THE ACQUISITION OF PEDAGOGICAL CONTENT KNOWLEDGE BY PROVISIONALLY CERTIFIED SCIENCE TEACHERS

by

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(Under the Direction of J. Steve Oliver)

ABSTRACT

The debate over teacher qualifications has been characterized by two opposing factions – professionalization and deregulation. The former supports high standards for certification while the latter seeks relaxed licensure requirements. With the critical shortage of science and math teachers, the Georgia State Board of Education is seeking alternative methods for increasing the pool of prospective teachers. Individuals with an undergraduate degree can be employed as full-time classroom teachers, with the understanding that they must be fully certified within three years. These "shortcuts to the classroom," however, have met with opposition from professional teacher organizations because of a perceived indifference for the more traditional form of teacher education. The major concern was whether or not a provisionally certified teacher could effectively explain the required scientific concepts to the students without the benefit of pedagogical training. This dilemma between content and pedagogy was explicated by Lee Shulman in his work on teacher knowledge, in which he evaluated the relationship between content knowledge, general pedagogical knowledge, and a unique ability to explain content called pedagogical content knowledge (PCK). It is the formulation and modification of the novice science teacher's PCK that is the basis for this study.

The purpose of this investigation was to determine how provisionally certified science teachers, with significant content knowledge but little or no pedagogical knowledge or teaching experience, developed pedagogical content knowledge. The participants, who were in their first year of teaching, were recruited from an alternative certification program at a large research university. By employing symbolic interactionism as a theoretical lens, a hypothetical formulation of PCK acquisition was constructed utilizing a grounded theory methodology.

The data indicated the presence of two levels of pedagogical content knowledge – structural PCK and functional PCK. Structural PCK, the form that clarifies specific facts and aids in information recall, was closely linked to the participants' level of content complexity. On the other hand, the development of functional PCK, the type more closely associated with depth of knowledge and conceptual understanding, was dependent on the degree of the participants' pedagogical sophistication, with the frequency and quality of teacher-student interactions being of crucial importance.

INDEX WORDS: Pedagogical Content Knowledge, PCK, Pedagogical Knowledge,Shulman, Novice Science Teachers, Alternative Certification, Teaching Experience, Pedagogical Sophistication, Content Complexity, Grounded Theory, Symbolic Interactionism.

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DEDICATION

I dedicate this dissertation to my wife, Susan, and my two children, Amanda and Adam, for their patience, support, and encouragement throughout this project.

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CHAPTER 1: INTRODUCTION

The state of Georgia is currently suffering from a critical shortage of classroom science teachers. In order to meet this increasing demand for qualified instructors, special programs, such as the "Troops to Teachers" initiative and the "Teach for Georgia" agenda, have been instituted by the state department of education (Georgia Department of Education website, 2001). These programs have been severely criticized by professional teacher organizations (Georgia Association of Educators online, 2001) because of an apparent indifference to the development of pedagogical understanding in the programs' participants. According to recruitment mandates, as long as teacher candidates possess an undergraduate degree in a specific discipline, a general pedagogical knowledge would not be necessary to gain initial access to the classroom. Following from this philosophy, teaching methods and techniques would develop over time with experience and concurrent methods coursework. This belief contradicts the assertions of teacher educators who claim that individuals who are not properly "educated" in teaching methods would not be effective in the classroom (Darling-Hammond, 1998). In other words, knowing how to teach, in many cases, may be more important than knowing what to teach. This contention is supported by many of today's practicing teachers who believe that if one knows how to teach, one can teach anything (Shulman, 1986). This pervasive belief implies that pedagogy, as reflected through teaching behavior, is the cornerstone of effective instruction.

A similar debate is evident at the national level between advocates of professionalization and supporters of deregulation. According to Cochran-Smith and Fries (2001), those who promote professionalization endorse high standards for preservice preparation and certification, while proponents of deregulation maintain that college and university program requirements and state certification standards are preventing highly motivated and talented individuals from gaining access to the profession. Both sides attempt to bolster their positions by referring to the empirical evidence gleaned from countless investigations. Linda Darling-Hammond, the spokesperson for professionalization, claims that " teachers who are fully prepared and certified in both their discipline and in education are more highly rated and are more successful with students than are teachers without preparation" (1998, p. 10). Ballou and Podgursky, two economists whose analysis of the research supports the deregulation agenda, claim that "teacher ability appears to be much more a function of innate talents than the quality of education courses" (1999, p. 57). Based on these two schools of thought, the implications concerning alternative certification are enormous. "Teachers who enter through alternative certification programs seem to be at least as effective as those who completed traditional training, suggesting that training does not contribute very much to teaching performance" (Ballou & Podgursky, 1999, p. 57). Again, the problem appears to focus on the relative merits of content versus pedagogy.

Challenging the prominent role that pedagogy plays in teacher preparation is the current reemphasis on the importance of content knowledge (Cochran, 1997; Abd-El-Khalick & BouJaoude, 1997: van Driel, Verloop, & de Vos, 1998). Based on the work of Lee Shulman (1986), the ability of the teacher to take conceptual knowledge and transform it into a comprehensible explanation for students appears to be a major component of effective teaching. Although general pedagogical knowledge is important, the capacity to explain difficult concepts, what Shulman calls pedagogical content knowledge (PCK), is directly related to an in-depth understanding of the subject matter. Very possibly, what is observed in the classroom as effective teaching is more dependent on understanding what is taught rather than how to teach it. If this assertion is correct, then it may be possible for content-oriented individuals to enter the classroom and perform just as effectively as graduates of teacher education programs. This statement, however, is purely speculative. This study was not designed to determine whether individuals with high content could perform effectively in the classroom without pedagogical training. Rather, the intention of this investigation was to determine how teacher candidates with ample content knowledge developed the ability to explain difficult science concepts to their students. If, as Shulman indicated, significant subject-matter knowledge is a primary factor in the transformation of content, then studying provisionally certified teachers who have not experienced any pedagogical training provides the perfect opportunity to investigate the relationship between content knowledge and the development of PCK.

Purpose

This investigation was concerned with the nature and development of pedagogical content knowledge in a pre-selected sample (3 cases) of provisionally certified science teachers. The participants for this study can be characterized as having satisfactory to high levels of content knowledge, as evidenced by either an undergraduate or graduate degree in a specific science discipline (or what was judged to be an equivalent amount of content development), and relatively low levels of general pedagogical knowledge, as evidenced by the provisional certification. In all cases, the research participants were part of an alternative certification program involving teaching methods coursework. In addition to these basic criteria, the research participants also exhibited some level of pedagogical content knowledge development as determined by preliminary classroom observations and interviews. This initial indication of PCK formulation, whether rudimentary or more advanced, indicated the potential for further growth. These investigative parameters made possible a determination of how the prominent variables of content knowledge, teaching experience, and pedagogical training interacted in the development of PCK. The purpose of this study was to formulate a substantive theory on the development of pedagogical content knowledge in provisionally certified, first-year teachers. By utilizing a grounded theory methodology (Glaser and Strauss, 1967), an explanation of the factors affecting the formulation and modification of PCK was developed. The generation of a substantive theory concerning pedagogical content knowledge could subsequently inform the educational research community of the proper balance between content and pedagogy in the training of both preservice and inservice teachers.

The following research questions were addressed:

1. How do provisionally certified first-year teachers, with ample content knowledge but minimal pedagogical training, develop pedagogical content knowledge?
2. What are the sources of this knowledge?

Rationale

A substantial amount of educational research has emphasized the necessity of managing the learning environment by means of well-developed pedagogical skills (Stofflett & Stoddart, 1994; Thorley & Stofflett, 1996). These teaching behaviors, which are readily observed and evaluated, form the basis for methods curricula throughout the nation's colleges and universities (van Driel, Verloop, & de Vos, 1998). The act of teaching has become both an art and a science and, whether intentionally or not, entry to the profession was restricted to those who could master the pedagogical standards. Many state departments of education and professional teacher organizations mirror this stance by supporting extensive certification requirements for prospective teachers.

The recent shortage of teachers, not only in Georgia but also throughout the nation, has forced both state legislators and teacher educators to contemplate teacher recruitment programs that are based on the prospective candidate possessing an undergraduate degree in a specific discipline. According to many practicing teachers, this strategy appears to de-emphasize pedagogical skills in favor of mastery of content. This situation, however, provided the opportunity to study how novice teachers, with ample content knowledge but relatively low levels of pedagogical knowledge, acquired pedagogical content knowledge.

Current research on Shulman's knowledge structures has indicated that PCK is simply a natural by-product of teaching experience (Geddis, 1993; van Driel, Verloop, & de Vos, 1998), but additional studies indicate that both novice and veteran teachers have varying levels of PCK which is independent of years of experience (Abd-El-Khalick & Boujaoude, 1997). A substantive theory of PCK development would provide teacher educators with the necessary tools for the cultivation of high levels of PCK in both preservice and inservice teachers. From the prospective teacher's standpoint, an enhanced PCK would be of benefit in making decisions on how to explain a difficult concept more effectively, thereby fostering a more thorough understanding of students' alternative conceptions.

Presentation vs. Explanation

Two terms that are frequently used throughout this dissertation are presentation and explanation. These terms are not intended to be equivalent. A presentation of content involves the teaching approach and instructional strategy deemed most appropriate for conveying a particular science topic to the student. For example, the teacher may choose to conduct a demonstration as an introduction to a concept, followed by a question and answer session to generate additional variables for student inquiry. Although certain elements of pedagogical content knowledge are inherent in the selection and sequencing of activities, the ability to plan and implement lessons is not in-and-of itself indicative of a well-developed PCK (Shulman, 1987). It is in both the initial explanation of a science concept, and the interaction between the teacher and the student to determine the degree of comprehension, that a teacher's level of PCK becomes apparent. The explanation itself involves a transformation of content knowledge for the purpose of making it more comprehensible. How successful the teacher is in promoting student understanding through this transformation determines the level of PCK development.

Theoretical Framework

The organizational scheme for both the epistemological and methodological theoretical frameworks was taken from Michael Crotty's enumeration of the four elements of qualitative research (1998) – the methods, methodology, theoretical perspective, and epistemology. Although a thorough explanation of the research design follows the literature review, an understanding of how the methods and methodology are related to the other investigative components is essential. The methods involve the tools for gathering data relevant to the research questions and the techniques used to analyze and interpret the data. The methods deemed most appropriate for answering the research questions are part of an investigative tradition or methodology, which establishes a connection between the chosen methods and desired outcomes. Guiding the research process is the theoretical perspective – a philosophical stance that attempts to establish a set of assumptions concerning the researcher's views on social and cultural influences and interactions. Embedded in this philosophy, and thereby in the methodology, is an epistemological position on knowledge and its acquisition. Rather than being isolated components of the research process, these four elements are intricately related to one another. The methodology incorporates specific procedures for the collection and analysis of data, while the assumptions of the theoretical perspective provide a context for the research process and are reflected in the methodology. Informing every part of the investigation is an epistemological understanding of "what it means to know."

Epistemology

A constructivist epistemology pervades every aspect of this investigation. Constructivism rejects the notion that knowledge about the world may exist independent of the knower and therefore views knowledge as being formulated or constructed in the mind of the individual. "Constructivists are deeply committed to the view that what we take to be objective knowledge and truth is the result of perspective. Knowledge and truth are created, not discovered by mind" (Denzin & Lincoln, 1994, p. 125). From an educational standpoint, students construct knowledge as they attempt to make sense of what is being taught by trying to fit it in with what they already know. Ernst von Glasersfeld proposed a radical form of constructivism, which advances the notion that knowledge is not a kind of product that exists apart from the knower but an activity or process that has purpose and direction. "The validity of a knowledge claim is not to be found in the relationship of reference or correspondence to an independently existing world; rather, a claim is thought to be valid if it is viable or if it provides functional fit, that is, if it works to achieve a goal" (Denzin & Lincoln, 1994, p. 127).

Cognitive constructivism has profoundly influenced educational research; however, it fails to consider the enormous impact of the social and cultural influences on teaching and learning. In response to this insufficiency, a somewhat different approach to constructivism emerged. Social constructivism addressed knowledge construction in the context of social interactions. "Contrary to the emphasis in radical constructivism, the focus here is not on the meaning-making activity of the individual mind but on the collective generation of meaning as shaped by conventions of language and other social processes" (Denzin & Lincoln, 1994, p. 127).

Lev Vygotsky, a Russian psychologist in the early 1900's, formulated a sociocultural theory of teaching and learning which established the foundation for present-day ideas about social constructivism. Of particular importance to science instruction are three key theoretical elements:

1. the social interactional nature of learning
2. the role of technical and psychological tools
3. the role of social interactions in mediating students' thinking

Vygotsky envisioned learning as occurring in two different phases or on two separate planes (Shepardson, 1999). The first phase, which involves the presentation of new science concepts in the social setting of the science classroom, is the interpsychological plane. This phase concerns the social interplay between the teacher (the more knowledgeable individual) and the student through language, which becomes the psychological tool for thinking. Once a basic conceptual framework has been established interpsychologically, the student then internalizes and reconfigures this knowledge on an intrapsychological plane. This entire process of conceptual assimilation is mediated through the use of signs, symbols, and words.

> Initially speech follows actions, is provoked by and dominated by activity. At a later stage, however, when speech is moved to the starting point of activity, a new relation between word and action emerges. Now speech guides, determines, and dominates the course of action (Vygotsky, 1978, p. 28).

Vygotsky further postulated that in order for the intrapsychological plane to develop and expand, the student has to have access to two types of "tools" – technical and psychological (Shepardson, 1999). Technical tools, such as microscopes, scales, and other laboratory equipment, allow the student to study the scientific concept from different angles or perspectives. But in order to think about and make sense of the observations provided by technical tools, and to incorporate these thoughts into the intrapsychological plane, the student must possess the psychological tool of language.

> Thought does not express itself in words, but rather realizes itself in them . . . thought is mediated by signs externally, but it also is mediated internally, this time by word meanings . . . Thought must first pass through meanings and only then through words (Vygotsky, 1986, pp. 251-252).

The acquisition of speech accomplishes two things.

> Speech first functions to establish a point of reference between teacher and child; then social speech becomes the means by which teachers mediate (students') thinking and through which (students') appropriate psychological tools, or words, to represent thought. (Students) internalize social speech as a means to mediate their own psychological functioning (Shepardson, 1999, p. 630).

When students attain this level of development, symbolic language can be used in social interactions with both the teacher and other classmates to achieve higher levels of cognitive development in relation to science concepts. Furthermore, students are better able to mediate their actions and thinking when presented with new concepts.

> To learn science, (students) must be engaged in verbal interactions with a more knowledgeable individual, wherein the psychological tools (words) mediate the formation of the (student's) intrapsychological structure; first as a way of seeing and acting, then as a way of talking and thinking about scientific phenomena (Shepardson, 1999, p. 631).

The educational psychology of Vygotsky firmly established the importance of the social environment in teaching and learning (1926, 1997). It proposed that the manipulation of the social setting was the primary means for promoting learning. Vygotsky stressed the difficulty of attempting to directly impact the learning of the individual student through conventional means, such as lecture and recitation. "It is impossible to exert a direct influence on, to produce changes in, another individual, one can only teach oneself, i.e., alter one's own innate actions, through one's own experience" (Vygotsky, 1926, 1997, p. 47). Instead, he hypothesized that the teacher influences the student's learning by manipulating the social environment.

> Though the teacher is powerless to produce immediate effects in the student, he is all-powerful when it comes to producing direct effects in him through the social environment. The social environment is the true lever of the educational process, and the teacher's overall role reduces to adjusting this lever (Vygotsky, 1926, 1997, p. 49).

Vygotsky viewed the social environment as a collection of human relationships mediated by social speech (1926). The act of teaching involves manipulating these social elements to create novel and intriguing forms of the social environment.

> The teacher fashions, takes apart and puts together, sheds, and carves out elements of the environment, and combines them together in the most diverse ways in order to reach whatever goal he has to reach. Thus is the educational process an active one on three levels: the student is active, the teacher is active, and the environment created between them is an active one (Vygotsky, 1926, 1997, p. 54).

An interesting corollary to Vygotsky can be found in the writings of Paul Cobb, who advances the notion that mathematical development in students is dependent on both individual construction (cognitive constructivism) and social interactions (social constructivism). Unlike Vygotsky, who prioritizes the learning process by stressing the interpsychological social interaction phase first, Cobb proposes that both theoretical positions have equal merit based on the problems being investigated. Cognitive constuctivists should acknowledge the role of social interactions in the construction of knowledge and social constructivists should concede that intrapsychological struggles are worth considering. In an attempt to achieve a compromise, Cobb suggests that "the sociocultural perspective gives rise to theories of the conditions for the possibility of learning, whereas theories developed from the constructivist perspective focus on both what students learn and the processes by which they do so" (1999, p. 18).

The implications of Vygotsky's theories and Cobb's speculations are fundamental in investigating pedagogical content knowledge. The teacher possesses a conceptual understanding that must be conveyed to the student. Only through social interaction mediated by signs, symbols, and words – what Vygotsky calls social speech – can the student develop the necessary psychological tools for acting and thinking. For science learning to be effective, the student must comprehend the science concept in the same way as the scientist or teacher. Although scientific phenomena are perceived by both the teacher and the student, the meaning that the student associates with the phenomenon may be completely different from that of the teacher. As Vygotsky observed, "the (student's) framework is purely situational, with the words tied to something concrete, whereas the adult's framework is conceptual" (1986, p. 106). By using social speech, the teacher facilitates incorporation of the concept into the student's knowledge constructions. This learning process promotes the development of psychological tools and social speech in the student, which results in new ways of seeing, acting, talking, and thinking.

The epistemological suggestions of Vygotsky and Cobb directly impact studies dealing with teacher knowledge. A cognitive constructivist theoretical lens was employed to investigate the individual teacher's construction of significant aspects of PCK, while a social constructivist viewpoint served to clarify how PCK development was affected by the social interactions of the science classroom. This investigation focused on both the intrapsychological struggles of the teacher in explaining subject matter in a meaningful way and the interpsychological effects of classroom interactions as student feedback compelled the teacher to modify her PCK.

The ultimate test of the effectiveness of content explanations is not in the original formulation, as the teacher reflects on the upcoming lesson and develops a comprehensible plan of instruction; but rather, teaching effectiveness is assessed by the level of understanding that the recipients of this instruction, the students, attain. It is in the observing and appraising of this interaction between student and teacher that both the fundamental and definitive development of pedagogical content knowledge occurs. Although Shulman does emphasize the importance of "testing student understanding at the end of lessons or units" (1987, p. 15), a major factor in his model of pedagogical reasoning is evaluation, which necessitates "checking for student understanding during interactive teaching" (1987, p. 15). An additional component of the evaluation category involves teacher reflection, which ultimately leads to new comprehension. This concept not only implies that the teacher has gained a more robust understanding of the topics being taught, but has also added new ideas and strategies to her explanatory repertoire, thus promoting PCK development (Shulman, 1987). No amount of prior preparation can insure that the lesson will run smoothly and be successful – that it will make sense. By studying the social interplay that occurs in the classroom through the teacher's perspective, a more thorough understanding of PCK can be developed, and the role of teacher-student interaction in the shaping of PCK can be evaluated to determine its significance.

Theoretical Perspective

The fundamental theoretical perspective for this study was the interpretivist approach of symbolic interactionism. Historically, interpretivism developed as a means of extricating social science research from the grasp of natural science methodologies. Wilhelm Dilthey (1976) speculated that the reality of natural science and the reality of social science are completely different entities and therefore demand radically different research methodologies.

Symbolic interactionism is derived from the pragmatist philosophy of Charles Sanders Pierce (Crotty, 1998). According to this philosophy, usefulness and practicality are the key criteria for assessing the merit of any knowledge claim and that "the authentic meaning of ideas and values is linked to their outcomes and therefore, to the practices in which they are embedded" (Crotty, 1998, p. 73). George Herbert Meade, a pragmatist philosopher and associate of John Dewey, introduced pragmatist thought to the realm of social research in the form of symbolic interactionism. This theoretical perspective postulates three basic assumptions that are embedded in several social science research methodologies, including grounded theory (Blumer, 1969, p. 2):

1. Human beings act toward things on the basis of the meanings that these things have for them.
2. The meaning of such things is derived from, and arises out of, the social interaction that one has with one's fellows.
3. These meanings are handled in, and modified through, an interpretive process used by the person in dealing with the things he encounters.

The theoretical perspective of symbolic interactionism is especially well suited for investigations involving knowledge construction in teachers. In terms of pedagogical content knowledge, the teacher "selects, checks, suspends, regroups, and transforms meanings in light of the situation in which he is placed and the direction of his actions" (Blumer, 1969, p. 5). In the classroom, this highly interactive process of meaning-making is strongly dependent on communication, an essential aspect of symbolic interactionism. "Communication is symbolic because we communicate via languages and other symbols; further, in communicating we create or produce significant symbols" (Denzin & Lincoln, 1994, p. 124). These symbols are manipulated and modified during social interactions to meet a need or to achieve some goal.

