific requirements for pieces of evidence to be placed in the portfolio (see Figure 3). These requirements were changed for the 1996-97 year of the program to specifically require the students to identify the evidence they wished to use to demonstrate their professional growth, and the students were required to provide a reflection describing their growth in relationship to the six domains of knowledge (see Figure 4).

Professional Teacher Education Program

1. Title Page that minimally includes name, major professor name, date of oral exam, the statement "Portfolio completed in partial fulfillment of the requirements for the Master of Arts in Teaching and the Professional Teacher Education Program at Oregon State University.
2. Introduction/overview explaining the contents and organization of the portfolio
3. Table of Contents with page number identification of some sort
4. Professional Resume
5. Philosophy of Science or Mathematics Education statement
6. Work Sample 1
7. Work Sample 2
8. Two videotaped lessons form the units and one summary video
9. Diverse learner project
10. Research projects (2 - one is stimulated recall, other from fall)
11. Case study with analysis; reflective analysis of another intern's case study.
12. Curriculum case study project
13. Curriculum development project
14. Curriculum Review
15. Optional: additional information you wish to use to demonstrate your growth as a professional educator.
16. A concluding statement that summarizes that ties the entire portfolio together.

Figure 3. 1991-96 Portfolio Table of Contents

THE FUTURE OF THE PROGRAM

The Science and Mathematics Education Preservice Teacher Preparation Program (the MAT program) at Oregon State University has based its program beginning in 1991 on contemporary research on teaching and learning and has philosophically and substantively aligned the program with the professional organizations for science and mathematics education. The organizational framework for the program is *knowledge growth in teaching*. However, in January, 1999, new teacher licensure requirements will be implemented. Once again, the faculty have been asked to redesign the program to meet new requirements. With the success of the MAT program, the faculty have identified that the organizational framework will continue to be *knowledge growth in teaching*. Beginning science/mathematics teachers need to develop a highly integrated view of current reforms consistent with the translation of research into practice; and the research and evaluation have demonstrated that the current program is successful in developing this view.

Professional Teacher Education Program

Science/Mathematics Portfolio Table of Contents

1. **Title page**
2. **Professional Resume**
3. **Introduction/overview** explaining the contents and organization of the portfolio.
4. **Table of Contents** for the portfolio, including the videos; including page numbers.
5. **Subject matter knowledge.** This section describes growth in knowledge of foundational ideas and conceptual schemes, data, and procedures within your specific subject matter area. The nature of your subject matter must be well-represented.
6. **Pedagogical knowledge.** This section describes growth in knowledge of broad principles and strategies of classroom instruction and management that transcend subject matter.
7. **Knowledge of schools.** This section describes growth in knowledge of educational contexts, ranging from the place of the classroom in the school to the school in the community and other social contexts (including legal expectations for schools).
8. **Knowledge of learners.** This section describes growth in knowledge of relevant aspects of intellectual, social, and emotional development of your students. Include both how learners are similar and how they are different.
9. **Knowledge of the curriculum.** This section describes growth in knowledge of the development and implementation of programs and materials designed to support instruction.
10. **Pedagogical content knowledge.** This section growth in knowledge of representing and formulating subject matter knowledge that make it comprehensible to others (knowledge of how to transform and represent subject matter so that it is comprehensible to students or others). This section is the specific professional knowledge of mathematics and science teachers that demonstrates planning, implementation and reflection.
11. **Conclusion.** A concluding statement "tieing" the portfolio together.
12. **Appendices**
    A. Work Sample One
    B. Work Sample Two
    C. Videotapes of lessons (minimum of two complete lessons from different units designed and taught)
    D. Video Summary
    E. Additional pieces of evidence that are referred to often and not placed as pieces of evidence within specific sections. Limit these pieces of evidence to a maximum of two or three best pieces.

Figure 4. 1996-1997 Portfolio Table of Contents

One important feature of the redesign is the extension of the program to include the preparation of science/mathematics teachers for grades 3-12. Specifically the new program will have two options:

Option 1 will prepare teachers for elementary (3-8) and middle (5-10) grades.
Option 2 will prepare teachers for middle (5-10) and high (7-12) grades.

The extension of the program will specifically prepare teachers who are specialists in teaching science/mathematics for the elementary and middle school grades. This decision was made based on the faculty's belief in the organizational framework of *knowledge growth in teaching* and the recognition that currently elementary and middle school teachers are primarily generalist teachers with little preparation for teaching science/mathematics (in content knowledge as well as pedagogical content knowledge).

Another factor in the decision results from the nature of the current reforms in science/mathematics standards. These reforms require a significantly better prepared teacher for teaching science/mathematics. For this reason, the program development will also be guided by the competencies provided by national recommendations supported by National Science Teachers Association (NSTA), National Science Education Standards, National Council of Teachers of Mathematics (NCTM), and National Council for the Accreditation of Teacher Education (NCATE). These competencies will guide the development of the two options of the new program within the organizational framework of *knowledge growth in teaching*:

- Subject matter- demonstrate science/mathematics/technology literacy
- Design of inquiry- design and conduct scientific investigation/mathematics problem solving/reasoning
- Nature of science/ nature of mathematics/ nature of technology
- Science-Technology-Society (STS)- relate science, mathematics, technology to everyday life; promote decision making; science, mathematics and technology in context; relate science, mathematics and technology connections
- Design a learning environment to facilitate inquiry
- Assessments- use traditional and alternative that are equitable
- Use family and community resources
- Learning and learners- develop knowledge of both
- Reflection- analyze teaching and learning
- Leadership- develop professional abilities
- Pedagogy- design appropriate discourse/tasks
- Communications- use the language of mathematics and science

As the new program is developed, however, the program will adhere to Shulman's model of teaching; enhanced pedagogical content knowledge will be the primary goal. Naturally a strong knowledge of subject matter and pedagogy and their interactions are necessary to achieve this end. Throughout the current program and the new, redesigned program, students are and will be expected to consider the inter-relationships of subject matter and pedagogy. The research is quite clear that one of the differences between expert and novice teachers is the novices' tendency to fragment pedagogy and subject matter and treat instructional situations in a generally reductionistic manner. One of the strengths of the program is and will continue to be a constant attempt to have students develop understandings that move them away from this documented perception of a novice teacher.