Symbols are social because they are developed and refined through social interaction, and they are significant because they convey pertinent meanings to both the user of the symbol and the recipient during communication. “The person who uses symbols does so for the purpose of giving off meaning that he or she believes will make sense to the other” (Charon, 1992, p. 43). The fundamental symbols in social interaction are words. How words are assembled and organized plays a significant role in developing symbolic relationships.

> Acts and objects have meaning to us only because they can be described through using words. Meaning involves understanding what symbols stand for – that association is made not through simple training, but through a description that involves words. Words, then, are not simply one kind of symbol, but are in fact the most important kind, and make possible all others (Charon, 1992, p. 46).

By studying classroom interactions symbolically during the explanation of difficult science concepts, the researcher was able to determine the theoretical “fit” between substantive symbols and their shared meanings in the context of social exchanges.

A major strength of symbolic interactionism as a theoretical perspective lies in the assumption that the researcher must take the role of the other, the research participant, to fully comprehend the phenomenon under investigation. “Taking the role of the other is best understood as taking the perspective of the other . . . and directing one’s own actions accordingly” (Charon, 1992, p. 105). This strategy provided the researcher with two important tools for analyzing and interpreting the data. First, “taking the role of the other is the basis for human symbolic communication” (Charon, 1992, p. 113). By viewing the process of pedagogical content knowledge development from the perspective of the participant, the researcher was better able to determine the meaning and significance of words and acts. Conversely, if the participant can assume the role of the researcher, a more precise and in-depth interpretation of the data is possible. Secondly, when the researcher takes the role of the other, an enhanced understanding of personal perspectives is attained. "To gain a perspective is to understand the other through taking his or her role and to come to share that perspective" (Charon, 1992, p. 111). A theoretical understanding of pedagogical content knowledge was contingent on learning the perspectives of others.

Symbolic interactionism provided the theoretical lens for ascertaining and interpreting teachers' symbolic representations of their content knowledge during instruction. In many cases, the participants attempted to provide explanations of difficult concepts by establishing symbolic relationships that were relevant and meaningful to the student. Subsequently, classroom interactions produced modifications in these symbolic representations, thereby enhancing student understanding. The development of pedagogical content knowledge is both an inter- and intrapsychological process, affected by a multitude of external and internal variables. The goal of this research study was to determine the nature of these variables and how they influenced PCK development.

Additionally, the teacher must determine the adequacy of content description and explanations through continuous dialogue with the students. "Only through dialogue can one become aware of the perceptions, feelings, and attitudes of others and interpret their meanings and intent" (Crotty, 1998, p. 75). But the act of dialogue conveys much more than simple interpretation. The dialogic function of language, in which there is active communication between the teacher and students, is a significant factor in the social construction of knowledge. Through open dialogue with the student, the teacher facilitates, modifies, and extends his/her pedagogical content knowledge. From the student's viewpoint, the dialogic function is the means by which knowledge is internalized and therefore personalized. Mikhail Bahktin, an influential contemporary of Vygotsky, proposed that the development of the individual, the construction of self, is highly dependent on language that is selectively appropriated from others (Emerson, 1996). Delving into the realm of education, Bahktin postulated two ways by which students can assimilate the words of others – by recitation or by retelling in one's own words (Emerson, 1996). Recitation is authoritative, unyielding, and univocal; retelling is flexible, responsive, and dialogic. According to Bahktin:

> In retelling, one arrives at "internally persuasive" discourse – which . . . is as close as anything can come to being totally our own. The struggle within us between these two modes of discourse, the authoritative and internally persuasive, is what we recognize as intellectual and moral growth (Emerson, 1996, p. 127).

This method of knowledge construction is a reciprocal process involving conceptual understanding in the student and pedagogical reasoning in the teacher. In the social construction of knowledge, one cannot exist without the other. The dialogic function of language provided the proper perspective for evaluating how classroom interactions, and more specifically, how student understanding and feedback, modified the teacher's pedagogical content knowledge.

Implications of the Theoretical Perspective

The first major component of this investigation was to determine how the novice teacher organized and modified her cognitive structure for the purpose of presenting it to the students. The data concerning this aspect of teaching was interpreted in light of a cognitive constructivist epistemology. During classroom instruction, the investigative focus shifted from the teacher's initial explanation of the material to how the student was responding to the instruction. The interplay between the teacher and the individual student, resulting in the social construction of knowledge, was analyzed through the eyes of a social constructivist. Of crucial importance in this investigation was how each party involved in this construction of knowledge, the teacher and the students, interpreted the teaching and learning events that occurred in the classroom. Early in the first semester, it became apparent that both the teacher and the students were involved in a "struggle for understanding." The teacher was struggling to effectively explain the science content in a meaningful way and the students were struggling to make sense of it. According to the tenets of symbolic interactionism, in order to truly understand another individual's viewpoint, one must attempt to take the place of that other person and interpret, by means of the dialogic function of language, what is being said. Of course, the argument could be made that the students were more concerned with determining what the teacher was "thinking" in terms of how they were going to be evaluated for that final grade. This situation is reminiscent of the "playing-the-game" scenario, in which the students are simply trying to "make the grade" by determining exactly what the teacher wants in terms of achievement. In this case, there may not be much of an effort on the part of the student to take the place of the teacher, thereby incorporating the teacher's understanding of science into their own knowledge structures; however, in a classroom based on a constructivist epistemology, where the teacher values what the student already knows and what he/she can contribute to discussions, at least the majority of students may in fact be involved in "taking the place of the other." The degree to which the students were involved in this process, however, was not a focus of this study. The primary investigative goal was to determine how the teacher modified her initial teaching philosophy and instructional approach to promote greater student understanding. This phenomenon was viewed through the theoretical lens of symbolic interactionism.

CHAPTER 2: LITERATURE REVIEW

Introduction

A review of the literature on pedagogical content knowledge will invariably include a substantial amount of discussion on the work of Lee Shulman, a prominent investigator in the study of teacher knowledge. After a brief definition of PCK, a thorough explanation of Shulman's categories of teacher knowledge will be presented, followed by an explanation of Shulman's concept of pedagogical reasoning. This concept establishes a set of procedural steps for the generation of PCK. A considerable portion of current research attempts to modify Shulman's original formulation of pedagogical reasoning. These studies will be discussed in conjunction with structural models of PCK, which incorporate an understanding of conceptual change teaching. Because the primary participants for this study were first-year teachers, a review of research investigating the level and development of PCK in preservice and novice teachers will also be presented. A final section on theories and models, as they pertain to grounded theory research, will serve to clarify the relationship between the generation of theory and the construction of explanatory models.

Pedagogical content knowledge (PCK) refers to the ability of the teacher to take her personal knowledge of the discipline and reconstruct or transform it in such a way that it becomes more understandable to the student. According to Lee Shulman, PCK:

> … embodies the aspects of content most germane to its teachability. (It includes), for 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 (1986, p. 9).

Along with presenting content in an understandable way, the teacher who possesses well-developed pedagogical content knowledge must be able to assess understanding and then modify the lesson if the level of comprehensibility is not sufficient. Whether or not the novice or veteran teacher is capable of accomplishing this task is strongly dependent on ample content knowledge. Shulman was particularly concerned with educational researchers' total disregard for how well preservice and inservice teachers mastered their respective disciplines. Studies of effective pedagogy were pervasive in the research literature and appeared to reinforce the education profession's commonly held view that if one possesses the ability to teach, one can teach anything. This mindset resulted in the vast majority of investigations concentrating on overt teaching behaviors. Shulman and his colleagues rejected this notion and focused their attention on the underlying knowledge structures that appeared to control teaching and learning.

Teacher Knowledge

Shulman's research led to the formulation of seven categories of teacher knowledge (1987) – content knowledge, curriculum knowledge, pedagogical content knowledge, general pedagogical knowledge, knowledge of learners, knowledge of educational contexts, and knowledge of educational ends, purposes, and values.

Content knowledge consists of three major components (Schibeci & Hickey, 2000) – disciplinary knowledge (facts, concepts, theories, etc.), substantive structures (the explanatory frameworks in the discipline), and syntactic structures (ways in which new knowledge is generated by the discipline). Smith and Neale (1989) contend that a teacher's substantive content knowledge needs to be both factually correct and conceptually organized, with a comprehensive understanding of the theoretical relationships within the discipline. On the other hand, the syntactic structure (Schwab, 1978), addresses the construction of knowledge within that discipline and, especially in science, the role of evidence in accepting or rejecting knowledge claims. In other words, the teacher should have a thorough grounding in the nature of science. According to Shulman (1987):

> (The teacher) must understand the structures of subject matter, the principles of conceptual organization, and the principles of inquiry that help answer two kinds of questions: What are the important ideas and skills in this domain? How are new ideas added and deficient ones dropped by those who produce knowledge in this area (p. 9)?

A comprehensive understanding of content lays the groundwork for the development of pedagogical content knowledge (Shulman, 1986). With preservice teachers, the formulation of PCK involves a somewhat radical shift in the thinking of the individual from that of an expert learner to one of a novice teacher. The problem becomes one of restructuring or transforming scientific concepts for the purposes of representing them in a more teachable and comprehensible manner. Assisting in the development of representational thinking, which is a major aspect of PCK, is curriculum knowledge, which facilitates the choice and sequence of materials and activities for instruction.

> The curriculum is represented by the full range of programs designed for the teaching of particular subjects and topics at a given level, the variety of instructional materials available in relation to those programs, and the set of characteristics that serve as both the indications and contraindications for the use of particular curriculum or program materials in particular circumstances (Shulman, 1986, p. 10).

An additional, and often overlooked aspect of curriculum knowledge is the teacher's understanding of the goals and expected outcomes in the other disciplines that comprise the student's grade level. This cross-disciplinary knowledge allows the teacher "to relate the content of a given course or lesson to topics or issues being discussed simultaneously in other classes" (Shulman, 1986, p. 10). Even though interdisciplinary considerations are a key strategy for highly effective teachers (Porter & Brophy, 1988), cross-curricular knowledge is usually lacking in the vast majority of teachers.

The most intensively studied aspect of teachers' professional knowledge is general pedagogical knowledge, which involves teaching methods that are not subject specific, such as classroom management strategies and organizational procedures (Shulman, 1986, 1987; Wilson, Shulman, & Richert, 1987; Abd-El-Khalick & Boujaoude, 1997). The rationale behind these pedagogical skills is to create a classroom environment "where pupils can attend to instructional tasks, orient themselves toward learning with a minimum of disruption and distraction, and receive a fair and adequate opportunity to learn" (Shulman, 1987, p. 10). In many cases, pedagogical decisions are influenced by how the teacher views the cognitive and physical development of the student (knowledge of learners). This knowledge structure contains major implications for the development and modification of PCK, particularly in light of conceptual change teaching, because it deals with "the knowledge of students, what they currently think about the subject, what misconceptions they have, and what knowledge they lack" (Kennedy, 1998, p. 257). No matter how well a teacher explains a concept through example, analogy, or metaphor, she must be capable of discerning student understanding. There must be a link between explanation and comprehension. How this link is interpreted depends on the theoretical position of the respective educational researcher.

> Advocates for more attention to subject matter assume that good teaching depends largely on the teacher's ability to correctly present the content. Advocates for more attention to pedagogy assume that good teaching depends on the ability to keep students motivated, orderly, and on task (Kennedy, 1998, p. 252).

The last two components of Shulman's knowledge structures, although often overlooked or minimized in educational methods courses, are just as important to the professional survival and success of the teacher as classroom management. The first is knowledge of educational contexts, which involves a through understanding of one's professional surroundings. It encompasses all levels of the education spectrum, not just classroom interactions and collegial relationships. In order to perform effectively as a professional educator, the teacher should be familiar with:

> institutions with their hierarchies, their explicit and implicit system of rules and roles; professional teachers' organizations with their functions of negotiation, social change, and mutual protection; government agencies from the district through the state and federal levels; and general mechanisms of governance and finance (Shulman, 1987, p. 9).

In addition to these "political" considerations, the teacher should be aware of the importance of community and culture in the educational context.

Finally, the effective teacher should possess a philosophy of education, or instructional theory, which clearly defines her beliefs about teaching and learning. This belief system comprises the knowledge structure that deals with educational ends, purposes, and values. It should contain the teacher's "visions of what constitutes good teaching, or what a well-educated youngster might look like if provided with appropriate opportunities and stimulation" (Shulman, 1987, p. 10).

All seven of these knowledge structures contribute to the development of a highly effective teacher. They are all extremely important in promoting academic excellence; however, a major concern among educational researchers is how the various aspects of knowledge develop and how they interact in both the preservice and inservice teacher. More importantly, is there an underlying knowledge component that forms the foundation for further development? This question is of paramount importance to educational researchers as they attempt to correctly present and sequence instruction for the prospective teacher.

Pedagogical Reasoning

Shulman maintains that a major contributor to student understanding and achievement is pedagogical content knowledge. This category of teacher knowledge, however, embodies much more than the development of multiple representations for specific topics. It demands a completely new and unique way of thinking about the content and context of teaching and learning. The explanation of difficult concepts is an ongoing, reflective process, incorporating a great deal of planning and a significant amount of trial and error while focusing on what does and doesn't work for specific students. Because effective PCK involves this radical shift in thinking about the content of a discipline, Shulman further postulated the concept of pedagogical reasoning. This cognitive strategy incorporates six steps of content processing and explanation – comprehension, transformation, instruction, evaluation, reflection, and new comprehension (Shulman, 1987).

Comprehension includes both a thorough understanding of a specific scientific concept and the way in which that knowledge was generated and validated. For example, the biology teacher should not only be aware of the structure and function of DNA and RNA, she should also have some knowledge of how the models of these molecules were postulated and the empirical evidence supporting these models. Once the essential knowledge is comprehended, the cornerstone of pedagogical reasoning is the process of transformation. According to Shulman (1987), this activity can be divided into four subprocesses – critical interpretation, representation, adaptation, and tailoring. Critical interpretation is the ability to discern correct and appropriate meanings in the instructional materials and the overall presentation. In other words, transformations should not oversimplify the materials to the point of being incorrect. The second subprocess, representation, is the key to transformation. The teacher attempts to find alternative ways of explaining the concept. For example, relating the processing of camera film, with its progression of negatives and originals, to the transcription and translation of DNA and RNA, is one way of representing the DNA-RNA code. Adaptation, the third subprocess of transformation, takes into account significant student characteristics, such as ability level and degree of motivation. More importantly, this is the point in pedagogical reasoning where the teacher will attempt to explicate alternative conceptions of the students. A key component of adaptation in particular, and PCK in general, is the realization that students bring to the science classroom preconceptions and misconceptions concerning scientific phenomena. Adaptation addresses "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" (Shulman, 1986, p. 12). Closely related to adaptation is the subprocess of tailoring, in which the teacher shapes the explanation of material to the individual class or even to individual students within a class. Each period of instruction throughout the day is characterized by a unique classroom dynamic, formed from a multiplicity of variables. Recognition of this factor brings with it the realization that what works for one class may not be effective with the others; hence, adaptation and tailoring work together in formulating the most successful instructional strategy.

Instruction and evaluation are the next two phases of pedagogical reasoning, comprising the pedagogical component of PCK. "It is during the process of instruction that the corpus of research on teacher knowledge intersects with the literature on teaching effectiveness" (Wilson, Shulman, & Richert, 1987, p. 120). This phase is characterized by both the art and the act of teaching as the lesson unfolds. Both during and after instruction, evaluation informs the teacher as to the effectiveness of the lesson. This process assesses both student achievement and teacher effectiveness. Without evaluation, the modification and evolution of PCK would be impossible.

Evaluation will inevitably result in teacher reflection, a necessary attribute of effective instruction. "It is what a teacher does as he or she looks back at the teaching and learning that has occurred and reconstructs the events, the emotions, and the accomplishments" (Wilson, Shulman, & Richert, 1987, p. 120). Ultimately, reflection will lead full circle to the final phase of pedagogical reasoning – new comprehension. This culminating process entails an enriched and in-depth understanding of the concepts being taught. Many times, the teacher is rewarded with an enhanced appreciation for the content, allowing her to perceive interrelationships with previously overlooked or misunderstood concepts within the discipline.

Conceptual Models of PCK

Several researchers have attempted to reformulate Shulman's notion of pedagogical reasoning by generating structural models of pedagogical content knowledge. Shulman envisioned PCK as a unique blend between what to teach and how to teach; hence the name, pedagogical content knowledge. Marks (1990) proposed a similar formulation by hypothesizing that PCK develops as a result of the integration of content knowledge and general pedagogical knowledge; however, he noted several instructional situations in which this blend was not evident. In other words, the teacher was relying solely on his understanding of content or his ability to instruct. These observations would tend to cast doubt on whether PCK exists as a separate knowledge category. Lederman, Newsome, and Latz (1994) also noted a similar difficulty in their work with preservice teachers and their conceptions of subject matter and pedagogy. They concluded that "the interaction and possible melding of these two domains of knowledge . . . remains an enigma" (p. 130).

A number of research studies have attempted to explicate the structural components of pedagogical content knowledge. For example, Reynolds (1992) postulated that PCK consists of teaching methods, content organization, knowledge of students' content learning, content representation, and assessment knowledge. Although this reformulation still contains Shulman's basic ideas about teacher knowledge, it emphasizes the importance of student feedback in modifying subject matter representations. Cochran, DeRuiter, and King (1993) advanced the notion that PCK consists of a knowledge of pedagogy, content, students, and context, but suggested that the relative utility of these various components changes with the instructional situation. To emphasize this evolving nature of PCK, they proposed a new phrase – pedagogical content knowing (PCKg). In an attempt to understand the developmental structure of PCK, Oliver (2002) established a list of instructional devices and strategies and teacher qualities and characteristics that either directly or indirectly impacted student understanding. Five categories of pedagogical content knowledge were identified – language devices, thinking devices, strategies for the elaboration of content, laboratory strategies, and the affective characteristics of the teacher.

Investigations dealing with conceptual models of pedagogical content knowledge have also attempted to identify possible sources of PCK. Bell, Veal, and Tippins (1998) established a hierarchy of PCK that progressed from specific to general content. Through the continual teaching of concepts, such as DNA replication or acceleration due to the force of gravity, a specific topic PCK would emerge. The teaching of many different concepts, coupled with a corresponding development of specific topic PCK, would result in a specific discipline PCK (Biology, Physics, or Chemistry). In other words, PCK develops as a result of the teaching experience. Grossman's structural model of PCK (1990), which consists of knowledge and beliefs about purpose, knowledge of students' conceptions, curricular knowledge, and knowledge of instructional strategies, also depends on the teaching experience as a major source of PCK. In addition to classroom practice, he speculated that experiences as a student, courses dealing with subject matter, and teacher education programs were major contributors to PCK development.

Another avenue of research involving teacher knowledge investigates the relationship between pedagogical content knowledge and current views on conceptual change teaching. In an attempt to identify forms of teacher knowledge that are required for successful conceptual change in students, Smith and Neale (1989) subdivided PCK into three segments:

1. Knowledge of students' concepts.
2. Conceptual change teaching strategies.
3. Shaping and elaborating the content by using examples, metaphors, analogies, and representations.

Studies concerning PCK and conceptual change conclude that "unless teachers have the scientific models to contrast with the student models, they are not likely to be able to foster their students' conceptual change" (Schibeci & Hickey, 2000, p. 1155). In his research on transforming subject-matter knowledge, Geddis (1993) supports this belief and concludes that conceptual change teaching strategies are the essence of PCK. Furthermore, most investigators would agree that a major strength of PCK studies involving conceptual change teaching is the belief that what the student knows shapes what the teacher does. Future research may ascertain whether student feedback is a critical component in PCK development.

Novice Teachers and PCK

An area of research of primary importance to this study investigates the level of pedagogical content knowledge in preservice and novice teachers and how this knowledge develops and changes. Most researchers would suggest that "PCK is developed through an integrative process rooted in classroom practice, implying that prospective or beginning teachers usually have little or no PCK at their disposal" (van Driel, Verloop, & de Vos, 1998, p. 677).

This conclusion appears to be supported by several studies that indicate novice teachers have very marginal levels of PCK (Carpenter, Fennema, Petersen, & Carey, 1988; Feiman-Nemser & Parker, 1990). "A novice teacher tends to rely on unmodified subject matter knowledge (most often directly extracted from the curriculum) and may not have a coherent framework or perspective from which to present the information" (Cochran, 1997, p. 3). Carpenter, et al., (1988) indicated that beginning teachers fail to assess students' prior knowledge and present instruction without taking into account students' ability levels and learning styles. Wilson, Shulman, and Richert (1987) expounded on the transformational struggles that beginning teachers experience when presenting content, and Grossman (1990) identified similar conflicts in new teachers with subject-specific master's degrees. Most of these studies inferred that PCK develops over time as a result of teaching experience (Cochran, 1997).

Theories and Models

The purpose of this research was to formulate a substantive theory on the development of pedagogical content knowledge in provisionally certified science teachers. As a means of visually enhancing the theory's conceptual relationships, a theoretical model is usually constructed. This statement tends to cause some confusion in that it combines what is usually construed as two separate entities – a theory and a model. In grounded theory research, concepts related to the investigated phenomenon are identified and manipulated for the purpose of determining and demonstrating significant associations. According to Strauss and Corbin (1990), this process of theorizing involves "the act of constructing from data an explanatory scheme that systematically integrates various concepts through statements of relationship" (p. 25). An important tool for accomplishing this task is a visual, diagrammatic representation of the evolving conceptual relationships. Hence, a model is constructed to aid in the evaluation of the "fit" between the data and the generated theory. Also, a visual representation enhances the usefulness and predictive power of the theoretical formulation just as a graphical representation in a quantitative study enhances the usefulness of data and subsequently adds to the power of data analysis.

Justi and Gilbert (2003) conducted an investigation with thirty-nine science teachers to determine their understanding of the role and function of modeling in science. Their results indicated a great deal of diversity in the thinking of the participants as to a scientific model's properties. The authors' analysis of the data resulted in seven aspects of model representation – "the *nature* of the model; the *use* to which it can be put; the *entities* of which it consists; its relative *uniqueness*; the *time* span over which it can be used; its status in respect of the making of *prediction*; and the basis of *accreditation* for its existence and use" (p. 1375). In some cases, the participants expressed conceptions of modeling that were scientifically accurate, such as the correspondence between the model and reality, the use of a model as a means to test ideas, and the reconstruction of a model to account for new ideas; however, a large percentage of responses also suggested a somewhat naïve understanding of scientific models, such as "a model as a standard to be followed" or "a model as a reproduction of something" (p. 1379). In terms of how this investigation relates to grounded theory methodology and the usefulness of theoretical models, two aspects of model representation are particularly significant – the aspect of use, in which "a model serves as a way of understanding or explaining something" (p. 1375), and the aspect of prediction, in which "a model can be used to make predictions about behavior or properties" (p. 1376). This explanatory and predictive power of a model, which is derived from a theory grounded in the data, is the cornerstone of grounded theory research.

A grounded theory methodology can be used to generate two types of theory – substantive and formal (Strauss & Corbin, 1990). A substantive theory attempts to explain the investigated phenomenon in a specific setting or for a unique sample or set of conditions. This research project is concerned with generating a substantive theory because the phenomenon in question, the development of pedagogical content knowledge, is being investigated with a very specific population under precise conditions – provisionally certified, first-year science teachers. If the researcher had chosen to study the same phenomenon using a variety of contexts, such as veteran mathematics teachers and first-year teachers who are education graduates, then a formal theory on the development of PCK would be the primary research goal.

In the realm of science, the various notions of theory are both disparate and contentious. The classic definition of a theory is "a set of logically consistent abstract principles that explain a body of concrete facts" (Cromer, 1993, p. 137). However, with the current interest in nature of science studies, contemporary views concerning the role of theorizing and modeling in the scientific enterprise have changed somewhat since Newton proposed his laws of motion in the seventeenth century. For one thing, a great deal of controversy has resulted as to the correspondence between theoretical propositions (and the models derived from those propositions) and reality (Duschl, 1990). For example, does the atomic model accurately reflect an entity in nature, or is its utility in understanding natural phenomena the primary consideration? This question, which addresses the two opposing philosophical stances of realism and instrumentalism, has caused many philosophers of science and scientists themselves to view models as "useful fictions" (McComas, 1998, p. 67).

Another area of contention concerning the role of theory focuses on the question of whether or not observations are theory-dependent (Duschl, 1990). Researchers in both the natural and social sciences are well aware of the importance of going into a research project with some idea of what they are looking for and what they expect to find. Some form of pre-conceived theoretical notion is absolutely necessary to insure valid interpretation. This situation is no different with grounded theory methodology. Even though the goal of this form of research is to generate an explanatory and predictive theory directly from the data, there must be some prior theoretical understanding guiding data analysis and interpretation. There is, however, an enormous distinction between the process of theorizing in the scientific realm and the form of theorizing as advocated by grounded theory proponents. Whereas the scientific community recognizes the speculative nature of theorizing (observations are theory-dependent), Glaser and Strauss (1967) support a diametrically opposite proposition embodied in the generative nature of theorizing. This position resulted in a good deal of opposition from those who supported strictly quantitative methods for research. In the words of Glaser and Strauss (1967), adherents to the quantitative approach contend "that data should fit the theory, in contrast to our position that the theory should fit the data" (p. 261). This position demonstrates both the strengths and, to some extent, what natural science may perceive as a weakness of theorizing according to grounded theory methodology. On the one hand, a generated theory attempts to objectively evaluate a very human condition (teaching and learning) couched in a very tenuous situation (the classroom) involving numerous uncontrollable variables. On the other hand, a certain level of subjectivity is necessary to determine the direction of the research and to assist in the interpretation of data. Because of this tension between the opposing forces of objectivity and subjectivity, it is absolutely imperative that the researcher identifies and continuously revisits his assumptions concerning the investigated phenomenon before, during, and after data collection and analysis.

CHAPTER 3: METHODOLOGY

Introduction

This investigation was conducted utilizing a grounded theory methodology, in which a theory concerning the phenomenon under study was generated from field data that was systematically collected and analyzed. This research strategy was initially conceived by sociologists Barney Glaser and Anselm Strauss (1967) in response to what they perceived as inadequacies in social research methodology. Contrary to the contemporary research tradition of using data to verify theory, Glaser and Strauss proposed that qualitative data could be used to generate new theory or modify and expand existing theory. "Theory evolves during actual research, and it does this through continuous interplay between analysis and data collection" (Denzin & Lincoln, 1994, p. 273). This analytical approach is referred to as the constant comparative method, a major attribute of this methodology. When using this strategy:

> The researcher begins with a particular incident from an interview, field notes, or document and compares it with another incident in the same set of data or in another set. These comparisons lead to tentative categories that are then compared to each other and other instances. Comparisons are constantly made within and between levels of conceptualization (Merriam, 1998, p. 159).

Rationale

The rationale behind choosing grounded theory methodology for this investigation was based on the inherent relationship between the theoretical framework of symbolic interactionism and ethnography. At the heart of symbolic interactionism is the desire to put oneself, the researcher, in the place of others, the research participants (Crotty, 1998). Grounded theory, a form of ethnographic research, developed directly from this philosophical stance. As a research strategy, it formulates its theoretical postulates directly from the experiences of the individuals involved in the research.

The science education community places considerable importance on the forms of knowledge that prospective science teachers should possess to be effective in the classroom. It is essential for teacher educators to have an understanding of how these various forms of knowledge develop and interact to ensure superior preparation of prospective candidates. Grounded theory is a powerful methodology capable of producing a substantive theory of pedagogical content knowledge by analyzing the cognitive struggles of the research participants. This form of analysis incorporates the personal interpretations and perspectives of the participants into the overall conceptualization of the phenomenon. "Grounded theory procedures enhance this possibility, directing attention, for instance, to concepts that reflect (participants') own deep concerns; or its procedures force researchers to question and skeptically review their own interpretations at every step of the inquiry itself" (Denzin & Lincoln, 1994, p. 280). This statement emphasizes an additional strength of grounded theory – the rigor associated with systematically collecting and analyzing information from the "field" to insure as true a fit as possible between the actual data and the generated theory. "And this faithfulness to the substantive data, this 'fit' to a substantive area, is a powerful condition for usefulness in the practical life of the theory" (Denzin & Lincoln, 1994, p. 281).

Assumptions

Grounded theory is a powerful methodology that emphasizes and capitalizes on the evolving nature of conceptual understanding. Practitioners of this process reject the notion of verifying a logically deduced theory in favor of generating a substantive theory based on the data. Because of this position, theorizing or hypothesizing prior to data collection is minimized: however, it is assumed that the investigator enters the field with prior assumptions and expectations concerning the phenomenon under study. Contrary to the opinion that these assumptions would inhibit the generation of new theory, some level of theoretical underpinning is necessary for interpretation and validation.

Based on the literature review, it was anticipated that numerous, complex variables influence the development of pedagogical content knowledge. These variables include the structure of the teacher's content knowledge, prior educational experiences, personal reflection, concurrent pedagogical training, classroom interactions, curricular influences, and relationships with colleagues and mentors. The formulation of PCK is simply not a matter of gaining experience and thereby developing a greater understanding of how best to explain scientific concepts in a comprehensible way. There must be other factors associated with teaching that have a powerful influence on teacher knowledge and practice; otherwise, most teachers would develop PCK to a somewhat similar degree, and this is simply not the case. How, when, and to what degree these various factors exert their influence is crucial to an understanding of PCK; and it is precisely the interrelationship between these variables that formed the foundation for a substantive theory of PCK development.

Pilot Study

A crucial first step in this investigation was to develop a preliminary understanding of the major components of pedagogical content knowledge and to devise a method for identifying instances of PCK use in the classroom. A total of three, first-year, provisionally certified teachers, and two experienced teachers, with a total of 23 years of classroom experience, were observed and interviewed over a period of three months (Table 1). The key question for the pilot study centered on how instances of PCK use could be identified in the classroom. Using the current literature as a guide, specific situations were identified during the observation phase in which the participating teachers used various explanatory strategies, such as analogies, metaphors, examples, etc. Interviews were then conducted to verify the observational data and to determine the instructional effectiveness of the various PCK strategies. To gain a better understanding of how PCK influences actual classroom teaching, the two veteran teachers were interviewed utilizing a "think-aloud" format in which they were to identify and describe the various stages in the planning and implementing of an instructional unit. This tactic helped to clarify the pedagogical decisions involved in the selection and sequencing of instructional activities related to specific science concepts. Of primary concern was to discover whether these experienced teachers planned and modified their lessons to optimize student understanding, and, if so, how these modifications were accomplished.

Primary Research Participants

Initially, participants were chosen by means of purposeful sampling from a cohort of inservice, provisionally certified teachers seeking certification through alternative programs at local universities. "Purposeful sampling is based on the assumption that the investigator wants to discover, understand, and gain insight and therefore must select a sample from which the most can be learned" (Merriam, 1998, p. 61). Candidates for this study had to possess a minimum of a bachelor's degree in a specific science discipline, such as biology or physics, or what was judged to be the equivalent.

The screening process for potential research participants began in June 2002, with an evaluation of twenty-nine applicants. Only four of the original group of candidates met the selection criteria – provisionally certified, actively enrolled in an alternative certification program, and in their first year of teaching in August at either the middle school or secondary level (Table 1). After the participants agreed to participate in the research, the associated school systems were notified for the purpose of gaining access to the individual schools (Appendix A). This process proved to be a rather daunting task, with permission finally being granted by the principals after two months of forms, typed reports, and countless emails and phone calls. The superintendents, principals, and participants were given a through explanation of the nature of the study and dates and times were established for the periods of data collection. All necessary consent forms (Appendix B) and procedural papers were signed and submitted to the proper agencies.

Table 1

Research participants

Research component	Participant	Professional Status	Location	Teaching Responsibilities
Pilot Study	Brenda	Provisional, first year	Private high school	Physics
	Marjorie	Provisional, first year	Private high school	Biology, environmental science, physical science
	George	Provisional, first year	Private high school	Biology
	Bob	9 years of experience	Suburban high school	Physics, biology
	Greg	14 years of experience	Suburban high school	Physics, physical science
Primary Investigation	Emily	Provisional, first year	Suburban middle school	Life science
	Rhonda	Provisional, first year	Suburban high school	Biology, physical science
	Gloria	Provisional, first year	Suburban middle school	Life science
Theoretical Sample	Tina	4 years of experience	Rural elementary school	First grade
	Keith	10 years of experience	Rural middle school	Physical science
	Jim	7 years of experience	Rural middle school	Earth science
	Brandi	4 years of experience	Rural middle school	Social studies, life science
	David	20 years of experience	Suburban high school	Physics
	Bill	8 years of experience	Suburban high school	Chemistry, anatomy and physiology

Initial, get-acquainted observations and interviews were then conducted to evaluate which novice teachers were already formulating at least a minimal level of pedagogical content knowledge. Since a link between content knowledge and PCK had already been established by the work of Lee Shulman, it was anticipated that more significant data would be collected from those individuals who were actively engaged in the transformation of content knowledge into comprehensible and meaningful conceptual explanations. During the preliminary observation, the level of PCK development was determined by assessing the depth of content explanations as evidenced by the teacher's use of relevant examples, analogies, metaphors, and any other instructional techniques that promoted student understanding. The initial selection interview incorporated a "think-aloud" lesson planning strategy to assess the prospective candidates' tactics for transforming content. Finally, due to the fact that many of these provisionally certified teachers were widely distributed geographically, convenience also played a role in the purposeful sampling process. For the purpose of convenience, and to better handle the large influx of data, the number of participants was reduced to three. For the next six months, the remaining participants were observed and/or interviewed every four to six weeks, with additional communication occurring via email and the telephone.

Once initial categories began to emerge from the data, a special form of purposeful sampling, theoretical sampling, was used to identify an additional pool of participants who could contribute to the evolving theory. "Theoretical sampling is the process of data collection for generating theory whereby the analyst jointly collects, codes, and analyzes his data and decides what data to collect next and where to find them, in order to develop his theory as it emerges" (Glaser & Strauss, 1967, p. 45). Although the initial criteria for selecting research participants through purposeful sampling was guided by prior assumptions and beliefs, further decisions concerning the recruitment of new participants was not controlled by any preconceived theoretical framework; however, a similar screening process to the one used for the primary participants, involving observations and interviews, guided the selection. In addition to the standard methods for collecting data in a grounded theory study, a preliminary survey (Appendix C) was also utilized to generate a large amount of data in a more convenient manner. The survey helped to reduce the amount of travel to the various study sites at the outset of theoretical sampling. Some of the same types of questions on the survey were also administered to the primary research participants. Prior to theoretical sampling, the researcher attempted to establish a hypothetical outline of the concept being studied by minimizing differences between the participants. In other words, purposeful sampling was used to recruit participants in similar teaching situations, i.e., provisionally certified, novice teachers. When this was accomplished, theoretical sampling was employed to examine the phenomenon in different settings and with different individuals, thereby maximizing differences between participants.

The purpose of this strategy was to view the phenomenon of PCK from multiple perspectives. Differences noted in the pedagogical content knowledge of teachers in diverse situations forced a closer inspection of the original set of categories to determine if these differences were also present in the initial participants. According to J. Creswell, "the rationale for studying this heterogeneous sample is to confirm or disconfirm the conditions, both contextual and intervening, under which the model holds" (1998, p. 119). But more importantly, maximizing differences between research participants leads to a greater understanding of the theoretical postulates and broadens the scope of the potential theory. "Maximizing brings out the widest possible coverage on ranges, continua, degrees, types, uniformities, variations, causes, conditions, consequences, probabilities of relationships, strategies, process, structural mechanisms, and so forth, all necessary for the elaboration of the theory" (Glaser & Strauss, 1967, p. 57). An important attribute of this technique, therefore, was to enhance and expand upon the original hypothetical construct by adding perspective. Not only did this strategy add to the diversity of the categorical properties, but it also served to identify the underlying foundational factors of the phenomenon itself – what Glaser refers to as the core category. In essence, as the continuum of properties expanded, significant commonalities emerged.

Through theoretical sampling, a group of six inservice teachers were identified – one from early childhood, three from middle grades, and two from the secondary level. The elementary and middle school teaches were recruited from a masters-level methods course at an evening and weekend college of a small private university and the two high school teachers were staff members of a large suburban school.

Data Collection and Analysis

The usual form of data collection for this type of research strategy is the interview; however, field observations and document analysis also provided pertinent information. Although Creswell (1998) indicates that the typical grounded theory study involves 20-30 interviews, Glaser and Strauss are quick to point out that the theorist cannot enter the field with a set number of participants or data-collecting episodes in mind. Data collecting should proceed, utilizing multiple perspectives, until the generated categories have been theoretically saturated. "Saturation means that no additional data are being found whereby the researcher can develop properties of the category" (Glaser & Strauss, 1967, p. 61). In other words, no new information is being added to the database.

The first step in the research process was to obtain a signed consent form from each participant. Since the preponderance of the data for this investigation was obtained by utilizing the interview process, the research participants indicated convenient times for conducting an informal one-hour interview in a private setting. The format of the interview was relaxed, spontaneous, and open-ended, allowing for greater in-depth discussion. A semistructured interview guide (Appendix D) was used to generate preliminary information concerning the research questions. Probe and follow-up questions developed as the interview unfolded. The researcher took notes when appropriate and the interview was audiotaped for transcription. To insure valid analysis, the researcher's interpretations of the interview data were discussed with the participants in subsequent interview sessions to check for agreement. No set number of interviews or member checks were established as data analysis proceeded. The discovery of emergent themes and categories, coupled with the need for participant validation, determined the number of data collection episodes.

It was anticipated that the necessary data for answering the research questions would be obtained through the interview process; however, due to the importance of social interaction, particularly student feedback, four to six field observations were also conducted. The purpose of this strategy was to ensure consistency between what the participant recalled and communicated in the interview and the events as they actually unfolded during classroom instruction. Possible discrepancies provided an opportunity for enhancing the depth and breadth of emerging theoretical categories. Additionally, the field data were used during subsequent interviews for generating specific questions about when and how pedagogical content knowledge was used in the classroom. This particular technique was especially useful for determining the effect of classroom interactions and student feedback on PCK development.

Preliminary data analysis involved the establishment of categories by means of an open coding process. According to Strauss and Corbin (1990), a category represents a unit of information composed of events, happenings, or instances. In open coding, the investigator conceptualizes patterns among many incidents rather than labeling every act or occurrence as a category. The former process serves to generate theoretical constructs while the latter results in a conceptual description. During this initial stage of data analysis, a continuous process of evaluation, the constant comparative method, was used in the construction of categories and their properties. Once categories were established by looking for patterns among various events, other episodes contained within the data were compared to the generated categories, resulting in subcategories or properties. As additional participants were recruited by means of theoretical sampling, the number of emergent properties increased significantly, thereby enhancing the database by viewing the phenomenon from multiple perspectives. These different viewpoints not only added to the richness of the original categories but also reduced "the data base to a small set of themes or categories that characterized the process or action being explored" (Creswell, 1998, p. 151). This entire research strategy of going to the field and bringing back the data to see how it corresponds to existing relationships epitomizes the constant comparative method.

Strauss and Corbin (1990) suggest that the open coding process be followed by two additional coding procedures to eventually arrive at the formulation of conditional propositions or hypotheses. The first method is called axial coding, which is defined as "a set of procedures whereby data are put back together in new ways after open coding, by making connections between categories. This is done by utilizing a coding paradigm involving conditions, context, action/interactional strategies and consequences" (Strauss & Corbin, 1990, p. 96). Glaser, however, rather vehemently disagrees with this artificial packaging of data, claiming that axial coding is unnecessary if the researcher is theoretically sensitive. "Theoretical sensitivity refers to the researcher's knowledge, understanding, and skill, which foster his generation of categories and properties and increase his ability to relate them into hypotheses" (Glaser, 1992, p. 27). The second analytical method of Strauss and Corbin is called selective coding, which culminates in the selection of a core variable – "a central phenomenon around which all other categories are integrated" (Strauss & Corbin, 1990, p. 116). This core concept would be used to develop a narrative description of the central phenomenon. On the other hand, Glaser argues that the core variable should already have emerged from the data, serving as a guide for further data collection and increasing the theoretical sensitivity of the researcher. "The goal (of grounded theory) is not voluminous description, nor clever verification. The goal is generation of theory around a core category" (Glaser, 1992, p. 75).

All of the interview transcripts (21 hours) were analyzed by using a very precise open-coding technique, which labeled virtually every participant comment with a descriptive code. This rather laborious process resulted in the generation of over 180 initial categories. By identifying similarities in the properties of related groups of open codes, the number of significant categories was reduced to 16. For example, numerous instances involving interactions with other teachers were identified in the data and ascribed codes, such as "talking with teachers," "questioning teachers," "observing teachers," "ideas from teachers," etc. These initial codes were brought together into a broader category that was subsequently labeled "collegial support." During axial coding, these main categories were again grouped according to similarities to produce the hypothetical constructs that would ultimately form the substantive theory. In this example, "collegial support" was combined with other pedagogically oriented categories, like relevancy, student-centered instruction, and sequencing, to form the hypothetical construct of pedagogical sophistication. As illustrated by the final model of PCK development, the number of theoretical concepts was eventually reduced to four – content complexity, structural PCK, functional PCK, and pedagogical sophistication.