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APPENDIX A

SCIENCE/MATHEMATICS EDUCATION
PROFESSIONAL TEACHER EDUCATION PROGRAM
OREGON STATE UNIVERSITY

Summer Term, 17 credits[1]

SED 412/3 Instructional Technology & Teaching Math/Science
(3 credits)
A laboratory course designed to provide the preservice mathematics/science teacher with experience with instructional technology for teaching secondary mathematics/science in the twenty-first century. Instruction, with current technology for enhancing learning of mathematics/science, emphasizes the integration of technology with other strategies for presenting mathematics/science concepts.
Relationship to Knowledge Base: This course is particularly directed toward the integration of modern technology into classrooms to enhance instruction in learning. Consequently, a strong integrated emphasis is placed upon the domains of pedagogy and subject matter within the context of current curriculum reforms. Again, instruction and learning do not occur in a vacuum so the domains of knowledge of learners and schools are critical underlying contextual factors bearing upon all activities.

SED 452/3 Math/Science Methods/Practicum I
(3 credits)
The course is designed to allow each student to develop the theoretical background, practical knowledge, and skills that are essential for successful mathematics teaching. Specific emphasis is placed upon instructional methods/modes, curriculum development, contemporary mathematics curriculum goals and instructional planning.
Relationship to Knowledge Base: The primary focus of this course is upon research on teaching and learning and the wisdom of practice. All teaching methods and strategies, other than attention given to classroom management, are subject specific. The overall context in which these teaching approaches are considered are the national curricular reforms in mathematics. Clearly, this course primarily attends to the domains of pedagogy, pedagogy and its relationship to subject matter, curriculum, and pedagogical content knowledge. Given that the learner must always be considered and that the general context of instruction is the school, the domains of learners and schools are also emphasized, however, to a lesser degree.

SED 582/3 Math/Science Pedagogy
(2 credits)
These courses are designed to allow each student to develop pedagogical content knowledge. Specific emphasis is placed upon classroom tested instructional activities and approaches as presented by actual mathematics secondary school classroom teachers. Each course addresses a specific theme of the 6-12 mathematics curriculum.
Relationship to Knowledge Base: This course is specifically directed at enhancing the development of pedagogical content knowledge (PCK). Based upon a series of presentations made by classroom teachers, university instructors and interns, students are asked to reflect upon the accuracy and appropriateness of subject matter and its representation in instructional practice. In short, this course directly attends to helping teachers to develop a variety of representations of subject matter within instructional context.

[1] Students also complete 11 credits of Professional Core courses: Educational Psychology (3); Foundational Perspectives in Education (2); Multicultural Perspectives in Education (2); Civil Rights for Educators (2)

Fall Term, 14 Credits[2]

SED 510 Professional Internship: Science/Math
(3 credits)
A part-time, supervised teaching experience in which the student experiences all of the general classroom and professional responsibilities common to the regular science/mathematics teacher.
Relationship to the Knowledge Base: This experience is intensive applications of program objectives and outcomes. In effect, this field experience addresses the same issues and knowledge bases as the microteaching course (SED 562/3) only in actual classroom situations. In a way this experience represents "capstone" experience involving all aspects in the life of a teacher.

SED 511 Directed Activities in Teaching/Learning
(3 credits)
A practicum designed to provide the preservice science/mathematics teacher with experience with the organization in the secondary science/mathematics curriculum, the students in the science/mathematics setting and with administrative and instructional activities of the secondary science/mathematics teacher. The practicum begins in late August to provide observation and experience with the process of beginning the school year.
Relationship to the Knowledge Base: This course applies observational techniques to enhance students' understandings of the complexities of classrooms. Techniques focus on the interactions of teachers and learners in the context of field experiences. This process enhances students' understandings of subject specific pedagogy (PCK) and general pedagogy within the framework of current reforms as specified by NCTM, NSTA, and AAAS.

SED 552/3 Math/Science Methods/Practicum II
(3 credits)
Methods and problems in planning for mathematics/science instruction using an activity and laboratory approach. Includes selecting teaching strategies, organizing materials, evaluating student progress, and managing student behavior. Practical experience in using current manipulatives, models, and technology.
Relationship to Knowledge Base: This course is a follow-up to SED 452/3. Consequently, its focus is a more in-depth attention to those domains of knowledge previously addressed, that is the focus of this course is upon research on teaching and learning and the wisdom of practice. All teaching methods and strategies, other than attention given to classroom management, are subject specific. The overall context in which these teaching approaches are considered are the national curricular reforms in mathematics. Clearly, this course primarily attends to the domains of pedagogy, pedagogy and its relationship to subject matter, curriculum, and pedagogical content knowledge. Given that the learner must always be considered and that the general context of instruction is the school, the domains of learners and schools are also emphasized, however, to a lesser degree.

SED 562/3 Math/Science Microteaching Laboratory
(3 credits)
Develop, practice, and improve specific instructional skills, strategies, and modes in small-group teaching learning situations with video-tape feedback and critique by self, peers, and supervisor. For mathematics preservice teachers.
Relationship to the Knowledge Base: This course provides students with an opportunity to apply the skills and knowledge obtained in the program's campus-based and field-based courses, with systematic feedback. Lessons which are taught must necessarily consider the school environment and the nature of learners. Naturally, the development and implementation of lessons presented directly involve knowledge of subject matter, knowledge of pedagogy, knowledge of curriculum, and knowledge of subject specific pedagogy. Consequently, the combination of personal instruction, observation of others, and personal reflection enhances the development of each of the six domains of knowledge upon which our program is based.

[2] Students also complete 3 credits of graduate level course work in their subject area.

Winter Term, 15 credits

SED 510 Professional Internship: Science/Math
(12 credits)

A full-time, supervised teaching experience in which the student experiences all of the general classroom and professional responsibilities common to the regular science/mathematics teacher.
Relationship to the Knowledge Base: This experience is intensive applications of program objectives and outcomes. In effect, this field experience addresses the same issues and knowledge bases as the microteaching course (SED 562/3) only in actual classroom situations. In a way this experience represents "capstone" experience involving all aspects in the life of a teacher.

SED 515 Seminar: Professional Internship for Science/Math
(3 credits)

On campus seminar to provide on going instruction integrated with the full-time, supervised teaching experience of the preservice science/mathematics teacher.
Relationship to the Knowledge Base: This seminar focuses on weekly reflections of experiences within the professional internship (SED 510). Students examine and assess skills in planning, implementing and managing instruction. Consequently, each of the six domains of knowledge are directly addressed within this seminar.

Spring Term, 16 credits[3]

SED 582/3 Math/Science Pedagogy
(2 credits)

These courses are designed to allow each student to develop pedagogical content knowledge. Specific emphasis is placed upon classroom tested instructional activities and approaches as presented by actual mathematics secondary school classroom teachers. Each course addresses a specific theme of the 6-12 mathematics curriculum.
Relationship to Knowledge Base: This course is specifically directed at enhancing the development of pedagogical content knowledge (PCK). Based upon a series of presentations made by classroom teachers, university instructors and interns, students are asked to reflect upon the accuracy and appropriateness of subject matter and its representation in instructional practice. In short, this course directly attends to helping teachers to develop a variety of representations of subject matter within instructional context.

SED 585 Math/Science Curriculum Practicum
(5 credits)

The aim of mathematics/science education for the 1990's is to develop mathematics, science, and technological literacy for all citizens. This aim emphasizes a general understanding of mathematics, science, and technology including knowledge, processes, applications, and information concerning opportunities for those interested in careers interested in mathematics and science. To accomplish this goal each participant will gain exposure to science, mathematics, and technology in the everyday lives and workplaces of future citizens. Through this exposure the beginning teacher will gain an in-depth knowledge of appropriate curriculum content and structure.
Relationship to the Knowledge Base: This course primarily focuses upon the development of curriculum materials based upon current reforms and a community based practicum. Naturally, the development of these materials considers the students' prior experiences and knowledge related to learners, pedagogy, schools, and subject matter. Consequently, although this course can be said to focus primarily upon the domain of curriculum knowledge, it also addresses the other five domains of knowledge to a significant degree.

[3] Students also complete 6 credits of graduate level course work in their subject area.

CHERYL L. MASON

12. THE TRIAD APPROACH: A CONSENSUS FOR SCIENCE TEACHING AND LEARNING

Human beings have stepped on the moon, explored the vast depths of the oceans, miniaturized computers to a microscale and outlined plans to colonize Mars. Yet, with all of our technological accomplishments we continue to disagree with factors concerning the influential educational arena and the profile of those involved within it (Harmin, 1994; Yeany, 1991; Tobias, 1992). Even as we delve more into the workings of our cognitive processes and how they are influenced by the coexistence between genetics and our environment, the conversation protracts concerning what should be happening in the science classroom (Sylwester, 1995; Gallagher, 1991). Unfortunately, our disjointed attempts to rethink and improve teacher education, to a great extent, have impeded progress and created a loss of confidence on the part of the public. What should be taught? and How should it be taught? are questions whose answers inevitably impact changes in extant teacher preparation programs. Is it more important to know science or how to teach it? Are all of these questions mutually exclusive? Experience has indicated that they are not.

REALITIES OF THE CHALLENGE

Teacher preparation programs run the gambit of requirements and length of coursework and field experiences. Part of the controversy, and one of the major criticisms of them, is that they tend to stress unilaterally either content or pedagogy, often merely providing future and current teachers with an array of noncontexualized, unconnected activities, concepts and demonstrations. The concern is that the educational pendulum continues to swing from focusing on content as compared to instructional strategies and vice versa (Hurd, 1997).

Shulman (1987) argued that, historically, teacher development and education programs stressed the art of teaching at the expense of content knowledge. Exacerbating the situation is the realization that professional education courses are notorious for presenting philosophical theory without assisting teachers in translating those constructs into practice. In addition, courses in subjects such as science, which are taken by these potential teachers, are designed mainly for detail and depth rather than articulation and conceptual understanding. Another challenge for teacher educators is that teachers tend to model the teaching techniques encountered during their sixteen or more years spent as students. For the most part, the salient feature of instruction has been someone standing in front of the classroom dispersing information in a text-driven, lecture mode, while neglecting to provide transi-

J. Gess-Newsome and N. G. Lederman (Eds.) PCK and Science Education, **277-292.**

tions and relevant connections. Because these episodes dramatically influence how precollege science is taught, an important facet of teacher preparation and a core issue of science education reform should be addressing these prior experiences.