The following example illustrates how another hypothetical construct, "functional PCK," was formulated utilizing the various coding techniques of grounded theory research. During the open coding process, numerous instances in the data were encountered in which the participants questioned their students. Different codes were ascribed to these occurrences based on the teacher's intent – motivation, assessment, review, control, focus, participation, paying attention, checking for understanding, confusion. Underlying properties of these categories were then identified utilizing a series of analytical questions, such as (for the motivation category), "why does questioning motivate students, how does questioning motivate students, when and how often do you motivate students by using questioning, what happens as a result of using questioning to motivate students?" These types of questions were used to establish connections between the original concepts for the purpose of developing a more comprehensive category. In other words, the researcher is attempting to determine what the data is actually trying to show in relationship to the investigated phenomenon – pedagogical content knowledge. The first major category to emerge from the data for the initial questioning codes was "calling on students." Even though all of the original codes were subsumed by this concept, it seemed to imply a one-way line of communication, which may have been the case early in the research process but certainly was not true as the school year progressed. Consequently, a new conceptual category was needed to illustrate a two-way path of communication, hence the code "teacher-student interaction." In the next analytical procedure, axial coding, categories generated during open coding were combined to form major concepts that were ultimately used in the formulation of theory. The category of teacher-student interaction eventually became the prominent component of the hypothetical construct labeled "functional PCK."

The major difference in the analytical techniques of Glaser as compared to Strauss and Corbin is a result of the difference in the character of the final research product – theoretical understanding or conceptual description. Although the methods of data analysis advocated by Strauss and Corbin appear to be rigorous and systematic, a feeling of forcing data into preconceived themes is evident. Conversely, Glaser's techniques promote sufficient rigor for data manipulation with ample flexibility for creative analysis. It is because of this blend that Glaser's more conventional mode of data analysis was used for this study.

The cornerstone of Glaser's methodology is the constant comparative method. It consists of four interrelated stages (Glaser and Strauss, 1967, p. 105):

1. Comparing incidents applicable to each category.
2. Integrating categories and their properties.
3. Delimiting the theory.
4. Writing the theory.

The first stage involves open coding for the generation of categories and their properties. The basic underlying principle of the constant comparative method is embodied in this phase of analysis. "While coding an incident for a category, compare it with the previous incidents in the same and different groups coded in the same category" (Glaser & Strauss, 1967, p. 106). This strategy results in a set of concise conceptual categories richly detailed with a continuum of properties. In the second stage, categories and properties are integrated through theoretical sampling. This process is referred to as axial coding by Strauss and Corbin (1990). Theoretical understanding begins to develop "as different categories and their properties tend to become integrated through constant comparisons that force the analyst to make some related theoretical sense of each comparison" (Glaser & Strauss, 1967, p. 109). The prominent feature of the third stage of data analysis is reduction, which involves a determination of the underlying uniformities in the original set of categories. This procedure, similar to Stauss and Corbin's selective coding, yields a smaller set of higher-level concepts. Consequently, a tighter focus on key categories for the generation of theory is possible. It is at this point that the researcher begins to achieve two major requirements of theory: "*parsimony* of variables and formulation and *scope* in the applicability of the theory to a wide range of situations" (Glaser & Strauss, 1967, p. 111). The final phase of data analysis, the writing of the theory, is the culmination of the techniques employed in the first three stages. "When the researcher is convinced that his analytical framework forms a systematic substantive theory, that it is a reasonably accurate statement of the matters studied, and that it is couched in a form that others going into the same field could use – then he can publish his results with confidence" (Glaser & Strauss, 1967, p. 113).

The substantial influx of data from qualitative investigations emphasizes the importance of proper data management. All interviews and observations were audiotaped and then transcribed as soon as possible. Researcher notes taken during the interviews and observations were cross-referenced with the transcripts. All notes and data were stored in the computer and indexed for easy identification and access. Significant quotations, phrases, incidents, and ideas were highlighted during analysis. All hard copies of data were stored in secured locations and pseudonyms were used for all data files.

Validity and Reliability

Several procedures were used to achieve an acceptable level of validity and reliability. Internal validity was enhanced by peer review, member checks, and a thorough clarification of the researcher's biases. Colleagues familiar with the components of teacher knowledge and qualitative methodology were asked to critique the data collection and analysis techniques. To insure valid analysis, the researcher's interpretations of prior data were discussed with the participants in subsequent interviews to check for agreement. The researcher's biases were clearly delineated in the form of assumptions and limitations prior to data collection. External validity was achieved through the use of "thick description" (Merriam, 1998, p. 29), as emerging categories were identified, illustrated, and substantiated with quotations taken from the interview data. By relating these categories back to the current literature on pedagogical content knowledge, a form of modal comparison emerged in which participants' knowledge structures were compared to the typical case. An audit trail, along with peer review, served to develop reliability for this study. The audit trail, which documents the research process, was especially useful in insuring consistency of design.

Ethics and Researcher Bias

Ethical conduct throughout the study was maintained by stringently following the research procedures as approved by the University's Institutional Review Board. Informed consent was obtained from the participants and written permission to access the study sites was granted by the superintendents and/or school principals. The possibility of deception was eliminated by fully informing the participants of the research protocol. Permission was granted to audiotape the interviews and all tapes, transcripts, and notes were kept in a secured location. Unauthorized access to computer files was prevented by establishing passwords.

Researcher bias is always a major concern in a study of this type. Ultimately, it is the researcher who must interpret the data and report the findings. It is the researcher who must determine the significance of statements and events in establishing emerging themes and categories. These decisions were made through the theoretical lens that the principal investigator had constructed through years of experience and study. The fact that the primary researcher spent a considerable amount of time in the public school system as a science teacher and very little time in the field actually conducting research could very well bias not only the selection of pertinent data but the interpretation as well. But the very nature of qualitative research forces the investigator to recognize these limitations, resulting in a tighter focus on the research questions. In essence, the subjectivity associated with interpretive approaches "can be seen as virtuous, for it is the basis of researchers making a distinctive contribution, one that results from the unique configuration of their personal qualities joined to the data they have collected" (Peshkin, 1988, p. 55).

CHAPTER 4: FINDINGS

Introduction

Much of the current literature on pedagogical content knowledge (PCK) indicates that classroom experience is the major contributing factor to its development; however, observations of teachers with varying levels of experience suggest that a broad spectrum of PCK exists. Very simply, experienced classroom teachers may exhibit a wide range of PCK, from very little development to quite sophisticated formulations. Conversely, it is not unusual for a first-year teacher to demonstrate a significantly advanced PCK. An evaluation of this situation led to the speculation that a number of previously overlooked variables may influence the development of PCK in teachers. With this in mind, the purpose of this study was to generate a substantive theory of how teachers develop pedagogical content knowledge. The primary focus was on first-year teachers who had ample content knowledge but no prior teaching experience or formal pedagogical training. The principal research participants were chosen from a group of provisionally certified teachers who were taking part in an alternative certification program, which involved concurrent teacher-preparation coursework, periodic classroom visits by college supervisors, and in-school mentor support. This situation provided a unique opportunity to determine the degree of impact such variables as formal teacher education courses, day-to-day classroom experiences, and collegial interactions had on PCK development. It is a difficult task to explicate all of the factors influencing pedagogical content knowledge development, let alone determine the positive and/or negative effects of each variable, such as teacher education coursework. The purpose of this study was to determine how these different variables influenced PCK development, and not to evaluate their need or potential benefit.

The first part of this chapter deals with a pilot study that was designed to identify specific examples of pedagogical content knowledge use in the classroom and to develop a preliminary understanding of the major components of PCK. Following the results of this initial research is a discussion of the primary research participants' beliefs about teaching and learning, along with a detailed description of their professional personalities. This data was of paramount importance in the construction of the model of PCK development presented at the end of the chapter.

Pilot Study

The three provisionally certified teachers in the pilot study, Brenda, Marjorie, and George (pseudonyms), were in their first semester of classroom teaching at the secondary level. They were also part of an alternative certification program that required concurrent teaching methods coursework. Brenda had a master's degree in physics and had some prior teaching experience as a teaching assistant for an introductory physics course at a small university. She was currently employed as a high school, college-prep physics teacher at a private school. Marjorie had a bachelor's degree in biology and had worked as a lab technician for a private corporation. Her present duties included the teaching of college prep biology, environmental science, and physical science at a small, private high school. George, who had worked as a lab technician for several state departments of natural resources, had earned a master's degree in environmental science. At the time of this pilot study, he was working as a college-prep biology teacher at a private school. The fact that all three teachers were employed by private schools was completely coincidental.

Pilot Study Results

Early work on developing a model of pedagogical content knowledge development was primarily concerned with establishing a list of PCK devices and instructional strategies. In order to construct a substantive theory of how novice teachers develop PCK, it was important to be able to identify classroom instances when these teachers were using this form of knowledge to construct meaning with groups of students. In addition to establishing a listing of the various forms of PCK, an attempt was made to differentiate or categorize these constructions. Whether or not some of these categories represented a higher level of PCK development could not be determined by the preliminary data; however, definite patterns began to emerge that would indicate multiple uses of pedagogical content knowledge. For example, the use of graphic organizers promoted understanding by facilitating a greater degree of organization on the part of the student, while simple mnemonic devices, such as "Roy G. Biv," helped with retaining factual information.

Initially, work with the three provisionally certified teachers resulted in a list of instructional devices that were used to enhance learning (Table 1). The data listed in the table was the result of both classroom observations and interviews. When asked about the origins of these explanations, all three teachers referred to their formal education – high school, college, or graduate school. Additionally, they identified mentors and colleagues as an important source of labs and activities. Based on comments from the interviews, these rudimentary examples of PCK promoted interest and helped the students remember specific pieces of information, but may have done little to foster a deeper conceptual understanding.

Table 2

Categories of PCK Instructional Devices

Pedagogical devices	Language devices	Elaboration of content	Activities
Graphic organizers	Analogies	Similar examples	Problem-solving
Questioning	Similes	Dissimilar examples	Inquiry
Group work	Metaphors	Discussions	Labs
	Acronyms	Narratives	Demonstrations
	Mnemonics	Depth beyond intended goal	
		Breadth beyond intended goal	

Note. Adapted from "Thoughts on PCK," by J. S. Oliver, 2002, Unpublished document.

The two veteran teachers who were interviewed provided a major component of the PCK developmental process. During their interviews, they stressed the importance of checking for student understanding both during and after the explanation of material. During open coding of their interview transcripts, these types of comments helped to establish the category of "making a connection with the student." As Bob (pseudonym) said during a visit to his classroom, "it doesn't make any difference how pretty your presentation is, if the kid doesn't get it, then it's no good." Other than this critical piece of information, no new or unique PCK strategies were identified by the veteran teachers as they planned their lessons. Once the concept of "connecting with the student" was discovered through the interviews with the veteran teachers, it became obvious that Brenda, one of the participants in the provisionally certified sample, was also adept at determining the effectiveness of her content explanations by checking for understanding. Brenda was very perceptive about how well her classroom explanations were received by her students. When Brenda sensed that her instruction was not clear, she attempted to explain the material in a different way. “If they didn’t understand the first way I explained it, why would they understand the same way a second time.” When asked how she developed this penchant for coming up with different ways to explain the same concept, she referred to her experiences in college physics. “I would always study the problems that I had from different angles, or in different ways. I would listen to how it was explained in class, then I would see how it was explained in the textbook.” She also talked about how she would question fellow students to see how they interpreted the same information. These different perspectives helped her to better understand the problem. “Because I learned how to figure things out on my own, I think this helps me when I explain how to deal with a physics problem in class.” Coupled with Brenda’s genuine love and enthusiasm for her subject, this desire to “find out why” may very well be a major contributing factor to the development of PCK. “I’m the type of person who wants to figure out why. I question things. Maybe people who go deeper with trying to understand are better at explaining things.” In response to how she knew if she had done a good job explaining a lesson on projectile motion, she said, “I don’t know. I know when I don’t do a good job.” She then proceeded to clarify her response by using an analogy. “You can always tell when a house is dirty, but you can’t always tell when it’s clean.”

Primary Research Participants

Four primary participants were originally recruited for this investigation. One of the candidates, Charles (pseudonym), was employed in a small city school system as a middle grades earth science teacher. Another participant, Rhonda (pseudonym), worked as a high school biology and physical science teacher in a suburban school system, and the final two candidates, Emily and Gloria (pseudonyms), were middle school life science teachers in a large, suburban, county school system. Charles was eliminated from the group due to access problems.

Professional Characterization – Emily

Emily was a seventh grade life science teacher at a large suburban middle school. Her educational background was exceptional, having earned a doctoral degree in the biological sciences with special emphasis on human anatomy and physiology. When asked about her feelings concerning her career change from a prestigious, high-paying position to a public school teaching job, she said, "so far, I'm pretty happy doing what I'm doing. I feel perfectly at home and I don't have any regrets for switching over."

Emily ranked her content knowledge as being very high, giving herself the maximum rating on a scale of one to ten, with ten being the highest. Based on classroom observations and comments made during the interviews, she truly loved her subject matter and was very enthusiastic about sharing her knowledge with her students. "I want my students to be as excited about biology as I am." She seemed to have the misconception, however, that if she was very familiar with human biology, and the associated areas of cellular biology and biochemistry, that she was competent in at least 90% of what there was to know in the biological sciences. Emily quickly realized during the first semester that her knowledge of critical biological subdivisions, such as genetics and evolutionary biology, was somewhat lacking. She was asked to again rank her knowledge on a scale of one to ten, but this time, for specific sub-divisions of biology. She gave herself a seven on botany, zoology, and evolutionary biology and a six on genetics. In other words, the broad-spectrum knowledge necessary for teaching a survey course was not present; however, her self-assurance in her knowledge base and in her rather substantial academic abilities gave her the confidence to handle virtually any question concerning almost any biological topic.

Classroom observations indicated that Emily utilized a teacher-centered instructional approach with a strong focus on conveying declarative knowledge. In other words, she viewed biology as a body of knowledge that should be transmitted to the students in a highly methodical and repetitive manner. "I really think that repetition is the key to learning something. That's why we go over it again and again." She was very concerned with teaching factual information, like the stages of mitosis, and therefore conveyed to the students the descriptive nature of biology ("the what," Duschl, 1990) rather than the theoretical nature ("the why," Duschl, 1990). Because of these beliefs, Emily perceived her subject matter as very cut-and-dried. "They either get it or they don't. There's no in-between."

During classroom instruction, Emily used a high frequency of questioning to promote student interaction and to assess student knowledge. She demonstrated a definite potential for continual development of PCK because she frequently used numerous analogies and mnemonic devices with her students, but she appeared to be more concerned with how these formulations promoted memorization rather than explanation. On many occasions, she appeared to be very concerned about whether or not her students were absorbing the information. "We've done a couple of things where we've gone on and on and they're still not getting it." When she perceived that there was a problem with comprehension, she attempted to alter her instructional approach; however, her modified explanations appeared to focus on the students giving specific information in response to a specific question. For example, in the teaching of osmosis and diffusion, the students were very confused about the movement of water in response to changes in solute concentrations. Although Emily attempted to explain the concept with additional examples, she never really returned to the underlying reasons for the movement of molecules. Once she gave the students a new example, she proceeded to ask the same types of questions to numerous students until it appeared that everyone was getting the right answer. But even though the students were giving correct responses to the questions, their understanding of why the answer was correct was lacking. This was especially evident when Emily introduced a new set of conditions and the whole process of repetitive questioning began again. These instructional instances again emphasized Emily's concern with making the connection between the student and the factual information, rather than creating conceptual understanding in the student.

Contrary to the tenets of professional educators, Emily did not seem to share the responsibility for learning with the student. As she said on several occasions in the classroom, "I can't learn it for you." This attitude, however, may partially be the result of collegial influences. Emily indicated that when she sensed a great deal of frustration with how things were going in her classroom, she would confer with her mentors and other teachers. During one of these visits, the comment was made by a colleague that "the sooner you realize it's them and not you, the better off you'll be." This statement tended to promote a separation between Emily and her students by reinforcing that artificial boundary between teaching and learning that existed in her classroom. In other words, this is what I do as the teacher (transmit information), and this is what you do as the student (absorb information).

In terms of teaching, Emily felt like her greatest weakness was classroom management. In an early interview, she stated that one of her biggest problems was a lack of classroom procedures and consequently she felt like she had a tendency to get off the subject too easily and therefore couldn't cover the necessary content. "In fact, I think that if I had set my classroom procedures the very first week of school, then I wouldn't be telling the kids to bring it back down a notch. Let's get back on track." This tendency to avoid what was perceived as off-task discussion was contrary to some of the results obtained during the pilot study. For example, based on Brenda's comments during several interviews, initiating and maintaining class discussions was considered to be a desirable aspect of PCK because it facilitated depth and breadth beyond the intended goal. Once again, Emily's intention was to be the purveyor of information and to cover all the material. "We've got to stay on track, otherwise, we won't be able to cover all of the standards." As alluded to earlier, Emily emphasized the importance of mentors and colleagues in helping her with both instructional activities and classroom procedures. "I go to my mentors when I need assistance on how to teach a particular concept." She was very much convinced that classroom experience, along with collegial support, was the key to becoming a better teacher. "I find just coming out here and doing it, and getting your hands dirty, is the best way to learn."

Professional Characterization – Rhonda

Rhonda was hired by a large suburban high school to teach college-bound biology and physical science. Although she expressed some concern about her knowledge of physical science in an early conversation, her background in life science was excellent, possessing a master's degree in applied biology with research experience in parasitology. Typical of many first-year teachers, Rhonda was very concerned about classroom management. "When I started teaching this first semester, I would say I was really nervous about what might happen in class. Since I was so concerned about losing control, I really spent a lot of time preparing my lessons. I think I always planned for more than I could possibly do." This inordinately large amount of time planning lessons resulted in her actually scripting her presentations. "I write up my notes when I give lectures. I write up my notes in great detail. I pretty much write up a script." It was noted during classroom observations that Rhonda had a very smooth and logical instructional delivery, which was of great benefit to the students. This ability was probably due to her extensive preparation outside of class along with the fact that Rhonda had experience speaking to large groups in her previous business career. "I've had a lot of experience talking in front of people and I have a lot of confidence doing that if I have something to share with them that I know they need to know."

Rhonda felt very confident in her ability to explain difficult concepts to her students. She felt that this attitude probably developed during her career with a large computer software company in which she had to train customers in the use of various software packages. Based on comments made during one of the interviews, Rhonda stated that in explaining some of these difficult computer operations, she would reduce complex processes into simpler terms and then employ some of the same strategies that she used to achieve personal understanding with her customers. Because of these work-related experiences, Rhonda ranked her ability to explain things as being fairly high, giving herself a rating of eight on a ten-point scale. "I still have a lot to learn about what works and what doesn't. I expect this to improve with practice. Plus, I'm getting a lot of good ideas from the classes I'm taking." Furthermore, she mentioned that just working with her own children at home probably also contributed to her PCK. "I think one of the reasons why I can explain things fairly well is because I've done so much of it with my own children when I help them with their homework." She also felt that these informal educational situations helped her to develop an awareness of how different "issues" in the students' lives could interfere with the educational process. Consequently, based on the field data, it was observed that Rhonda was very interactive with her students, spending a great deal of time talking with them and researching their backgrounds. "You've got to really know your students, not only how they respond and how they react, but also what their abilities and capabilities are." This interaction was instrumental in helping Rhonda develop a significant degree of PCK during her first year of teaching.

Early in the research process, Rhonda commented that a key factor affecting her professional growth was the actual planning and implementing of lessons. She was very much aware of the difference in how she had learned material for a test when she was in graduate school, and how she now viewed the material as she prepared to explain it to her students. Even though she acquired numerous ideas for lessons and activities from other teachers, she downplayed the benefits of her collegial relationships, claiming that many of the activities really didn't enhance student comprehension. "I don't want to give the kids busy work. I want to give them something real; something that is relevant and has value." After viewing several veteran teachers in the classroom, she commented, "I'm doing just as well as teachers who have been here for ten years. Maybe, I'm even doing better." Upon reflection, however, she realized that her classroom needed to be more student centered. "I do a lot of teacher-directed lessons, which means I'm still probably doing too much of the work myself and not requiring them to do enough of the work, but I'm learning." She had been exposed to discovery learning in her methods class and felt that this was a strategy worth trying. "It's hard for me to get them to do stuff where they're learning, but I'm not spoon-feeding it to them. I'm letting them discover it, you know, like the discovery learning we learned about in the methods class." But again, she expressed the need to maintain some degree of classroom control and did not want these lessons to turn into what she called "playtime." "It's hard to get them in the mindset where they're going to be doing something and not just playing with each other and chatting. Because a lot of times, when I let them do their own thing, they play."

Based on the interview data, Rhonda took total responsibility for promoting learning in her classroom. She felt that her extensive educational background contributed to her abilities to implement, assess, and modify instruction. "I think I'm pretty good at picking out the most important concepts and focusing on them. I also think that I understand the material well enough myself so that I'm comfortable condensing it, rewording it, or coming up with my own examples or analogies, at least in biology." Rhonda, however, indicated that she placed a greater degree of importance on "knowing the student," and sensed that an integral part of the education process was the quantity and quality of teacher-student interactions. "You really have to know your kids.

And you really have to get a feel for how they respond to you. When I turned the corner, when I started feeling better about my teaching, was after I knew all my students' names. Because once I knew their names and what to expect from them, it made things so much better somehow." As far as interacting with her students was concerned, in a passing comment about whether or not she got any work done in class, like the grading of papers, Rhonda very simply stated, "it's hard for me to get a lot of my work done in class because when there's people in here, I need to be interacting."

Professional Characterization – Gloria

Gloria was employed as a life science teacher at a suburban middle school. Of the three primary participants, her content knowledge was the least developed, with a BS in human resource management and additional post-graduate training in physical therapy. As stated earlier in chapter three, in the section describing purposeful sampling and the recruitment of research participants, a desired selection criterion was a formal educational background that included a minimum of an undergraduate degree in a specific science discipline. Even though Gloria did not fit this profile, it was decided that her undergraduate science courses, coupled with the training in biology that she received during her experience with physical therapy, would be sufficient to qualify her as an acceptable participant. Since her science background was somewhat limited, she ranked her content knowledge, on a scale of one to ten, as a six. "There are some areas I feel very strong in, because of my background as a physical therapist, and others that I feel weaker in, such as genetics." Because of these weaknesses, she spent a great deal of time preparing for her classroom presentations. "I want to make sure I have a good understanding of the material before the kids ask me questions. Plus, I like to try to present the lessons in different ways." This final comment was made very early in the first semester and indicated that, for some reason, Gloria was already progressing toward a higher level of pedagogical sophistication. When asked about her understanding of science, she stated that "science helps us to understand the world around us. It is full of amazing information." And in response to her teaching approach for first semester, she said, "I ordinarily introduce the facts first – by notes and lecture, reading of the book, vocabulary, etc." Although she shared a similar view of biology with Emily and Rhonda, that it was a body of factual information to be transmitted to the students, the fact that she was actively seeking alternative ways to "connect with the students" so early in the year was somewhat surprising. In interviews that occurred during the first semester, Gloria stressed the importance of being able to effectively communicate with the students. When asked about what constituted good teaching, Gloria responded, "good rapport with your students, which includes mutual respect, listening to what they have to say, a sense of humor, high expectations, and a willingness to go above and beyond when needed." She viewed the student as "a collaborator in his/her learning, with both rights and responsibilities." Even though she expressed concerns with classroom management and attempted to maintain a fairly high level of structure in class, her genuine desire to communicate and interact with her students was evident during classroom observations where the students responded very well to her teaching and performed according to her instructions.

When Gloria sensed that her teaching was not going well, she looked for help from her colleagues. She said that she relied very heavily on her mentor to provide different labs and activities that would add variety to her instructional presentations. "I was more inclined to actually use the other science teachers for more in-depth content questions and I used my mentor more for a source of class activities, teaching advice, and planning advice." She believed that "teaching is learning," and actually felt like she did a better job teaching material that was somewhat new to her. "I really feel like I do a better job teaching material that I'm not that familiar with; that I have to sort of learn along with the students." This attitude manifested itself in some of the collaborative work that she assigned to her students. For example, one of the activities she used during the second semester involved group work in which the students prepared reports on the different organ systems and then shared their findings with the class.

Gloria initially classified herself as a very traditional form of teacher. The early observational data indicated that her primary instructional approach involved lecture, worksheets, and tests. As she worked through the first semester, it was noticed during classroom observations that she moved away from this teacher-centered strategy and started to incorporate more labs, demonstrations, and other types of activities. At first, she brought in these activities to "break the monotony" because she indicated that the students were getting bored with all the information she was presenting to them. "Sometimes, just breaking up the routine can in itself be an asset – to give the students a break and a chance to rejuvenate as a class." But she later expressed dissatisfaction with a number of these lessons because she felt like she did them just to have something to do. "I think some of the teachers who gave me some of these ideas for activities were using them in class just to take up time. That the activities may not really have accomplished that much as far as helping the kids understand something." She commented that she had witnessed other teachers doing the same thing and wondered why it was so difficult to implement meaningful activities that promoted at least some student understanding. Even though she was frustrated by this dilemma, she didn't know what else to do. "I guess that's the way hands-on science teaching is supposed to be."

Gloria entered into her first year of teaching with no pedagogical training or classroom experience, but, based on subsequent observations, her concern for her students and her ability to interact with them was indicative of a more experienced teacher. Even though her content knowledge didn't rival that of Emily or Rhonda, classroom observations suggested that she did have a slight pedagogical advantage, and, like many outstanding veteran teachers, she was constantly reflecting on her classroom experiences. When asked how she could become a better teacher, she said:

> I would try to get more feedback from my students on what they think “worked” or “didn’t work.” I would continue to develop varied lesson plans, geared toward not only the “middle,” but the “lower” and “higher” ends also. And I would not be afraid to ask questions when I felt like I didn’t know what I was doing!

Model of PCK Development

A major goal of grounded theory research is the development of a model that attempts to explain the phenomenon in question by integrating the key categories and subcategories identified during the data coding process. To better illustrate this integration process, a diagram is constructed to depict conceptual relationships. The theoretical diagram acts as a visual representation of the formulated substantive theory. It actually serves as a tool for determining the efficacy of the conceptual relationships that were identified during data analysis. According to Strauss and Corbin, “diagrams help the analyst to gain analytical distance from materials. They force the analyst to move from working with data to conceptualizing” (1998, p. 218). Additionally, as the theoretical formulation becomes more complex, the diagram can reveal potential breaks in logic, thereby forcing the investigator to reconsider certain conceptual relationships and possibly seek additional information from the participants. This continual evaluation insures that the ultimate substantive theory, as illustrated in the diagram, is thoroughly grounded in the data. Furthermore, if properly constructed, the model adds to the predictive power of the substantive theory by visually displaying plausible and potentially unique combinations of variables that might otherwise be overlooked. During this investigation, analysis of the data through the constant comparative method forced the researcher to constantly re-evaluate the many conceptual relationships that emerged during data analysis. Subsequently, the construction of a theoretical model was a continually evolving process, resulting in numerous configurations. This analytical struggle is depicted in the following diagrams, with the final figure representing the most powerful construction in terms of the diagram's usefulness and its predictive power. A complete discussion of this predictive potential will be included with the last model.

Early in the research process, a somewhat simple diagram, dubbed the stair step model (Figure 1), was constructed to illustrate several major categories that were identified in the interview transcripts. One of the first and most prominent categories to be identified from the data was labeled "content knowledge." Two of the primary participants, who were very strong in content, expressed a great deal of confidence in their ability not only to effectively explain the subject matter to the students, but also to handle any student questions in a competent manner. In addition to the "content" category, a "teaching philosophy" concept emerged from the data that was rooted in an objectivist epistemology and a teacher-centered, transmissive instructional approach. Together, these two concepts resulted in a "commitment to the teaching of content" category in which the teacher was most concerned with the coverage of material as outlined in the course objectives. Even though a certain level of pedagogical content knowledge was evident at this time, the transformation of content was geared more toward the recall of declarative knowledge rather than the construction of student understanding. As indicated by the stair step progression, a more sophisticated instructional approach occurs when the teacher commits to "teaching for conceptual understanding." In this case, the focus of teaching shifts from the mere explanation of content to how the student is actually processing the information and the associated level of comprehension. Now, content transformation is used to illustrate the interrelationships between concepts rather than just to explain discrete bits of information. In other words, the instructional focus is now on the student rather than the content. Although this stair step model does illustrate PCK as a progressive development with an associated change in how the teacher viewed both the content and the student, it failed to incorporate several other major categories that emerged from the data, such as pedagogical sophistication and the various forms of pedagogical content knowledge. In addition, as more data was generated through theoretical sampling, some of the initial categories incorporated additional properties and exhibited greater dimension. For example, the concept of "content knowledge" evolved into the category of "content complexity," thereby emphasizing the importance of not only declarative knowledge but the substantive and syntactic structures of the discipline as well.

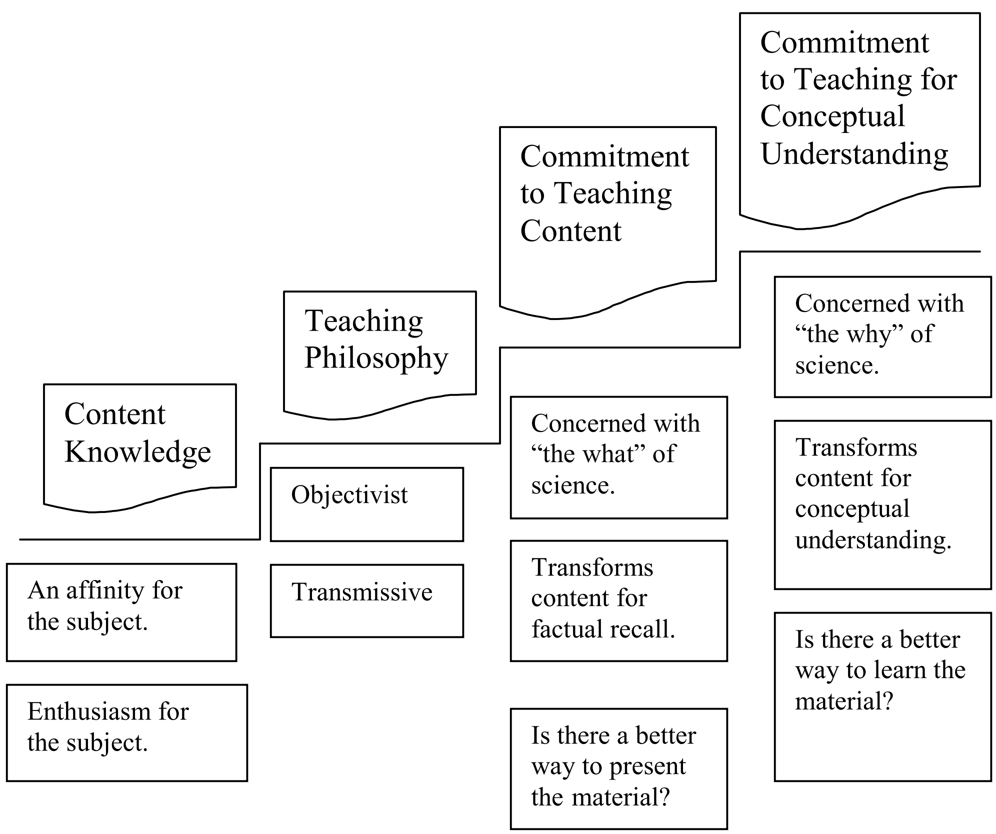

Figure 1. The stair step model of pedagogical content knowledge development.

As data analysis continued, a new model emerged that accounted for the additional concepts that were being coded. The following diagram (Figure 2) illustrates a more sophisticated theoretical model for the development of pedagogical content knowledge in first-year teachers. Even though the original research participants were attempting to qualify for their teaching credentials through an alternative certification program, data collected by means of theoretical sampling suggest that many first-year teachers, regardless of their preparation, may very well pass through similar developmental stages. For example, the conflicts associated with a commitment to the content as opposed to a commitment to conceptual understanding in students is familiar to both veteran and novice teachers.

The various coding processes associated with grounded theory research facilitate the development of key structural and procedural concepts that will eventually lead to a more thorough understanding of the phenomenon in question. Inherent in this process is the identification of one or two core categories that incorporate and integrate the other generated concepts. This central category represents the investigator's "interpretation of what the research is all about, what the salient issues or problems of the participants seem to be" (Strauss & Corbin, 1998, p. 146). Throughout the observation and interview sessions, one overarching impression continuously reasserted itself. This impression emerged as a characteristic of the new teachers and could be labeled, "the struggle for understanding." For the research participants, teaching became more than simply explaining the information. The need for increased teacher-student interaction and varied instructional strategies became more evident as the participants realized that their students "were just not getting it." Not only were the students struggling to understand the scientific concepts that were explained in class, but the teacher was also struggling to promote comprehension in her students by presenting and explaining these concepts in innovative ways. This mutual "struggle for understanding" became the primary impetus for the development of a more sophisticated degree of pedagogical content knowledge.

Definition of Terms

The following terms, which represent major categories identified during the coding process, are used in the various models of pedagogical content knowledge development that were generated from the data. The formulation and modification of these diagrams, illustrating a progression from relatively simple to more sophisticated representations, indicates, to some extent, how several prominent conceptual relationships evolved into a substantive theory of PCK development.

Development of Teacher Knowledge – The stages that occur during the formal education of the teacher that result in a personal understanding of the scientific discipline as well as a perception of how this understanding should be conveyed to students. These stages are the preliminary events that start the preservice teacher along the axes of content complexity and pedagogical sophistication. For the purpose of illustration, in the model depicted in figure two, the subject matter of biology is used for the scientific discipline.

Initial Instructional Theory – The participants' beliefs and perceptions about what teachers do and what students do. According to Trowbridge and Bybee (1990), the instructional theory provides the theoretical basis for making decisions about how to best structure and sequence the content to maximize teaching and learning and then how to assess the instructional effectiveness of those decisions. All of the participants in this investigation stated that their early attempts at teaching reflected the manner in which they were taught during their formal education. In all cases observed in this study, this perception resulted in a teacher-centered, transmissive, content-committed instructional approach. Based on the predictive power of the theoretical model on PCK development, it would be anticipated that education graduates would possess a more advanced instructional theory due to their pedagogical training, resulting in a more pronounced focus on the student and conceptual understanding; therefore, these first-year teachers would exhibit a progression up the vertical axis, thereby expressing a higher level of pedagogical sophistication.

<u>Teaching Commitment</u> – An applied instructional approach that is based on how the teacher addresses the task of teaching. This approach is dependent on how the teacher perceives the role of the subject matter, the students, and the goals within the teaching process. For the participants in this study, because of a lack of pedagogical training, their initial teaching commitment, a commitment to teaching content, was equivalent to their initial instructional theory.

<u>Commitment to Teaching Content</u> – An instructional approach that implies a broad coverage of the essential foundational information as delineated in most of the discipline's textbooks and in the teaching standards of most school districts. A teacher who commits to this teaching format would utilize a teacher-centered, transmissive style to present science as a body of factual information, with a focus on vocabulary and other forms of declarative knowledge.

<u>Commitment to Teaching for Conceptual Understanding</u> – An instructional approach that stresses depth of understanding over breadth of coverage. This student-centered teaching format, which focuses more on student comprehension and the teacher's reflective evaluation of instructional effectiveness, is highly dependent on the level of teacher-student interaction. Consequently, a teacher's transition to this more effective teaching and learning approach is accompanied by a need to "connect" with the student.

Making the Connection – This category entails both a desire on the part of the teacher to determine whether or not her content explanations are truly impacting the student and a proactive decision on the part of the teacher to shift from a teacher-centered form of instruction to a student-centered one. This situation is considered to be a learned condition that develops as a result of teaching experience. Once the need to connect with the student becomes apparent, a number of changes occur in the teacher's instructional approach. There is an increase in instructional activities that promote conceptual understanding along with a corresponding improvement in the teacher's pedagogical sophistication.

Pedagogical Sophistication – The ability to promote a student-centered learning environment by fostering high levels of teacher-student interaction. The teacher who is pedagogically sophisticated has moved away from the mere presentation of the content for the purpose of covering the standards to a commitment to promoting conceptual understanding by not only presenting and explaining the content in more meaningful ways, but by focusing on the instruction's impact on the student. Only by changing the focus of their commitment, from the teaching of content to teaching for conceptual understanding, can the teacher expect to achieve a more significant level of pedagogical sophistication. An additional criterion of pedagogical sophistication, especially at the secondary level, is a relatively well-developed content complexity. The modification of explanations of difficult science concepts during a series of teacher-student interactions demands a thorough understanding of the disciplinary knowledge. Other indicators of the progression toward pedagogical sophistication would involve attempts to make the content more relevant, changes in the sequence of instruction, and an increase in the use of student-centered activities.

Content Complexity – The teacher's mastery of the content, as evidenced by the level and type of content interrelationships utilized during instruction. It entails a thorough understanding of the subject's declarative knowledge as well as the discipline's substantive structure. Additionally, it would be apparent that a teacher with a high level of content complexity would formulate the answers to student questions in accordance with the accepted theoretical structure of the discipline, thereby emphasizing "the why" of the subject and not just "the what" (Duschl, 1990).

Structural PCK – The range of explanatory strategies which may take the form of either rudimentary devices, such as mnemonics, which facilitate the encoding and recall of declarative knowledge, or more detailed forms of explanations, such as narratives, which may enhance the overall explanation of a specific science fact. The term "structural" was taken from an article by Chan, Tsui, and Chan (2002) which discussed a hierarchical model called the SOLO taxonomy (Structure of the Observed Learning Outcomes). This construction was used to measure students' learning outcomes by classifying the complexity of their responses, from low-level categories, termed "structural," to high-level ones, termed "functional." The key facet of structural outcomes was the focus on learning and recalling single, unrelated bits of information with no apparent concern for establishing conceptual relationships. Structural PCK is characterized by these same qualities. For example, relating to students that a lysosome can be called a "suicide sac" because of the potency of its hydrolytic enzymes definitely helps students to recall the organelle's function on a subsequent quiz. Relating a current event or story about how cancer research is attempting to find ways to activate the lysosmes in cancerous cells for the purpose of destroying those cells is another way of clarifying their function and sparking the students' interest. But these strategies deal with a specific chunk of information and do not adequately address the role of the lysosome in the overall functioning of the cell. In order to accomplish this task, the teacher must develop a more functional form of PCK. A key component that differentiates structural PCK from the more sophisticated functional PCK is the lack of teacher-student interaction that is necessary for promoting conceptual depth.

Functional PCK – A more sophisticated form of pedagogical content knowledge which causes students to think about several elements at the same time and consequently consider them in a broader context. Again, the term "functional" was taken from the SOLO model (Chan, et al., 2002), and is indicative of a higher level of understanding. The ultimate purpose of functional PCK is to bring together the various conceptual components into a unified whole, thereby eliciting "the big picture." In-depth, student-centered discussions following an inquiry activity or problem-solving session incorporate the primary ingredient of functional PCK, which is the increased quantity and quality of interaction between the teacher and the student. Development of functional PCK is possible only if the teacher possesses sufficient content complexity and has made the commitment to teach for conceptual understanding, with a resultant increase in pedagogical sophistication. To take the above example of the lysosome a step further, to promote greater conceptual depth, examples of lysosome activity in various types of cells, such as phagocytosis in amoebas and white blood cells, could be introduced and discussed to establish the relationship of structure and function in different biological systems. The observation that lysosomes develop from membranes of the Golgi bodies could also be used to establish previously unrealized associations and promote further discussion of the important role of phospholipid membranes. In other words, the student is simultaneously incorporating several elements of cell structure and function while at the same time developing interrelationships between what may have been originally perceived as discrete facts. But the development of conceptual depth involves significant two-way communication between the teacher and the student. The teacher must determine how well her explanations of these various relationships are being received by the students. She must determine whether or not she is "making a connection." Consequently, a key ingredient of functional PCK is the level of teacher-student interaction.

An Overview of the Diagram

The diagram (Figure 2) takes the form of a graph that displays four variables. In essence, there are two horizontal axes, one at the top of the graph displaying the variable of "structural PCK," and another in the normal x-axis position at the bottom of the graph labeled "content complexity." Originally it was believed that there was a direct relationship between these two variables as indicated by the directions of the arrows. A teacher with a high level of content knowledge has probably encountered a significant number of structural PCK devices and strategies during her formal education, and will more than likely utilize these same strategies when transmitting scientific information to her students; therefore, it appeared that a high level of content knowledge fostered a similar degree of structural PCK. There are also two vertical axes. The one on the left signifies the important concept of "pedagogical sophistication" while the axis on the right represents a second form of pedagogical content knowledge called "functional PCK." These two variables exhibit a direct relationship, in that an increase in pedagogical sophistication can potentially lead to an improvement in functional pedagogical content knowledge. It should be emphasized at this point that the term pedagogical content knowledge implies a melding of content with pedagogy. Both of these factors are important in developing a more substantial PCK. The concept of content complexity relates to the content aspect of PCK while the category of pedagogical sophistication addresses the pedagogical component. How content knowledge and pedagogical knowledge come together during classroom instruction determines, to a great extent, the teacher's instructional effectiveness. In order to develop functional PCK for the purpose of promoting conceptual understanding, the teacher must demonstrate both content complexity and pedagogical sophistication. A superior level of PCK is impossible without both of these instructional components.

Two different teaching approaches are represented by the statements concerning teaching commitments in the interior section of the diagram. If the novice teacher views science as an accumulation of factual material and perceives the task of teaching as being the transmission of this descriptive information to the student, then her instructional approach would focus on a "commitment to the teaching of content." If, however, the teacher becomes more concerned with her students' depth of understanding and attributes greater value and meaning to "the why" of science rather than "the what," then her instructional approach would entail a greater "commitment to teaching for conceptual understanding." The pathway to the latter commitment, however, is not a direct one, as illustrated by the diagram. Because of the position of "the teaching for conceptual understanding" category in the upper part of the graph, a certain level of pedagogical sophistication must be attained. If these two factors coincide, it can be seen that the development of enhanced functional PCK is possible. The converse is also true. If the teacher continues to be committed to the content and even develops a somewhat higher level of pedagogical sophistication for presenting the material, but fails to promote the necessary teacher-student interactions, then the potential for developing even a rudimentary level of functional PCK is very low. In other words, a high level of content complexity could foster a well-developed structural PCK, but without the proper commitment and corresponding pedagogical growth, the development of functional PCK would be hampered.