The goal is not to train teachers to act in a specified manner. It is critical that we rethink the process and focus more on realizing that preservice education is an exercise in preparation instead of an effort to train people to become teachers. Preservice education is just the beginning of a professional life that should be spent reflecting and learning both content and pedagogy. Teachers must be prepared for perpetual growth as they face the challenging profession of making subject matter, such as science, comprehensible to a diverse population of students in an ever-changing world.

Content versus Pedagogy

As alluded to earlier, the majority of novice teachers are not provided the opportunity to apply pedagogical knowledge to specific issues and, therefore, tend not to understand what particular teaching strategy should be used to contextually teach specific concepts (Bethel, 1984). Working from John Dewey's ideas about the differences in the scholarly knowledge of a discipline and the knowledge needed for teaching and learning of that discipline, Shulman (1987) postulated that the nature and structure of different content areas may require the use of equally different instructional approaches. As an example, generic methods textbooks rarely address the unique issues in the science classroom and laboratory. Along with other educational researchers (Grossman, Reynolds, Ringstaff, & Sykes, 1985; Hashweh, 1985; Magnusson, Borko, & Krajcik, 1994; and Wilson & Shulman, 1987), Kennedy (1990) reminds us that teaching the use of generic instructional strategies fosters a belief that all strategies work equally well in every context. She also points out that there is not a correlation between individuals understanding their content as compared to their having an insight into how to teach it to others.

Another factor to be taken into consideration is that, for the most part, science majors have spent their academic careers memorizing vocabulary and algorithms for courses that are not taken in any particular order except for prerequisite concerns. Although the professors view their curriculum as having a valid and traditional sequence complete with all logical requisite bridging concepts, in reality the assumed bridging logic is transparent to their students. The result of this experience can be well-trained individuals who have learned science as discrete bits of information and who lack an overall view or understanding of the relationships among the bits (Mason, 1992; Kennedy, 1990). Even a course's main tool, science textbooks, in and of themselves do not foster coherent understanding. When future science teachers have not been encouraged to construct a comprehensive view of their discipline, they are only able to present science to their students as they learned it, in the form of disjointed facts.

Pedagogical Content Knowledge

The preparation of teachers continues to be embroiled in controversy. However, with the recent knowledge that we have gained about teaching and learning, it logically appears that we need to blend content competencies with pedagogical effectiveness; that is, guide teachers into developing pedagogical content knowledge (PCK) (McEwan & Bull, 1991). Stofflett (1994) calls attention to the natural reciprocal dependence that exists between content and pedagogical knowledge. Having a broad and deep knowledge of their discipline, along with the ability to transform that knowledge into multiple forms for their students, allows teachers to have their own convention of professional understanding. This more stringent and cohesive knowledge should lead to an increase in their effectiveness in instruction.

A crucial element of pedagogical content knowledge is helping teachers to understand that students do not learn subject matter in a meaningful manner by passively receiving information, but rather require experiential endeavors to actively construct their knowledge base. As with their own students' education, teachers must learn to assimilate new teaching strategies effectively, rather than rejecting them outright because of unfamiliarity, or using them without understanding the underlying rationale (Stofflett, 1994; Kennedy, 1998). For example, guided instruction might work quite well in a biology class centered around identification of microorganisms, but as an instructional tool in an English literature class it may be less successful. Concept mapping can be of great benefit to students studying how bills are passed in Congress, but of little use to students studying various aspects of finite mathematics. Again, what is extremely important is the teacher's ability to ascertain which strategies are operative for teaching particular concepts.

Both content and pedagogy are significant domains of teacher preparation. Rather than being in isolation from one another, content and pedagogy should be melded together. Teaching specific concepts to specific students, so that meaningful learning can occur, requires a thorough understanding of the interconnectedness of content knowledge, learning theory and instructional strategies. The phrase pedagogical content knowledge is used aptly to describe this ability to combine knowledge of a specific discipline along with the teaching of that discipline. It was the desired acquisition of this critical type of knowledge (PCK) in future teachers that led to our formulation of instructional teams called TRIADS. The term TRIAD is in all capitals to emphasize the unique collaborative structure.

TRIAD DESIGN

In restructuring the secondary science education program to specifically address the aforementioned inadequacies of teacher preparation programs, three new courses were designed and offered at San Diego State University: one is scheduled to be taken during a student's senior year and the other two during both semesters of her or his teacher credentialing year. (Note: California students planning careers as secondary science teachers earn an undergraduate degree in science and then enroll in the credentialing program during their fifth year.) The uniqueness of the foci of the courses demanded a total rethinking and developing of curriculum and methodology on behalf of the instructors. The resulting coursework and delivery were grounded in theory-based practice that emphasized integration of the teaching and learning of science.

A major contribution to the robust and varied nature of instruction was the fact that each course was developed and taught by a TRIAD of instructors - a high school science teacher, a professor in the academic content area, and a professor in science education with a science background. Participants in the TRIADS were selected on the basis of their exceptional teaching ability, an extensive background in science, and their progressive attitude toward teacher preparation.

Working as a team, each TRIAD utilized the paradigm of PCK to develop appropriate content knowledge and teaching behaviors in preservice teachers. Each course was designed in a collaborative and cooperative manner. The key to this joint endeavor was that there was a genuine collegial relationship with each member of the TRIAD helping other members of the team to gain an insight into his/her area of expertise. The TRIAD instructors alternated leading lessons, with the non-lead faculty contributing to the conversation during pre-class and in-class sessions. As a result of this teaching configuration, the instruction was a blend of the nature of science and its related body of knowledge, and learning theory grounded in the real world of the classroom.

The TRIAD's had three main goals for their courses: (1) to assist students with conceptually organizing their newly and formerly acquired knowledge of scientific concepts, (2) to model effective techniques for teaching in an interdisciplinary and intradisciplinary manner, and (3) to encourage students to reflect upon their ideas about the teaching of particular scientific concepts in a specific context (Mason, 1989). To realize these goals, activities were designed to help students systematically analyze and structure their knowledge in an organized, logical fashion so that they would be better equipped to teach meaningful concepts to their students.

Evolution of the TRIAD Instruction

To address some of the concerns raised by critics of the educational system, the TRIAD's sought to resolve the conflict of what emphasis should be placed on science content as compared to science teaching. Bringing together science educators, scientists and science classroom teachers provided a rich environment for inquiry into the theoretical underpinnings of pedagogical content knowledge and their translation into practice. The mixture of perspectives from these three areas of concentration in science education allowed for an interesting and productive collaboration. TRIAD members met and discussed the critical linkages between content and pedagogy, and how science teacher credentialing curriculum could more fully reflect those linkages.

In attempting to foster an environment for the effective preparation of science teachers, basic questions needed to be addressed: What is the nature and structure of the discipline? What role does cognitive science play? What strategies should be employed to facilitate the learning of selected scientific information? What are the contextual factors that affect curricular and instructional decisions? What degree of content knowledge is absolutely essential for preservice teachers to possess as they enter the profession? What should be included in the university curriculum to foster continued learning and reflecting by these future science teachers?

As TRIAD faculty struggled with these questions, a clearer understanding of the relationship between content knowledge and pedagogical knowledge unfolded. TRIAD faculty were compelled to view science education from one another's perspective in order to more fully comprehend the complex nature of teaching and learning. The results have been richly rewarding for all participants and have yielded a teacher preparation program that both clarifies and expands the definition of a science teacher.

Following the initial planning stages, the instructors have continued to meet frequently during the subsequent years that the courses have been offered. Conversations during these meetings have provided an opportunity for the faculty to re-evaluate the direction and effectiveness of the courses, and to make revisions. Due to the uniqueness of these courses, designing activities and instruction that help course participants comprehend the nature of pedagogical content knowledge and its importance to education continues to be a major challenge.

COMPONENTS OF THE COURSES

Class assignments and activities for the senior level course stressed knowledge and understanding of science content. This emphasis was a continual effort toward forcing these future teachers to think about their own limitations in scientific content and processes. They were also urged to recognize the need to develop the ability to transform their knowledge and understanding as they sought to help learners construct their own individual knowledge base. The credentialing year courses continued to stress scientific concepts but used them as a vehicle for role modeling and discussions of teaching strategies. During every class session the instructors exposed students to three slightly different ideas and viewpoints concerning the learning and teaching of particular concepts, while at the same time formulating a coherent, plausible model of science teaching and learning.

Aspects of the TRIAD sessions included discussions revolving around results from educational research studies and their implications for science teaching. Subsequent interactions focused on ways for infusing the essence of these studies into curricular models, using curriculum as an all encompassing facet of the classroom. The resulting impact was that, probably for the first time in their scholarly careers, these students discussed ways to connect and transform information from their coursework in science content and educational pedagogy, and to incorporate this knowledge into a meaningful teaching context.

Case studies; reflective logs with specific questions; concept maps; analyses of textbooks and other written materials; lesson planning that reflects equity in backgrounds and learning styles; use of current issues in science; and an analysis of preconceptions, misconceptions and attitudes that students bring to the learning situation are examples of vehicles used to promote pedagogical content knowledge (Mason, 1992; Novak, 1990). In addition, videotape review and constructive criticism of self and peer teaching performances served as a way to monitor and assess progress toward blending science teaching and learning.

Insights into Student Learning

One of the most powerful thrusts of the current effort to reform science education is a better comprehension of the nature of the learning process itself (Tinker, 1994). The TRIAD faculty worked toward sensitizing these future teachers to the necessity for recognizing that students learn in a variety of ways and that science should not be taught strictly as a vocabulary course using the lecture format (Armstrong, 1994). Instead, teachers must understand that there are many vehicles for engaging students in scientific processes that reflect the nature of science, along with the assimilation of the body of knowledge that goes along with these processes (Mullis & Jenkins, 1988; Yeany & Padilla, 1986; Simpson & Oliver, 1990).

Another element of pedagogical content knowledge is identifying ways of meeting the needs of the varied academic abilities in the science classroom. Related to these issues of learning styles and multiple intelligences are the significant cultural and gender characteristics that affect the learning of science. It is imperative that teachers are sensitive to the different belief systems, social behaviors and language proficiencies of today's students, especially since they are often quite different from what teachers have experienced during their own educational career (Kahle, 1988; Mason & Kahle, 1989). Expanding the concept of PCK beyond just teaching certain content is the fact that teachers also must be cognizant of individual differences and prior experiences as curriculum is developed.

Another important aspect of student learning that was deliberated by TRIAD faculty and their students involved acknowledging that everyone has acquired alternative conceptions and preconceptions concerning various topics in science. It was pointed out that students are inhibited in their learning of science if teachers do not realize the importance of recognizing and addressing the naive conceptions about scientific phenomena that students bring into the classroom (Glynn, Yeany & Britton, 1991). In striving to gain an insight into student learning and the direction of students' thoughts, teachers need to be attentive to the questions raised by their students and the incorrect answers given during assessment. The cognitive processes involved in attending, comprehending, internalizing, connecting ideas/concepts, remembering, and transferring what has been learned to novel situations also need to be considered. It is imperative that teachers analyze how students construct their own knowledge of science so that the discipline is relevant and logical to the learners.