It should be noted that although the diagram takes the form of a graph with vertical and horizontal components, it does not lend itself to the plotting of a line to illustrate growth in pedagogical content knowledge over time. Rather, it is a visual representation of the events, categories, and concepts that were identified in the data, and how these factors contributed to the development of PCK. An additional section of the diagram, the box at the bottom labeled "development of teacher knowledge," illustrates a linear sequence of events that ultimately leads to the development of the teacher's cognitive structure concerning the subject matter and her instructional theory, which entails basic beliefs about teaching and learning. These two components have a profound effect on how the subject matter of science is viewed and how it should be presented to students.

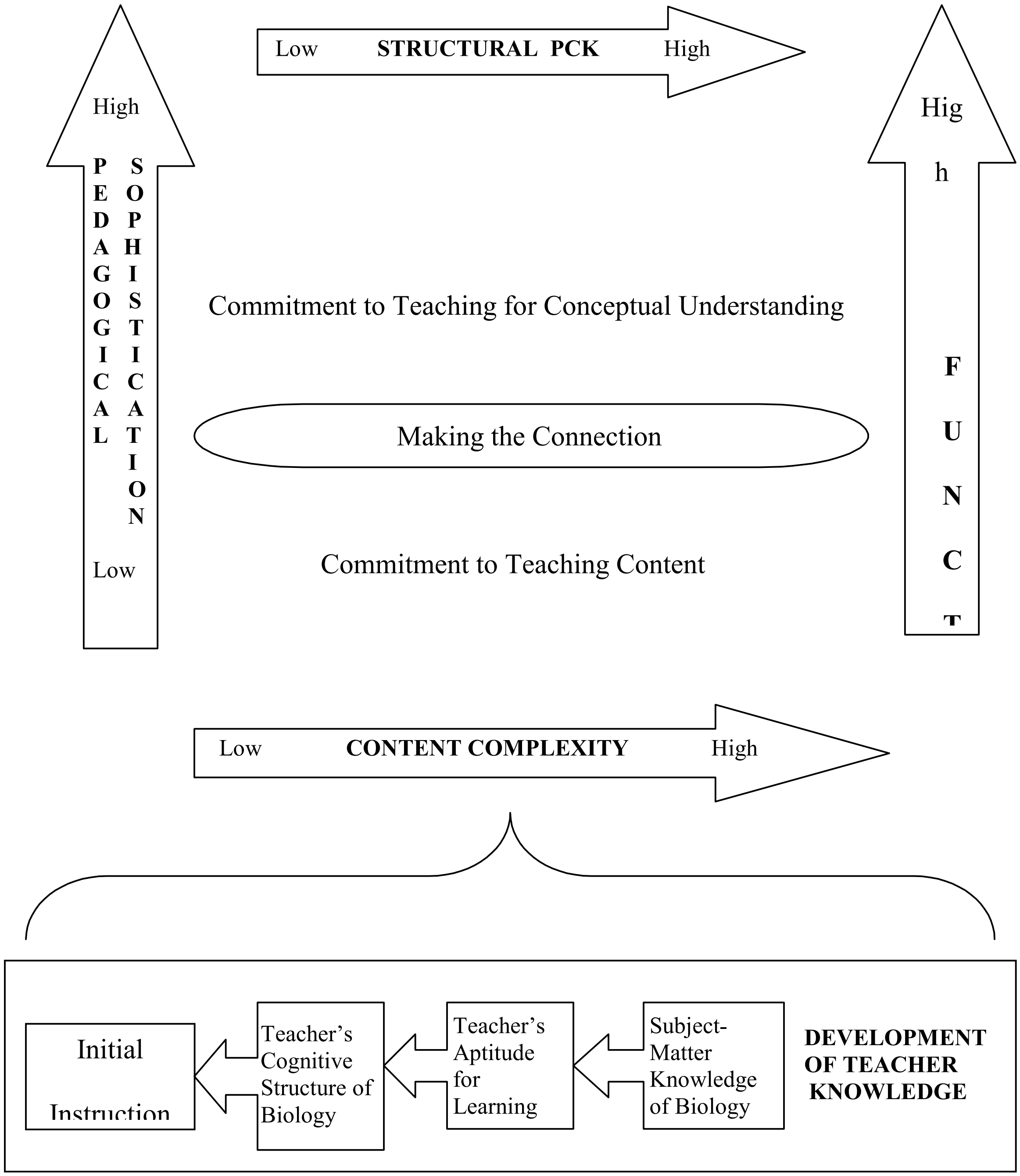

Figure 2. "The struggle for understanding." A diagram of PCK development.

The Relationship Between Variables

Two methods for ensuring validity in qualitative research are peer reviews and member checks. These techniques identified a possible discrepancy in the relationship between two of the variables on the original diagram. As indicated by the directions of the arrows representing the horizontal axes, there is a direct relationship between content complexity and the development of structural PCK. This correlation would imply that a high level of content knowledge leads directly to a similar degree of development in structural PCK. Although a teacher with a good understanding of content has probably encountered a significant number of structural PCK devices and strategies during her formal education, there is no evidence to show that greater content knowledge leads naturally to greater powers of explanation. On the contrary, two of the research participants recalled having brilliant college professors who happened to be extremely weak in explaining concepts. Even though all of the other relationships on the diagram were supported by the data, a new construction was needed to better illustrate the relationships between content complexity, structural PCK, and functional PCK. The subsequent model (Figure 3) helps to deal with this problem. It should be emphasized that this model is not an adjunct to the previous diagram but represents the next step in the evolution of the theory on pedagogical content knowledge development. Also, it appears that the sections on teaching commitments have been deleted from this construction; however, in order to maintain parsimony of variables and formulation, it is assumed that pedagogical sophistication cannot be achieved without a commitment to teaching for conceptual understanding; therefore, this category is subsumed under the heading of pedagogical sophistication.

The new diagram takes the form of a cube composed of eight smaller cubes. The major advantage of the cuboidal shape is that it provides a third axis to demonstrate the interplay between the three variables of content complexity, structural PCK, and functional PCK. The x-axis on this diagram is still occupied by the concept of content complexity, with the y-axis signifying functional PCK and the z-axis representing structural PCK. The two smaller blocks along each axis represent varying ranges of low and high development. The low and high labels do not represent distinct categories of either possessing content complexity, for example, or not possessing it. Rather, within a cube labeled "low," there is a range of possible development that could also be characterized as low to high.

Each cube within the diagram illustrates a different combination of the three variables. For example, the small cube in the lower left-hand corner represents low content complexity, low structural PCK, low functional PCK, and a lack of pedagogical sophistication. No participants in this study demonstrated this low level of development. The two boxes to the right of the preceding example would represent teachers with advanced content complexity but an inability to teach for conceptual understanding due to a lack of pedagogical sophistication. In other words, their functional PCK is low. The fact that a teacher who would occupy the box in the lower right-hand corner of the main cube would be able to provide adequate and sometimes even exceptional explanations due to a high degree of structural PCK is overshadowed by the fact that his functional PCK is not well-developed. According to comments made by some of the participants concerning their formal education, the two boxes in the lower right side of the main cube are representative of college professors in a content area who possess an excellent knowledge of content but lack the necessary pedagogical skills to successfully interact with their students.

The box in the upper left foreground would be indicative of an individual who may possess adequate interaction skills and consequently may have the potential to promote high levels of understanding in students, but lacks the necessary support from the content to really accomplish anything. The box toward the back of the cube, in the upper left-hand corner, is representative of a first-grade teacher from the theoretical sample. Due to of a lack of subject-matter coursework in her formal education, her content complexity was relatively low; however, because of a genuine desire to teach science to her students, coupled with her experience in researching, planning, and implementing specific science lessons, her pedagogical sophistication was judged to be quite high. This conclusion was supported by two separate classroom observations in which she taught the characteristics of living things by convincing students, through a series of logical propositions, that creatures such as fish and grasshoppers are classified as animals, even though they don't have fur, and plants are living things, even though they don't move or appear to eat anything. This form of PCK, involving high structural and functional components but low content complexity, was initially hypothesized in a research study on pedagogical content knowledge in elementary school teachers (Appleton & Kindt, 2001). Since one of the main criteria for pedagogical sophistication, however, was high content knowledge in order to deal with the complexity of science topics encountered in a middle or high school environment, this box was not shaded like the two in the upper right side of the model. The shaded box in the foreground corresponds to a teacher who is well-developed in all categories but structural PCK and simply may choose to forgo the use of structural explanations of subject matter in favor of allowing the students to construct a more functional understanding of selected science concepts. The ability to conduct a class in this manner would be dependent on a sophisticated pedagogy. And finally, the smaller cube in the background, on the right-hand side, represents significant development in all four categories. Like the teacher who demonstrates very little progress in these variables, it may very well be possible to identify teachers with these advanced qualities in the school population, but more than likely, most teachers who eventually achieve this level of sophistication may demonstrate these talents with certain topics and not with others. In other words, the teacher who possesses these abilities for all topics would probably be a rare find.

The following sections discuss each part of the diagram in detail by utilizing salient quotations from the data. Additionally, several current research studies from the literature of science education will be introduced to provide context and additional support for the model. Because these investigations were instrumental in this theoretical formulation, their inclusion in the chapter on results was deemed more appropriate than relegating these studies to the literature review. Again, this break from tradition is illustrative of the evolving nature of grounded theory research.

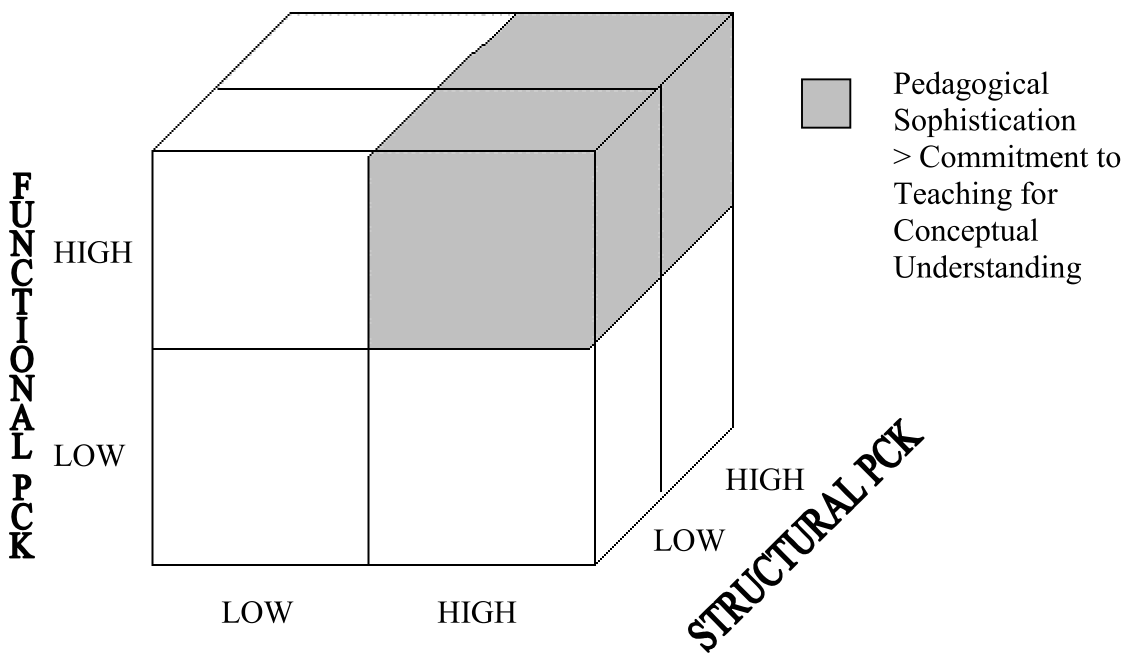

Figure 3. The relationship between content complexity and PCK.

Emergent Categories

The following sections are devoted to a detailed discussion of the six major categories that emerged through axial coding of the data – the teacher's cognitive structure, initial instructional theory, content complexity, pedagogical sophistication, teaching commitments, and pedagogical content knowledge. These key concepts were instrumental in formulating the intermediate model of PCK development (Figure 2). It should be noted, however, that this model, depicting "the struggle for understanding," was not the final construction. Since the cube model (Figure 3) evolved from the following categories, it is essential to thoroughly ground these concepts in the data.

The Teacher's Cognitive Structure

Shavelson defines structure as "an assemblage of identifiable elements and the relationships between those elements" (1974, p. 231). The structure of biology "ultimately rests in the minds of the scientists," who communicate this compendium of knowledge by way of scientific journals, conferences, and other channels of communication (Shavelson, 1974, p. 231). How the prospective teacher of biology receives, processes, and stores this information is dependent on two factors (what Shavelson refers to as filters) – the professor's aptitude for teaching, coupled with the future educator's aptitude for learning. The resultant assemblage of knowledge and interrelationships coalesces into substance within the future teacher's cognitive structure of scientific stuff.

The novice teacher, upon entering the field of education, is faced with the problem of teaching the information that makes up the major components of her cognitive structure of scientific stuff to her students. How this is accomplished is again dependent on the teacher's aptitude for teaching along with the student's aptitude for learning (Shavelson, 1974). In the case of Emily, Rhonda, and Gloria, their initial instructional approach focused on the acquisition of vocabulary and other forms of declarative knowledge, and their primary goal was to completely cover all the material as stipulated in the curriculum objectives. As they worked through their first semester, however, it became quite clear that a teacher-centered, transmissive presentation of material does not yield satisfactory results. This somewhat frustrating revelation, that conceptual understanding is not a natural by-product of instruction that focuses on vocabulary and a conglomeration of facts, signals the beginning of professional development along two distinct but interrelated lines – content complexity and pedagogical sophistication.

Initial Instructional Theory

The instructional theory, in its simplest form, deals with how the task of teaching is formulated. In other words, it entails an individual's beliefs and perceptions about what teachers do and what students do. The novice science teacher enters the profession with very definitive views on the processes of teaching and learning. These beliefs have been developed and modified during the individual's formal educational career. According to John Pennick, current president of the National Science Teachers Association, "I had little more to support my teaching methods than what my experiences were as a student, what I perceived about teaching and the roles of teachers, and what I thought I knew about science" (2003, p. 46). It is not unusual, therefore, for a provisionally certified, first-year educator to formulate and implement classroom lessons in a fashion that is very similar to the instructional presentations of college professors, with a heavy emphasis on absorbing large quantities of subject-specific information. As Rhonda so succinctly stated, "I guess I started out teaching like I was taught." This revelation was a dominant factor in all the provisionally certified teachers who were involved in this study. Very simply stated, these first-year teachers had not been exposed to any formal pedagogical training, and therefore, when they planned and implemented lessons, they relied heavily on what they had experienced during their periods of formal education. As Rhonda stated, "I didn't know anything about inquiry teaching or discovery learning. I thought it was my job to give the students the information and see if I could motivate them to learn it." During the majority of classroom observations conducted during the first semester, Emily lectured and had the students take notes. The same was true for Rhonda, who would have the students copy the notes from overhead transparencies. Virtually the same instructional format was used by all three participants at the beginning of their teaching careers. According to Gloria, "I ordinarily introduce the facts first – by notes and lecture, reading of the book, vocabulary, etc. Once I have introduced the information, I will then go on to do other activities – be they worksheets or labs. Then I try to do a comprehensive review followed by a test."

These strong influences associated with their personal educational experiences resulted in all three research participants initially expressing an educational philosophy that was oriented toward a transmissive mode of teaching. This instructional style involves the students first receiving knowledge from the teacher, and then, for purposes of assessment, giving the knowledge back on basic recall tests (Ebenezer & Connor, 1998). Lorsbach and Tobin (1992) would classify these types of teachers as objectivists. Objectivism is an epistemological perspective that views knowledge "as being separate from knowing and knowers. Knowledge is 'out there,' residing in books" (Lorsbach & Tobin, 1992, p. 1). Feeling compelled to cover all the material contained within the state and local standards, an objectivist-oriented teacher would focus primarily on lecture and book assignments, eliminating labs and activities if pressed for time. A key, if not central element in the thinking of all the novice teachers interviewed was the absolute and maniacal allegiance to "the standards." Even veteran teachers succumb to the pressure associated with the coverage of curriculum objectives and the end-of-semester standardized exams. Rhonda summed up the feelings of all the participants when she said, "we've got to cover the material. And sometimes that means we can't always take the time to check to make sure that all our students are with us."

Based on preliminary interviews, all three participants viewed biology as a body of factual information, with a focus on vocabulary and descriptive material ("the what" of science, Duschl, 1990). Early in the year, based on the observational data and the nature of their unit tests, there appeared to be no concern at all for promoting some form of conceptual understanding ("the why" of science, Duschl, 1990). As Emily said one time in class, when the students were having difficulty differentiating between genotype and phenotype, "guys, I'm going to give you the questions that are going to be on the test. You've got to learn this stuff anyway, so you might as well know the questions." The participants' instructional focus was totally geared toward declarative knowledge. Consequently, lecture and note taking were dominant classroom activities. Even though hands-on activities and projects were conducted on a fairly regular basis, their purpose was to reinforce or validate the presented material, rather than promote scientific thinking. The activities were always secondary to the lecture. For example, Emily spent almost an entire week lecturing and reviewing her class on the structure and function of the cell. Although her students were quite adept at reciting the jobs of the chromosomes, ribosomes, and golgi bodies, they established absolutely no connection between the three organelles, let alone any understanding of the central role of proteins and their synthesis within biological systems. As a follow-up activity, Emily had the students construct three-dimensional models of plant and animal cells. Again, this fairly common activity helped to reinforce the functions of the various organelles, but it did not promote an understanding of the interrelationships between structures.

The process side of the scientific enterprise was virtually ignored by all the participants except for Gloria. Aside from a brief introduction at the beginning of the year on scientific methodology, any further discussion of how scientists really do science was of secondary importance in relationship to the coverage of the content. In both Emily's and Rhonda's classes, no evidence was collected to indicate that the process skills were revisited during the rest of the year. Gloria, however, made a valiant attempt to teach scientific methodology throughout the year. On one occasion, she talked about how difficult it was to get her students to think about the process skills (communicating, hypothesizing, observing, measuring, classifying, etc.) and how they could be used to do scientific research. “Every time I do a lab, I spend a little time talking about a process skill that they’re going to use. At first, it seemed like a waste of time, but now the kids are really thinking about the best way to communicate data, or the best way to classify objects.”

Emily, Rhonda, and Gloria entered the teaching profession with very similar instructional strategies – they relied on their prior educational experiences for instructional guidance; their transmissive mode of instruction was the result of their objectivist epistemology; their instruction focused almost exclusively on “the what” of science. They all felt that they were making good progress, and they were, considering only the coverage of material; however, they quickly realized that they were not making that all important connection with the student when they evaluated the first few series of test and quiz grades. Perplexed by low test scores, Gloria asked the students what went wrong.

> Only about 50% of the kids said they had studied for that first test. And I accepted that as the reason for why the grades were so low. But then the same thing kept happening on every test after that, and, being a new teacher, I thought that maybe it was my fault.
>
> Maybe I wasn’t doing what I should be doing to help the kids learn the material.

Extremely poor student achievement, in comparison to the amount of time the participants spent in planning and implementing lessons, along with a feeling of helplessness, was the critical incident in the development of both pedagogical sophistication and a more advanced pedagogical content knowledge. The participants expressed concerns about why the students were not performing well on their quizzes and tests. Both Emily and Rhonda agreed with Gloria’s comment about the students not spending enough time learning the material. But as Emily commented during the first semester, when she was having trouble teaching the students about combining gametes in Punnett squares:

> There was so much confusion about what letters should go across the top and down the side of the Punnett square, especially when we went to a dihybrid cross. A few of the kids got it right away, but a lot of the class wanted to put just one letter in the boxes. And in a dihybrid cross, there's supposed to be two. And then they would want to put two of the same letter in the box. It seemed like the more times we did it, the worse it got.

These types of instructional dilemmas forced Emily to alter her instructional approach in an attempt to solve this comprehension problem. Emily thought that if she could spend time with individual students and walk them through the construction of a Punnett square, then she would have more success. She divided the class into groups and assigned students that had already grasped the concept to work with each group. Then she tried to focus on helping one student at a time. When asked about how successful she was with this strategy, she said, "I think working one-on-one with the kids really helped but I can't do that all the time. It put us way behind and I thought that the class got a little loud." Again Emily was expressing her concerns about the coverage of material and classroom management, two factors that controlled her teaching and that she could not resolve during her first year. But at least during the second semester, she was willing to communicate and interact with her students more frequently, especially when she sensed a major problem with understanding.