Reflection in Action

Rather than focusing just on the manner of teaching or the content to be presented, it is important for teachers to think about specific concepts and analyze how they may or may not be taught and why (Schön, 1983). Effective self evaluation skills are critical for teachers to gain new insights into teaching science. An important aspect of the teaching profession is the desire to continue to reassess and reflect upon the principles and purposes of the science content and the instructional strategies used to communicate information. In addition, effective science teachers strive for a consolidation of new understandings about teaching and learning from experiences both internal and external to the classroom environment (Yeany, 1991).

In line with this aspect of PCK, another component of the program involved supervision. Several of the TRIAD members were also responsible for supervising preservice teachers during student teaching. Members of the TRIAD observed the student teachers on several occasions and collaborated with the supervising teachers on the student teacher evaluations. The usual conflict between university supervisors and public school supervisors did not exist because the TRIAD approach helped to establish a similar philosophical framework and a set of goals on behalf of both groups. Theory was turned into practice without the usual mixed messages that student teachers tend to receive from their various instructors and supervisors. Instead of a conflict of directions, the TRIAD worked from a mutual consensus.

Throughout the program, the student teachers were asked the questions, Why did a lesson work? Why didn't it? Why did the lesson work with one group of students and not with another? How did you determine which concepts should be learned by your students? What made today's lesson relevant to students? Was there any evidence that students were learning? Supported by the findings of other colleagues (Kyle, Jr., Linn, Bitner, Mitchener, & Perry, 1991; Peterson, 1988; Schön, 1983), TRIAD faculty encouraged these novice teachers to reflect upon their teaching and to recognize that individual situations require definitive approaches to teaching. Most importantly, the student teachers were empowered to facilitate self-analysis, rather than merely hearing what was right or wrong with their lesson. They were persuaded to reflect upon the implications of their actions, not how well they survived a given situation.

Specific Activities in the Senior-level Course

Generally, the activities were designed to place the course participants in a position of recognizing their lack of understanding the cohesiveness and depth of scientific concepts. Specific activities which were developed for the course are described below.

Journals. To encourage continued reflection on the learning of science, the students were asked to maintain a journal and to submit copies of the entries on a weekly basis. The objective was for the students to consider how they learned scientific concepts and what particular mode of instruction seemed to be the most effective for them. They also were asked to observe how science fit into the world around them. To guide the focus of their thoughts on occasion, the students were directed to answer specific questions in their journals in addition to their general reflections.

For many, there was a resistance to sit down and reflect. They wanted to know what should be in the journal and how long the entries should be, rather than realizing the need to abandon the passive student role and assume a responsibility for their own reflection. If they were to evolve into effective teachers, they needed to think about their own learning and to be able to analyze whether or not their students were learning.

Concept Mapping. This particular strategy was designed to help these science majors rethink and organize their content knowledge so that they could begin to comprehend the interconnectedness and robust nature of scientific concepts. In addition, the concept maps were used as a tool for evaluating the effectiveness of presentations in and out of class, identifying misconceptions or naive conceptions, and developing critical thinking skills. Concept maps were drawn by the students throughout the semester. Examples of situations were as follows.

- Students were presented a specific list of concepts and asked to draw a concept map using only those concepts. This activity was performed individually and in small groups.

- Following class presentations, maps were drawn by classmates and shared with the presenters. The presenters then wrote comments concerning their reactions to the maps.

- Maps were drawn using small sections of a high school textbook. The purpose of this was to emphasize the quantity of terms within a small span of text.

- Maps were drawn by course participants following attendance at a science seminar. These maps were compared with a peer's map who also attended the lecture.

- Presenters had to draw a map for their own presentations and compare it to those drawn by their peers.

Not having had to think about scientific concepts as an interrelated entity, students tended in the beginning to draw their maps in a linear fashion. Also, when asked to describe their concepts maps, it was obvious that much of the information contained in the maps was memorized. As a result of this rote memorization, these future teachers were unable to explain the concepts in other ways, only in the way that they had learned the information. It was evident that a large portion of their college education did not involve meaningful learning which comes from constructing one's own knowledge, not memorizing fragmented facts. One of the most revealing aspect of the concept maps and subsequent explanations was the number of misconceptions and content gaps held by these course participants. These were discussed from the viewpoint of how people develop misconceptions and how teachers can seek to alter them (Mason, 1992).

Presentations. One of the roles of a teacher is to decide what the scope and sequence of scientific concepts should be for a course. Following that, they need to monitor student learning and alter strategies whenever necessary. Having the students (course participants) give a 20-minute presentation to their fellow classmates was an effective vehicle for beginning the development of these skills. The objectives for the presentations were as follows.

- Students needed to practice identifying and organizing concepts in a logical manner.

- Material presented in a short period of time would reflect the extent that the student could determine which concepts were important and what the scope and sequence would be.

- Questions posed by their peers required that the presenter be able to explain a concept in a variety of ways.

To prevent the *teaching as they were taught* syndrome the students were asked to develop their presentation around a unique approach. Although suggestions were made, it was hoped that the students would think about it and select their own topics. A source of difficulty with the class seemed to be the need to provide sufficient instruction without inhibiting the initiative and original thoughts of the students.

Once a topic was selected and approved, an initial outline was submitted and reviewed with the student. Again, an effort was made not to inhibit creativity but to help prevent obvious pitfalls, such as presenting too much and too detailed information. On the day of the presentation, a detailed summary, copies of any visual aids and a concept map were required to be turned in. Three to four presentations were given per class meeting. At the end of each presentation the students developed concept maps of the presentation which were given to the presenter, who later turned in a short written reaction to the resulting maps.

On the same day as the presentation the presenter and the instructors met privately for a brief discussion. During the discussions the presenters seemed to be more concerned about their techniques than about their content. The confidence that they knew the basics of their discipline was evident, even though the presentation often did not indicate this. As a result, the instructors changed the emphasis for grading the presentations for the next semester. Much more emphasis was placed on the accuracy of content, transitions, and scope and sequence of concepts. They directed the students to concentrate more on the content presented.

Classroom Observations. Many of the students indicated that they had not been in a middle or high school classroom in several years and didn't really have an idea as to what level to present material and in what manner. To remedy this situation, they were required to visit and observe three precollege science classrooms. The course participants were given a list of specific areas on which to focus, but even with the list they tended to look at how the teacher handled discipline problems rather than noting how content was presented and reacted to. On the other hand, most of the observers noted with dismay the number of teachers who presented science as a list of vocabulary words in a lecture-like mode to a group of bored-looking students. The subsequent class discussions revealed that these future teachers were looking at the ethos of science classes with a more critical eye.

Science Seminar. Science teachers need to strive to keep their information up-to-date. Attending professional conferences and seminars is one way. Whatever the source, even more importantly is the ability to assimilate newly acquired information within an existing lesson. The course participants were asked to summarize a science seminar in written form along with a concept map. In addition, they were to attend the seminar with a peer. Comparing notes after the seminar helped the students realize that not everyone learns in the same way. Also, concepts that are important to one individual are not necessarily important to another. It was also recognized that this wide difference in learning styles is a good rationale for the use of small group work in the science classroom. The final requirement for the assignment was for the course participants to indicate how they would incorporate information from the science seminar within a precollege science lesson. Most found it very difficult to glean information from the talk which could then be incorporated within their teaching. This inability to isolate information seemed to be an indication that either the material was not sufficiently understood or that they had not had enough practice in culling out salient features of the lectures. Being able to isolate important elements from a textbook or other source of information is a critical skill for teachers, indicating a true understanding of the concepts.

Textbook Critique. One of the assignments asked the course participants to analyze how concepts were developed in their introductory college biology textbook, and how the nature of science was reflected. They basically looked for the interconnectedness of concepts, number of terms presented in a small passage, signs of a conceptual versus a fact-based approach, and the order and context of the concepts or terms presented. Course participants observed that most texts were confusing and difficult to follow. The lesson to be learned from this was that science teachers should not just tell their students to read the chapter and answer the questions at the back. Instead effective teachers must provide strategies for reading text, and guidance toward interconnecting the concepts and placing them in a context.

Specific Activities in the Credential Year Courses

The basis for instruction in these courses was to provide practical ideas for activities and classroom management skills based upon data from the latest research in science teaching and learning. The philosophy of the instructors was not to present a bag of tricks for these future teachers, but to help them understand why certain techniques were appropriate for specific occasions. In this vein, the instructors sought to provide strategies for turning theory into practice. What resulted was that course participants gained an understanding of why certain techniques or approaches led to better student learning; they began to assess what was needed in a given situation.

Another challenge for the instructors was how to offer assistance to the student teachers who were assigned to teach subjects out of their major area of science. Having the triad of instructors available for consultation furnished the opportunity for these people to receive sources of information and guidance to help them through their difficult situation.

Topics such as analyzing a textbook, describing the nature of science, using proper questioning and answering techniques, conducting a laboratory activity, addressing equity issues in the science classroom, using student-centered activities, and so forth, were a large component of the course. Generally, the activities throughout the course were designed to provide the student teachers with specific examples of activities and strategies which have been shown to be effective in the science classroom. On the other hand, a common thread throughout the course continued to be an emphasis on the necessity of reflection upon the nature of science, and science teaching and learning. Some of the specific assignments which were required for the course are described below.

Journals. The same rationale and similar criteria for maintaining a journal were used for all three courses. In the credentialing year courses, students were asked to think and write more about how they were helping others to learn science and what seemed to be effective. Weekly entries were also to include how they were changing in their approach to science teaching and learning. The journals contributed toward the triangulation of data from other sources (class discussions, assignments, presentation, etc.) to support the notion that students enrolled in these courses were changing their ideas about the nature of science and science learning.

Concept Mapping. This particular strategy was used more extensively in the senior-level course, but was still an important component of the credentialing year courses. Class participants also were encouraged to use this technique in their own classroom. Some structured their yearly lesson plan around a concept map, so that they could see how all of the presented concepts fit together. Several other student teachers employed concept mapping as a tool during instruction to identify misconceptions or naive conceptions held by their students, to help their students put the big picture of science together, and to note which concepts were not presented in an effective manner.

Presentations. The student teachers also were required to make presentations during the credentialing year courses. At least one presentation was to be a demonstration of a scientific concept, and another focusing on unique ways to present the more abstract concepts of science. The goal of this assignment was for the student teachers to demonstrate within a lesson that they had assimilated the information presented or experienced throughout the courses; that is, they presented fewer terms, had student-centered discussions and activities, connected concepts to one another, gave relevant examples, took into consideration students' prior knowledge, and used a variety of teaching strategies to fit the variety of learning styles.

MONITORING THE PROCESS

In order to ascertain the impact of the TRIAD approach on the teacher preparation program, qualitative and quantitative data were collected. Vehicles for data-gathering were surveys, interviews, journal entries, concept maps, class discussions and observations. External evaluators were engaged to determine the success of the program in conjunction with internal evaluation. The evaluation process involved the determination of the extent to which students in the program had confidence and knowledge of science content and teaching strategies. For example, students were pre- and post-tested using a *Professional Self Profile Instrument.* They responded to the questions using a Likert-type scale from *not at all* to *completely.* Interview questions tested content knowledge by asking about presentation strategies for various concepts, and to what extent they were familiar or confident about certain content areas and teaching strategies. Making observations in the classroom and noting the extent of the conceptual approach to teaching science, in addition to the changes made to afford an opportunity for all students to learn science, also demonstrated the effect of the TRIAD approach to teacher preparation. Excerpts from interviews and surveys conducted by internal and external evaluators are among the results cited (St. John, 1988).