On the other hand, Rhonda had no problem relinquishing control of the classroom environment to the students and spent more time in the second semester as a facilitator rather than a transmitter of knowledge. As she stated in an interview, "I like to move around the room and work with groups. It seems like they understand things a little better. But it's sometimes really hard to keep everybody on task."

Very early in the first semester, Gloria, as well as the other participants, began to question the effectiveness of their instructional strategies. This frustration can be summed up by a comment made by both Emily and Gloria toward the end of the first semester, "I don't know what else to do!" Their views concerning the task of teaching were changing, while at the same time their instructional approach involved more student-centered activity. This alteration involved a conceptual shift from the commonly held perception of teaching as telling to a more effective insight of teaching as promoting understanding. And this change in their perspectives on the processes of teaching and learning would ultimately lead to a more sophisticated pedagogy.

Content Complexity

The horizontal axis on the model of PCK development labeled "content complexity" specifically refers to the teacher's mastery of content as evidenced by the level and type of content interrelationships espoused through the instruction she leads. A thorough comprehension of the discipline entails an understanding of the subject's facts, concepts, and theories, as well as knowledge of the substantive structures or explanatory frameworks of the discipline. Lee Shulman established the importance of content knowledge in his seminal work on teacher knowledge structures in the 1980's.

> The person who teaches subject matter to children must demonstrate knowledge of that subject matter as a prerequisite to teaching. Although knowledge of the theories and methods of teaching is important, it plays a decidedly secondary role in the qualifications of a teacher (Shulman, 1986, p. 5).

The three primary participants would agree completely with Shulman's assessment of the value of understanding the subject matter. In the very first interview, in response to questions about her content knowledge, Rhonda said, "If I know it, I can teach it. I feel like I have the ability to explain just about anything if I understand it myself." Emily stressed the importance of depth of knowledge when she said:

> You need to know a lot more than what you just have to teach. I'm not just familiar with biology, but I actually know it. And I think just having that extra knowledge is important. It really does help me to explain it better to my students, because it's not just touching the surface, but I know it on a much deeper level.

Interestingly, with the exception of one first-year teacher in the pilot study, Marjorie, all the research participants involved in this investigation considered themselves to be content specialists. This confidence in their content knowledge stemmed from what they considered to be superior preparation in both undergraduate and graduate degree programs. According to Emily, "everything from my preparation for my bachelors to my preparation for my doctorate has prepared me for this, for at least the content part of this particular class." Furthermore, the veteran teachers from the theoretical sample expressed an even greater self-assurance in their subject matter as they gained teaching experience. In most cases, this feeling developed, to some extent, because of a number of informal education opportunities, such as readings from subject-related magazines and books, and discussions with colleagues. Keith (pseudonym), a middle-school science teacher, stated, "I would have to say that books (textbooks and trade books) have been one of my greatest sources of knowledge. But I also get a lot of great ideas from other educators, and I often rely on them to help me understand some of the more confusing scientific ideas." But, according to veteran teachers, a significant improvement in content knowledge was a product of the actual teaching experience. As one middle-school science teacher of six years explained:

> When I went into the classroom for the first time, I was really pretty comfortable with my science content. But as I taught the concepts, students would ask questions that I should

> have been able to answer, but I couldn't. And I guess I realized that I didn't understand some of this stuff the way I should. So from then on, as I prepared for my lessons, I'd try to clear up my thinking on the concept, while at the same time figure out where my students would have trouble with their understanding. This helped me to head off potential comprehension problems before they even got started.

As the three main participants, Emily, Rhonda, and Gloria, progressed through their initial year, they too began to express this unique perspective – that "relearning" (or at the very least, re-evaluating) material for the purpose of presenting it to students is qualitatively different from the personal learning process that took place during their formal educational careers. Very simply put, all participants, whether novice or veteran, were firmly convinced that their understanding of scientific concepts was greatly enhanced by the planning, preparation, and implementation of lessons dealing with these concepts. Both Gloria and Rhonda commented that some of their best lessons concerned topics that were relatively unfamiliar to them. Another member of the theoretical sample, Brandi (pseudonym) commented:

> I was a middle school major, which meant that I could be called upon to teach any subject. I was not comfortable with science, but that was the job I got. The more I taught it, the more I studied, and the more I learned from other teachers. I had to feel confident about my own understanding before I felt comfortable presenting it to my students.

All three of the study's main participants expressed a high degree of self-assurance in their knowledge of content. As Emily so confidently stated, "I'm not just familiar with it, I know it." As the school year progressed, however, they all became painfully aware of areas of deficiency. As indicated in the section on professional characterizations, Emily felt she had an excellent grasp of molecular and cell biology due to her advanced educational background, but she struggled somewhat with botany, zoology, and genetics. Her understanding of genetics was further hampered by her lack of mathematical ability. "In genetics there's math. And I am definitely not a math person." A similar situation occurred with Gloria, who, because of her background as a physical therapist, felt very strong in human and cell biology, but lacked some of the basic knowledge associated with such areas as zoology, botany, and evolutionary biology. Rhonda, who held a master's degree in applied biology, and was one of the few participants to have research experience, ranked her knowledge of biology as a ten. Like many teachers, however, she was assigned classes that dealt with branches of science with which she was not that familiar, such as physical science. Even though she gave herself a preliminary ranking of six in physical science subject matter, she was certain that by the end of the year, her content knowledge would be at least an eight. When asked about the reason for the substantial improvement, she responded, "I think I really learn a lot by planning lessons for that class. So far, I've learned a fair amount of physical science content just by preparing to teach it." Again, there appears to be a definite relationship between the teaching of content and the learning of content by the teacher. Does classroom instruction, however, actually promote greater conceptual understanding on the part of the teacher, or does it simply foster a greater degree of confidence in one's ability to teach difficult concepts? This question is of paramount importance in determining the make-up of pedagogical content knowledge. Very simply put, what's the relationship between pedagogy and content in PCK? Which part of PCK is more important – the pedagogical part or the content part? Without hesitation, Emily, Rhonda, and Gloria felt that content was the cornerstone for a well-developed PCK. Their beliefs are summed up by Gloria's response.

> I feel that without the content foundation, the pedagogical part doesn't matter. If you don't know the content, it doesn't matter how good you teach, what your teaching

> philosophy or instructional approach is, or how hard you try – I think you need to know "what" to teach first.

This opinion was not unique to the three primary participants. Without exception, every teacher in this investigation, from the pilot study to the theoretical samplings, responded in a similar manner. As Marjorie of the pilot study so succinctly stated, "What's the point in learning about teaching methods if you don't have the content?"

As the school year progressed, the only teacher to reconsider and possibly alter her original beliefs concerning content and pedagogy was Rhonda. On several occasions, Rhonda was asked to describe a lesson that she thought was particularly effective in promoting student understanding. It was anticipated that she would focus on one of the multitude of presentations she had conducted in her area of expertise, namely biology. Contrary to expectations, Rhonda described lessons that she had implemented with her physical science class. "I almost feel like I did better in some of those lessons because I guess I had to learn it myself before I could present it to the students. It was all new ground for me." After further discussion of physical science activities, the question was asked, "Is there a difference between learning content for a college class and learning new material that you know you're going to have to teach?" Somewhat frustrated by this question, Rhonda said:

> I don't think you understand. It's not "learning" learning. I really did take physics in college. But it's like trying to figure out how to bring things together and how to sequence things. The more I struggled with how to present these physical science ideas to my students, the more I began to see relationships between the facts and concepts that I didn't realize before. In college, I learned a jumble of information, and I was really good at it. But when I had to teach kids about sound waves, and light waves, and electromagnetic waves, all that unrelated information began to come together and make

> sense. And I guess I have to admit that sometimes it didn't make sense. This stuff really didn't seem that difficult in college, but when I tried to teach it to a bunch of high school students, all of a sudden, it got really complicated.

Marjorie, from the pilot study, articulated a similar viewpoint.

> Now that I'm teaching, I'm really beginning to make connections between all of this knowledge that I got in school. When I came out of college and went to work in a biotech lab, I did PCR (polymerase chain reaction) all the time, but I couldn't really tell people exactly how to do it. I'm beginning to realize that there's a big difference between knowing and explaining.

The data indicated that a relationship does exist between the act of teaching and the enrichment of content knowledge on the part of the teacher. The teachers in this study continually stressed the role of planning and implementing lessons in improving one's content knowledge. The value of formal educational experiences has already been substantiated. Even though the primary research participants considered themselves to be content specialists, they all expressed weaknesses in certain areas. So the question of the use and value of informal sources of subject matter knowledge was raised. What types of content knowledge sources had been exploited during the first year of teaching? According to the interview data, all three participants stated that they spent an inordinate amount of time in planning and preparing lessons. And this included the referencing of the classroom textbook materials as well as supplementary resource books and related information obtained through the Internet. Rhonda commented, "a lot of times if I can't find an activity I like by talking with other teachers, I'll end up searching the Internet for something." A book that played a prominent role in lesson preparation for Emily was the high school advanced placement biology book by Campbell and Reese (2002). On numerous occasions, this text helped not only to clarify concepts for Emily before actual classroom instruction, but it also served as a valuable reference for finding answers to some of those difficult student questions.

> The one book that I always go back to is Campbell's biology, which is just freshman undergrad general biology. It's like the bible of biology. And in that sense, that general book helps me more than trying to find information out of some of my really in-depth graduate school books.

Another potential informal source of subject matter knowledge was the assigned mentor teacher. Both Emily and Gloria had very rewarding mentor experiences, but the mentoring relationship always dealt with pedagogical rather than content considerations. As Emily put it, "I find that I am who they come to regarding content information. But I go to them when I'm stumped on how to present the information." In addition to the standard advice on how to teach, other science teachers, rather than the mentor, were a major source of activities, labs, and demonstrations. According to Gloria, "all of my fellow teachers have been extremely helpful by providing me with labs and activities that I can use with my classes." Rhonda mentioned that a similar situation occurred with some of her teaching colleagues. Rhonda had difficulty communicating with her mentor because their respective classrooms were located at opposite ends of the school campus. This rather discouraging situation caused Rhonda to seek out other teachers who had similar classes.

> I would ask them about the activities that they used to illustrate tough concepts, and then I'd go and try them on my classes. More times than not, I wasn't satisfied with at least parts of the activity, so I'd alter them to suit my situation and my students.

The dissatisfaction that Rhonda experienced with so many of her colleagues' activities became a more prominent feature in her instructional preparation as the year progressed. And it also started to surface in some of the later conversations with Emily and Gloria. In other words, all three participants became very critical of the labs and activities they were using. If these activities didn't demonstrate or illustrate concepts satisfactorily, then they were discarded. Consequently, as the participants moved into their second semester of teaching, their repertoire of effective hands-on activities to illustrate the content increased along with their understanding of how best to present and explain science topics.

Pedagogical Sophistication

Pedagogical sophistication relates to the actual classroom presentation of pertinent science material. It entails both highly reflective and proactive decisions on the part of the teacher as to the best method for transmitting science knowledge. Pedagogical sophistication, however, implies much more than Shulman's general pedagogical knowledge structure. Whereas Shulman equated pedagogical knowledge with general teaching methods that are not subject-specific, pedagogical sophistication ultimately focuses on those unique teacher-student interactions that result in student understanding. An investigation conducted by Gunstone, Slattery, Baird, and Northfield (1993) found that successful first-year teachers must pass through three successive stages of development. The first stage deals with the projection of self – how does the novice teacher view herself in her new profession, and how does she think others view her? As these concerns are successfully resolved, the teacher's energies shift to the problem of how to present the content of science in the most meaningful way. At this point, the input of mentors and other colleagues is of critical importance. The final stage of development signals a transition from the all-too-common mode of teacher-centered instruction to a focus on the impact instruction has on the student. In other words, the teacher realizes that the true test of teaching effectiveness is whether or not a connection has been made with the student. "You begin to go beyond yourself and the activity and focus on what students are learning" (Ebeneezer & Connor, 1998, p. 2). Even though the initial research of Gunstone, et al. (1993) stressed the importance of addressing these developmental issues during formal teacher education, the data collected during theoretical sampling supported the contention that even veteran teachers do not successfully resolve the issues associated with each phase. It is not unusual to find experienced teachers who are very concerned about how significant others (principal, colleagues, students, parents) view their instructional performance; and there are those who present content in a masterful and highly organized manner, but never take the time to facilitate a connection with the student. Also, it must be emphasized that the primary research participants did not have any prior formal teacher education, and therefore, the resolution of issues associated with self, the teaching task, and learner impact had to be accomplished while on-the-job.

The teaching task at the beginning of the year, as perceived by the study's primary participants, was quite simple – the coverage of the material as delineated in the county curriculum standards. According to Rhonda, "we have to teach the county and state objectives. If we don't do anything else, we must cover the standards." In order to meet the course objectives, all of the research participants spent a great deal of time preparing for their instructional presentations. During one of the classroom observations, Emily commented that even though she was very confident in her extensive knowledge base, there was definitely a difference in just knowing the material as opposed to presenting it to twenty-eight seventh graders. "I really know my subject, but you can't believe how many times I have trouble with some of their questions." But Emily tended to equate teaching methods with classroom management, a perception that was more closely aligned with Shulman's notion of general pedagogical knowledge. Consequently, her pedagogical sophistication remained quite low. As Emily moved into the second semester, and she began to question her instructional strategies because of a relatively low level of student achievement, she focused more on how to present the material and whether her instruction made an impact on the students. Her level of teacher-student interaction increased dramatically, and in an extremely insightful moment, she said, "I think I need to talk less and listen to my students more." For Emily, a higher level of pedagogical sophistication was achieved by interacting with her students. During an interview, she stated, "I used to think I could tell whether they were getting it or not just by the look on their faces. But now I know that's not true. You've got to ask them questions and you have to listen to what they have to say."

Rhonda indicated in her very first interview that she was also very much concerned with classroom management and felt that a superbly organized presentation would serve to establish and maintain appropriate classroom decorum. Consequently, she said that she spent an inordinate amount of time actually scripting her presentations. But she soon realized that what she thought would take only one or two class periods to cover would extend throughout the entire week. In other words, one could not script for the myriad of unforeseen interruptions and questions that are so typical of a high school classroom environment. As the semester progressed, Rhonda lost her initial fear of managing the classroom and began to focus on classroom experiences and activities that would actually enhance student understanding. "I always try to find ways to illustrate what I'm trying to tell them. Sometimes my ideas work and sometimes they don't. I need to invest some time to get my 'failed' activities to work properly, add educational value to my presentation of the activity, and revise or discard them." She stopped worrying about how the students were going to behave, which was not a problem in the first place, and started to concentrate on what the students were learning. For Rhonda, a higher level of pedagogical sophistication was achieved through labs and activities that actually illustrated and clarified the key elements of scientific concepts.

An instructional situation occurred toward the end of the second semester that typifies this move toward a sophisticated pedagogy and a well-developed PCK. It involved an activity that Rhonda used to teach human anatomy and physiology. She utilized an instructional approach which entailed small group, collaborative work. She established a scenario in which each group of students represented a department (an organ system) in a large company (the human body). Due to cutbacks, at least three of the departments were going to be eliminated. It was the group's job to make a case as to the importance of each department (system) in maintaining the overall health of the company (the body). Each group conducted extensive research to make their case and they presented their findings to the class during a board meeting. But this presentation was much more than a simple factual report. According to Rhonda, "Instead of studying one system at a time, I was trying to get them to see how all the systems worked together, and I did this by making them argue about eliminating something." Throughout the research phase of this activity, Rhonda continuously moved about the room interacting with the students. "One of my biggest problems was steering them away from just making a report. I had to keep them focused on the original task." This lesson clearly exemplified several of the qualities of pedagogical sophistication and functional PCK – relevancy, student-centered instruction, an analogy that incorporates several conceptual elements at one time, resulting in the "big picture," and significant interaction resulting in possible modification.

Very early in the interview process, the participants were asked to rank their teaching ability on a scale of one to ten, with ten being the highest rating. All three novice teachers gave themselves a ranking of seven to eight, which may appear to be somewhat inflated considering these individuals had no formal training. In comparison, the ratings of teaching ability from the theoretical sample ranged from six to ten, with an average of 8.5. The participants defended their personal evaluations by referring to several informal sources of teaching experience, such as peer tutoring during graduate school or conducting training sessions for company personnel. Emily maintained that her ability to teach started when she was a student.

> I like to learn, and I think that goes hand-in-hand with being able to teach. First you have to teach yourself. And if you're good at that, then maybe the next step is you can teach your peers. I think a lot of those kinds of experiences have helped me during my first year of teaching.

When asked what she meant about teaching herself, she responded, "Think about a lot of the professors we had in college. You pretty much were left to fend for yourself. And so you had to sit down, and work through the material, and make sense of it in your own way." Emily went on to say that how you made sense of the subject matter, and the ways you used to understand the difficult concepts, translated into strategies that you could then use to teach others.

Rhonda, who had extensive experience teaching computer software to business colleagues, voiced a very similar opinion about the ability to explain. "People are teaching in the professional world all of the time; maybe not in the same situation where they're standing up in front of twenty-eight kids, but they're always teaching other people concepts." Rhonda added that she would prefer to classify these numerous teaching incidents as "life experience" rather than "teaching experience." Regarding Emily's comment about teaching oneself, Rhonda expressed a similar opinion.

> I feel like I usually try to make things really simple, almost like for kids. And I've always tried to do that. Like when I would try to explain some really complex pricing system for steel manufacturing applications software, and I would try to think of a way that would help me remember it. Then I would share that way with other people. So I think that's all I'm trying to do. This is the way my brain works and maybe theirs works that same way too.

Gloria also believed that she was doing a very adequate job for her first year of teaching, stating that the primary reason for her success stemmed from her attitude toward her students. As far as the source of her teaching ability was concerned, Gloria said, "I don't really know how I learned to teach – I think enjoying/relating to/respecting my students was a huge help, and my motivation to work hard and do my best for my students." This concern for relating to the student, or making a connection with the student, not only relates to the third stage of the Gunstone, et al. (1993) model of successful first-year teaching, but also supports one of the major findings of the pilot study; that the effective use of pedagogical content knowledge is measured by the degree of teacher-student interaction.

An additional source of pedagogical knowledge was the college teaching methods class that all three participants were taking as part of their alternative certification program. The participants were questioned as to the contributions the class made to both their teaching skills and their pedagogical content knowledge. According to Rhonda, the greatest benefit of the methods class was the opportunity to sit down and discuss similar problems with other teachers that were in comparable situations. Although the information on classroom management and laboratory safety was very beneficial, her greatest dilemma was how to effectively present specific science concepts. After her first semester, Rhonda was asked, "Out of all the things that you've been exposed to this semester – the methods class, your teaching colleagues, your mentor, the extensive research you do when preparing for lessons, the textbook materials – what do you think has had the greatest effect on how well you're presenting this material?" Rhonda's response:

> None of the things you mentioned. Just being in here and having done it so many times. I think the more times I teach a concept, the better I get, just from period to period. I think I get a better idea of what I'm actually trying to do. I understand the concepts

> better myself. Then I come back the next week to teach them something else, and the process starts all over again.

In response to the same question, Emily said, "just talking back and forth with the other people in the class, and using each other as sounding boards. That to me is more helpful than pulling out a PowerPoint presentation to see what so-and-so did his research on." When asked whether having the methods class before she actually started teaching would have been helpful, Emily replied:

> I don't know that it would have been that different. Because I would say that what's been most invaluable to me are my science teacher peers that are on either side of me. And just from them, I've gotten so much information, in terms of how to tackle a child who just isn't getting it, or how to deal with just day-to-day stuff.

The last comment Emily made on this topic, however, was virtually identical to Rhonda's final remarks. "I find just coming out here and doing it, and getting your hands dirty, is the best way to learn how to teach." Gloria was also very concerned about the job she was doing with her students as opposed to the things that were going on in her methods class. "Some of the things we did were very useful, like setting up a substitute folder, but I really didn't get that much out of the class because I couldn't put in that much time. I wanted to do a good job in the classroom." All in all, the participants found the methods class to be useful in terms of routine teaching tasks, or what could be called general pedagogical knowledge. But as far as subject-specific teaching methods, the actual classroom proved to be the best training ground.

It must be emphasized at this point that the participants for this study were exceptional individuals who not only set high standards for their students, but also demanded a great deal from themselves. When Rhonda was asked how and why she put so much time into her teaching, she said, "I'm just a perfectionist. I want to do the best possible job I can." Based on their classroom behavior and their comments during interviews, they expected their students to achieve. As Emily said, “I can’t believe the grades are so low. We’ve gone over this stuff again and again but it doesn’t seem to make any difference.” The interview data indicated that Rhonda and Gloria had made similar comments. The participants were beginning to realize that even though the content may be presented to the students in a competent manner, the learning of that content is not automatically guaranteed. To use the terminology of Rhonda, a “connection” has to be made between the teacher and the student to ensure understanding. What this “connection” was remained somewhat of a mystery throughout the first semester, but the participants’ beliefs about teaching and learning were definitely being challenged. When they began working with their students, it was obvious that they were very committed to delivering and covering the content in a superior manner. But they were not satisfied with the results. Failing test grades, poor student attentiveness and interaction, and, strangely enough, a personal sense of boredom with the day-in, day-out presentation of content caused some major frustration. At some point, the participants became more concerned with what was happening with the student. Not just the grades, but what the student was actually thinking. Connecting with the student and focusing more on student understanding became a primary concern as the novice teachers moved into the second semester.