For example, results showed that this innovative approach to teacher preparation had a large impact on the university science faculty, who now were closely scrutinizing their own philosophy of teaching science. A TRIAD member described how instrumental this approach was to involving additional faculty in the process of teacher preparation.

> One benefit of the [program] is that it brings the subject matter experts at the university directly into contact with the way their disciplines are being taught. . . this is often an eye-opener for them when they see the violence that is done to their discipline. . . they are forced to confront it. . Maybe this way the people who know good science and who know how to teach it will realize the responsibility they have. . . and they will get involved. . Also maybe they will realize that how they teach their undergraduate courses affect how the disciplines are taught at the secondary level.

According to another TRIAD member, the pedagogical content knowledge approach helped students

> . . see that they'll have to use their knowledge in a different way than it's been taught to them. Decide what information needs to be expressed and how to pick out what's important. Understand the interaction among content details.

Supervising teachers found that they were now treated in a more professional manner as one participant stated.

> Working as an equal team member of the TRIAD process made the whole thing very professional. I think that it showed us that we have developed teaching skills that we can share. . but also much of what we do naturally has to be explained to the student teachers. For example, we know how to conduct an effective laboratory exercise. . . . Also, I think it caused us to look at our own teaching and analyze why we do what we do. . I am very impressed with the program.

University student interviews revealed that the TRIAD approach provided a wealth of information. The students perceived that they were receiving accurate, relevant instruction since it was supported by members of the education community at various levels. Two students commented as follows.

> At the beginning of this semester I was skeptical about this course. I felt it was just 3 more units the Biology Department added on us. However, I learned a lot from this course and know I will find it irreplaceable as I start my teaching career.

> The class (credentialing year) looked at science from a simplistic, organized view, as opposed to the complicated views of my undergraduate courses. It was very effective in teaching me how to translate the difficult concepts to the high school level. It also put all of the concepts that I had learned into place and showed me how they related.

A local high school administrator echoed her sentiments concerning the collaborative relationships.

> Collaboration, you have to understand, is useful just as collaboration. We now can pick up the telephone and solve problems as they arise. We talk with complete candor to each other. . there are great inherent benefits to process that foster collaboration. We learn about each other's bureaucracies and the constraints we each have to face. . we break down naturally occurring barriers and distances. . .

The following are samples of the summarized results compiled and analyzed by an external evaluator.

- In general, [students] found the program more balanced between the academic and the practical; students in the standard [program] found the courses too philosophical.
- The . . . program, in some sense, simply puts back together pieces that should never have become so fragmented in the first place.
- The learning of subject matter and the learning of pedagogy become blended when real issues of the classroom are addressed in the TRIAD [classes].

- The coordinated advising and supervision of supervising teachers, education faculty, and academic faculty allow students access to a rich resource of perspectives and assistance.

SUMMARY AND CONCLUSIONS

With the renewed interest in improving education, researchers are once again looking at teacher preparation programs. According to Darling-Hammond and Hudson (1990), there are at least two main reasons for revisiting these issues: (1) the need to produce a critical mass of well-trained work force, as well as a more literate population, and (2) the realization of the impact that the caliber of teachers has on the educational process. Researchers are now asking a variety of questions including the following:

- What are the characteristics of an effective teacher?

- How can teachers be encouraged to reflect upon their knowledge base of content teaching and learning?

- To what extent do highly qualified educators depend on additional knowledge of teaching and/or a deeper and broader knowledge of their discipline?

Moving from a theoretical construct to a functioning program is a challenging and exciting endeavor. This is especially true when the theoretical concept is one which has not been fully tested. Pedagogical content knowledge is a realistic and logical framework for teacher preparation. It offers tremendous impetus for the restructuring of teacher preparation curriculum, and of university and public school priorities as well. As a result of input from collaborative members involved, and as insights into what was needed surfaced, the program, based on the PCK concept, has been continuously revised. With the guidance of experts in the field of education and other academic areas, the resulting impact of the program is that preservice teachers are able to distill and blend information from their coursework in content courses, along with educational theory and practice, and to incorporate this knowledge into a meaningful teaching context.

Involvement in the TRIAD's has had a profound affect on all participants: students, preservice teachers, supervising teachers, administrators at all levels and university faculty. Rather than the whole process of teacher preparation and development being a fragmented entity, the TRIAD teams provide the opportunity for collaboration, cooperation and collegiality among persons involved. This cohesive approach renders an effective outcome, unlike the more competitive, disjointed, and even isolated, hierarchical programs that continue to argue from the sides of content versus pedagogy.

With the reputation that the teaching profession has for keeping people in isolation from one another, an added benefit of the program includes a dynamic, interactive process among all of those involved. Members of the TRIAD faculty, along with the preservice teachers, are able to engage in a continuous exchange of views, impressions, classroom experiences, etc. Discussions include, but are not limited to, facets of teaching and learning that target topics revolving around learning strategies, learning theories and subject matter knowledge.

The approach of combining the talents and knowledge of teachers, educators and academic specialists is a step in the right direction toward effective teacher preparation. The perspectives of the cooperating faculty afford an opportunity to present the whole picture of learning and teaching. As a result, preservice teachers are compelled to think about their own content knowledge and the mechanism by which they can transform that knowledge in a way which will be comprehensible to any student in a given situation. Pedagogical content knowledge empowers teachers to decrease their dependence on externally-developed curricular materials, and to increase their ability to identify what aspects of science should be taught and in what manner. Acquiring such knowledge goes beyond gaining an information-level of understanding; it requires a deep understanding of science content and how people learn.

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