Teaching Commitments

A central issue of pedagogical content knowledge development deals with how first-year teachers perceive their subject matter, students, and the teaching profession. This section, which addresses two different instructional approaches, is closely tied to the teacher’s philosophical stance, degree of pedagogical sophistication, and level of content complexity. Very simply, it focuses on how the novice teacher addresses the task of teaching.

Based on the observational data, a commitment to the teaching of content was very evident in all the research participants, from the interviewees in the pilot study to the three main participants in the primary investigation. This commitment implies a broad coverage of the essential foundational information as delineated in most of the discipline's textbooks and in the teaching standards of many school districts. A teacher who commits to this teaching format would tend to present biology as a body of factual information, with a focus on vocabulary and descriptive material. The primary mode of instruction would be teacher-centered with a heavy emphasis on lecture and note taking. This instructional approach implies that the role of the teacher is to present the material and the job of the student is to learn it.

Emily, who remained committed to the content for the majority of her first year of teaching, said, "I present the material the best way I can, but I can't learn it for them. I put the information out there and they have to show me that they get it. It's as simple as that." Her beliefs concerning her role as a teacher were shaped by her basic instructional philosophy; that repetition is the key to learning. "It's not like Harry Potter, you can't just read your textbook once and absorb the information. You have to read it over and over." Because Emily successfully learned through the traditional methods of lecture and reading, she expected her students to be able to absorb the information in the same way. Consequently, she didn't feel like many of the labs and activities her colleagues were using in their classes were that beneficial. "A lot of times, I feel like hands-on activities are a waste of time. The main reason for doing them is because the students like the activities and they help bring up their grades."

One of Emily's more frustrating lessons dealt with cellular transport. Emily's approach to the teaching of diffusion and osmosis emphasized the definitions for the various types of cellular transport and the differences between the active and passive forms of movement. Although her initial presentation involved numerous examples of solvent and solute transfers based on varying concentrations, no type of lab activity was conducted to either illustrate or validate these processes. In other words, the students had an excellent grasp of the basic factual information (the vocabulary), but an understanding of the underlying concept of why and how these processes were occurring was not evident. As a result, the vast majority of students responded to application and evaluation type questions on the unit test incorrectly.

> I thought they had diffusion and osmosis down. But on the test, there's always a diagram or a picture that they have to interpret. For example, the students were asked to draw arrows to indicate the direction of water movement if a red blood cell is placed in a ten percent salt solution. And they were not able to apply their knowledge. They knew what osmosis was, and they knew it was the diffusion of water. And they understood all the different examples we've used in class, but then when I gave a new one on the test, they really kind of got thrown. They just were not able to apply their knowledge.

These situations were not unique to Emily. Every one of the participants in both the pilot study and the primary investigation experienced similar difficulties. How these problems were resolved was a major factor in determining whether the novice teacher developed a more sophisticated pedagogy with a resultant improvement in pedagogical content knowledge.

A commitment to teaching for conceptual understanding involves a significant effort on the part of the teacher to go deeper into the content; to sacrifice content coverage in favor of enhanced student understanding. During the first semester, Emily, Rhonda, and Gloria all experienced a great deal of frustration with the grades that their students were making on material that was presented in a fairly competent, teacher-centered manner. When the students were asked, both individually and collectively, what the problem was, the obvious answer, familiar to anyone who has taught, was insufficient study. Early in the first semester, this response seemed to alleviate the teachers' concerns. But, in addition to dealing with failing grades, all three participants expressed a feeling of monotony and boredom with the same day-to-day instructional tasks of lecture, worksheets, activities, and tests. And interestingly, all three novice teachers, at various times, felt that they had to relinquish more control of the classroom environment to the student. Their instruction became more student-centered. As Rhonda indicated, “I do think I need to get the kids to do more of the work. I think the students will learn more if they do more.”

A move toward student-centered instruction meant that the participants had to find and use more meaningful activities to illustrate concepts and promote greater student understanding. At the beginning of the year, the participants were more concerned with finding and using activities that would “break the monotony” that was so often associated with giving notes and doing worksheets and questions from the textbook. As Gloria mentioned at the end of a classroom observation, “we’ve been taking so many notes that I thought it would be a good idea to take a break and do this activity.” When asked about whether or not the activity would help students understand the material, she said, “I guess we’ll have to see how they do on the test.” Later on, she said that she thought all of the activities that she had done up to that point had served some benefit. This tendency to do activities just to fill up time and give students a break from the normal routine did not seem to last for long, especially with Emily and Rhonda. In an interview with Emily, she stated that, “I don’t want to do activities just to be doing something. That’s a waste of time. There’s just too much material to cover.” Rhonda also expressed a similar attitude when she related a situation in which she had been given “a really good activity” by another teacher to demonstrate acceleration. Since she was a little pressed for time, and because the activity appeared to be rather straightforward, she didn’t try out the procedure prior to class. When she attempted to conduct the lab with her students, she found that the procedures were faulty, as far as making accurate measurements, and came to the conclusion that the lab must have served as either a “fun” activity or to kill time. Rather angry with herself for wasting time in class, she hastily commented, “you know, about half of the stuff that teachers do either doesn’t work or doesn’t teach anything.” Rhonda was well aware that a good activity might be effective in illustrating a scientific concept. “I always try to illustrate what I’m trying to teach, whether it’s with a picture, a specimen, a transparency, an activity, or something.” Eventually, Rhonda’s and Emily’s primary consideration was how effective these various activities were in “making a connection” with the student. And to some extent, Gloria expressed a similar opinion, even though the observational data didn’t always support her contentions. In other words, the participants’ views concerning the teaching task were changing, with a resulting increase in their pedagogical sophistication.

Another major change in the instructional strategies of the participants concerned the amount and quality of teacher-student interactions. During the first semester, Emily observed other teachers utilizing both direct and indirect questioning techniques to promote learning in their classrooms. Because on-task behavior was one of her major concerns, she felt that using these questioning strategies would be very beneficial.

> I thought I would never be the teacher who called on students unless they volunteered. I just wouldn’t do that. I thought to myself, I hate it when teachers call on you and you’re totally off guard. But then I realized that the teachers who do this have more students paying attention. So I started calling on my students. And I saw more student interaction. I saw that they were actually trying to stay on-task.

At first, Emily’s questions focused on basic recall of factual information. True to her teaching philosophy, she would repeat the same question several times to emphasize important information, such as key vocabulary or important steps in some biological process. But as Emily’s questioning abilities became more sophisticated, she began to concentrate more on "how" and "why" questions rather than just "what." "I think I realized that I better figure out how much the kids understand before I actually give them the test. Because the grades were horrible." Even though Emily was not always successful in probing for greater understanding, the fact that her level of teacher-student interaction improved dramatically demonstrated a genuine concern for student comprehension.

In addition to promoting a student-centered learning environment and improving the quantity and quality of teacher-student interactions, the participants attempted to promote greater student understanding by making their instruction relevant and practical. According to Gloria, "whenever you bring in real world experiences, it helps them relate the material to something they're familiar with. Plus they're more interested and they pay closer attention." Rhonda's ability to link the content to practical situations was extremely well developed for a first-year teacher. For example, when studying fermentation, she made bread as part of the lesson. As an adjunct to her presentation on bacteria and viruses, the students reported on the current political climate in relation to biological and chemical weapons. When asked about the source for these ideas, Rhonda said, "it's just the way I think. When I work with my own children on school projects, I do the same thing." Again, in developing the ability to explain, the value of informal experiences cannot be ignored. Based on the comments of Emily and Gloria, the importance of making instruction relevant may also have been the result of their concurrent coursework in teaching methods and discussions with their colleagues.

The participants' notion about the overall objective of the teaching task began to change as they moved into the second semester. What was going on in the mind of the student became more important. All three participants became more concerned about "connecting with the student." As a result, Emily, Rhonda, and Gloria developed a somewhat lofty but fairly standard conception of what it means to promote understanding in their students. When asked about the meaning of conceptual understanding, Rhonda said, "it's the student's ability to see the big picture. The student may not remember the exact steps in the citric acid cycle, but he should remember why living things need energy and how they get it." Gloria expressed a very similar viewpoint. "If the students really understand, they can take a concept and actually apply it in a manner that they have not done before. They don't simply memorize the facts, but they're able to put it all together, to make sense of it, and they're able to apply it." These and other comments revealed a desire on the part of the participants to go deeper into the material, to find ways to achieve greater student comprehension. And it's this change in commitment that promoted further development in their pedagogical content knowledge.

Pedagogical Content Knowledge

Pedagogical content knowledge refers to the ability of the teacher to take her personal knowledge of the discipline (her cognitive structure) and reconstruct or transform it in such a way that it can be taught in a manner that becomes more understandable to the student. According to Shulman, PCK consists of "the most useful representations, the most powerful analogies, illustrations, examples, explanations, and demonstrations" (1986, p. 9). But PCK appears to encompass even more. During one of the interviews with Gloria, she talked about how much she enjoyed teaching and how excited she was to share some of the things she knew about biology with her students. It was fairly obvious during observations that this love and enthusiasm for her subject was somewhat contagious in the classroom. When asked about this situation, Gloria commented, "well isn't that what PCK is all about? Don't you think that if the kids are excited about learning, then they'll be more motivated? And if they're motivated, don't you think that leads to a desire to understand more?" This revelation, along with many other comments and observations during the investigative process, brought to light a basic fault or omission in many of the scholarly definitions of pedagogical content knowledge. For example, Trowbridge and Bybee (1990) define PCK as "the capacity to formulate and represent science in ways that make it comprehensible to learners" (p. 27). This definition describes PCK as very much a teacher skill or activity. But just as a beautiful, rare vase is worth a thousand dollars only if someone is willing to pay that much for it, so too is the value of PCK. The effectiveness of PCK does not lie in the actual explanation, as so many research articles imply, but rather in that critical connection that is ultimately made with the student. If the connection is not made, then that analogy, illustration, example, explanation, or demonstration is somewhat useless, at least for the current situation. In other words, PCK is not found in the analogy, but in the interaction between the student and the teacher as they struggle to understand; therefore, what happens after the initial explanation is made is more important in determining the teacher's level of PCK development. An interesting illustration of how interaction affects instruction is taken from the observational data collected in Rhonda's class. As mentioned earlier, Rhonda scripted her instruction in great detail and then relied to a great extent on her notes during her teaching. But as she moved from one period to the next, it was noted that not only did she use her notes less and less, but also the quality of her explanations was improving. As she told her students in her first period class, "you are my guinea pigs. I use you to see what works and what doesn't work." But significant changes were even noted between her last two classes in the day. When asked about this observation in a subsequent interview, she said, "if I don't think something's making sense, if the kids aren't answering my questions, I change it. I think I do explain things better at the end of the day than I do at the beginning." This scenario is not unique to anyone who has taught four or five biology classes in a row; however, it does demonstrate that Rhonda was actively involved in modifying her explanations in response to interactions with her students.

A classic example of a PCK strategy in biology is an analogy that is used during the first semester to teach cell structure and function. While teaching the functions of all the different parts of animal and plant cells, a comparison was drawn between the cell and the different tasks and activities that occur in a factory. Rhonda used a slightly different version, comparing the structures in a cell to the many businesses and utilities of a city. The teaching strategy involved in this analogy is to take a condition that the students are somewhat familiar with and compare it to an unfamiliar situation. Gloria, who not only used the "factory" analogy, but did "cell puzzles" and other activities, said that these instructional tactics had a very positive effect on student achievement. When asked about why the test grades, therefore, were so low, she cited problems with using "the big words." Rhonda was the most critical of the cell analogy, saying, "the test grades would probably be just as bad if I didn't even use it." As for Emily, who experienced limited success with the analogy, she found that the students understood what she was trying to accomplish with the comparison, but still failed to link up the organelle with the comparable factory component.

> They knew that you needed power in the factory to make things, but they just didn't make the connection with needing power in the cell. I think next year, I'm really going to hit them with the vocabulary at the very beginning before I bring up the analogy. I think you have to struggle a little bit with content before a metaphor or an analogy makes sense.

Although Emily was exhibiting a greater degree of pedagogical sophistication as she reflected on the question of instructional sequence, she still seemed more concerned with getting the information out to the students in a very transmissive style and then using her arsenal of activities to reinforce the factual information. Also, during the first semester, it became quite apparent that all three novice teachers were caught totally off guard by the failing test grades. They all thought that their presentations were more than satisfactory, and they couldn't understand why their students were having so much difficulty. Emily, Rhonda, and Gloria discussed these concerns during the interview process and concluded that they had to make more of an effort to "check for understanding" during their lessons. In other words, they needed to increase the level of teacher-student interaction in an attempt to determine the effectiveness of their explanations. And if student comprehension were lacking, they would then have the opportunity to remediate.

Once again, Emily provided an instructional situation that typified this interaction phase. During her lessons on genetics, she perceived, through continuous and repetitive questioning, that many of the students could not differentiate between the terms genotype and phenotype. Even though she had used the standard language devices for remembering the difference (genotype – types of genes; phenotype – physical appearance), the majority of the students could not grasp the concept. Although the underlying reason for this confusion was probably couched in a misunderstanding of the basic gene concept, the problem was discovered and confronted during instruction because of a significant increase in teacher-student interactions. Consequently, Emily had the opportunity to work through a series of possible solutions, resulting in improved student comprehension. The final solution involved the students constructing a table with four columns denoting the parents, offspring, the offspring phenotypes, and the offspring genotypes. Even though Emily used structural PCK in originally explaining this concept to the students, the differences did not become apparent until a more functional form of PCK was incorporated in which all the elements of the concept were unified.

The pilot study indicated that even novice teachers develop ways to present material in more understandable ways. But many times, the types of PCK devices used may be very specific depending on the nature of the information the teacher is trying to convey. For example, Gloria talked about how the lysosomes, filled with hydrolytic enzymes, "could break down proteins in the cell just like Lysol could break down bacteria on the kitchen counter." Even though this was an effective PCK device, and many students remembered the link between “lysosome” and “Lysol,” its use focused primarily on remembering the function of the organelle, a single piece of factual information. The students had no idea why something like a lysosome was present in the cell in the first place or what its role was in the overall scheme of cell function.

An interesting relationship can be developed between this relatively rudimentary form of PCK, termed structural PCK, and the SOLO taxonomy developed by John Biggs in 1982. The purpose of the SOLO taxonomy (Structure of the Observed Learning Outcomes) was to measure students’ learning outcomes by classifying their responses. “It is a hierarchical model of increasing structural complexity: increasing consistency, increasing number of organizing dimensions and increasing use of relating principles” (Chan, Tsui, & Chan, 2002, p. 513). In actuality, the model’s structure is very similar to Bloom’s taxonomy, with a marked division between lower levels of response, termed structural, and higher level, in-depth, functional levels. Students whose learning reflects structural development encode the given information and then use a recall strategy to provide an answer (Chan, Tsui, & Chan, 2002). This form of learning is virtually identical to the types of explanatory strategies utilized by the primary participants early in their development of PCK. Although fairly effective in helping students remember key pieces of information, structural PCK does little for tying together these bits of knowledge into a more comprehensive level of knowing and understanding.

The higher levels of student response depicted in the SOLO taxonomy are somewhat similar to the level of understanding the teacher would anticipate if an effective form of functional PCK were utilized. The purpose of functional PCK is to bring together all the many components of a concept or a process into a unified whole, so that the student has a chance to grasp “the big picture.” The type of student understanding elicited by functional PCK is similar to the functional component of the SOLO taxonomy, in which students are able to think about several elements at once and consequently may consider them in a broader context (Chan, Tsui, & Chan, 2002). Returning to the analogy between the cell and the factory, one can see that, on the surface, the purpose of this functional PCK strategy is to promote an understanding of the interactions that occur between the various organelles in the cell. An even greater depth of understanding can be achieved, however, when the teacher can broaden the students' understanding of biology by using the same activity to emphasize two of the major unifying principles of modern biology; namely the relationship between structure and function and the concept of levels of organization. This extension of what so many teachers consider to be simply a novel activity would signal an exceptional level of functional PCK. Granted, none of the participants demonstrated this ability at this point in their careers, but the tools for achieving functional pedagogical content knowledge were definitely present. They already possessed significant content complexity, and they were becoming more pedagogically sophisticated by adopting a student-centered instructional approach, increasing classroom interactions, altering their instructional sequence, and emphasizing relevancy and practicality. But more importantly, Emily, Rhonda, and Gloria, were committed to making that crucial connection with the student and had, without question, progressed to the third stage of the aforementioned Gunstone, et al. (1993) model. They were most concerned with the impact they had on the learner. They had gone beyond themselves and the activity and were focusing on what students were actually learning.

A Final Synthesis

As mentioned in the previous sections of this chapter, the graphical model depicting "the struggle for understanding" (Figure 2) could not adequately portray the relationships between the primary variables of content complexity, pedagogical sophistication, and PCK. Also, because the model attempted to illustrate the relationships between a large number of categories, it did not satisfy the stricture of sound theoretical models in relation to the parsimony of variables and formulation (Glaser & Strauss, 1967). By continually referencing the data, it appeared that several categories, that at first appeared to be independent, could actually be subsumed by some of the other major concepts; therefore, the categories of "initial instructional theory," "teaching commitments," and "making the connection," because of their relation to pedagogy, were integrated into the more inclusive category of pedagogical sophistication. In other words, the data had indicated that the development of PCK was rooted in the associations between the four primary variables as illustrated by the cube model (Figure 3).

Conclusion

The three main participants for this investigation, Emily, Rhonda, and Gloria, represent a growing population of novice teachers who are entering the profession after pursuing a career in some other field of endeavor. Because most of them have advanced degrees in their areas of specialty, they come into the teaching business with a substantial amount of content knowledge. But they obviously have no classroom experience and little, if any, understanding of pedagogy. These provisionally certified teachers are then thrust into the classroom with very little knowledge of what to expect. Consequently, they rely on their personal perspectives of their formal educational experiences as they plan, prepare, and implement lessons. Their initial instructional theory is based on an objectivist epistemology and a transmissive mode of teaching. In other words, they view science as a body of factual information and focus exclusively on the acquisition of vocabulary and the memorization of the steps and stages of significant processes. Also, they are very much committed to "covering the content" as stipulated in the curriculum objectives.

The participants in this investigation viewed their job as presenting the material, and the student's task as absorbing it. Many forms of pedagogical content knowledge were evident in their daily lessons, but they usually took the form of structural PCK – devices that aid in the memorization of factual information and procedural stages, but do little to promote a greater degree of conceptual understanding. If a form of functional PCK happened to be used, many times the intended relationships or comparisons were misconstrued, resulting in further confusion and frustration.

After about the first eight weeks of school, Emily, Rhonda, and Gloria expressed considerable dissatisfaction with the progress of their students. Although this is not always evident in novice teachers, or even some veteran teachers for that matter, they became very much concerned with "making a connection with their students." At first, this connection was primarily concerned with learning vocabulary and the steps of various biological processes, like mitosis and meiosis. But as the semester progressed, all three sensed, to a greater or lesser extent, that memorization was not enough. If the student does not have some understanding of the rationale behind biological processes and the relationships between these processes, then he/she will never exhibit true learning. In other words, it became obvious to all of them that knowing the definitions of diffusion and osmosis did not guarantee an understanding of the processes of diffusion and osmosis. This change in their views of teaching signaled the beginning of pedagogical content knowledge development at a different level. They became more concerned with formulating and representing biological concepts in ways that would ensure greater student comprehension.

As the participants began to question the effectiveness of their teaching strategies, they searched for better ways to illustrate concepts and to sequence their instructional activities, primarily by observing and communicating with colleagues. Eventually, all three participants became somewhat critical of instructional ideas from other teachers. Both Rhonda and Gloria expressed concerns about using activities as a change-of-pace for their students, or to break the monotony of the classroom. They were much more concerned with what the activity could teach or illustrate. Gloria was the most outspoken on this point.

> When I got activities from other teachers at the beginning of the year, I was looking for something to break the monotony. I was looking for something to do. But then I asked myself why I'm doing some of these activities if they don't work, if they don't help the kids to understand some concept better.

As they struggled to make instruction relevant and practical, their pedagogical content knowledge became more functional in nature. The emphasis shifted somewhat from PCK for remembering to PCK for understanding. As Rhonda stated in her last interview, "I used to lecture, do an activity, then test. I became so bored with that sequence, and if I was that bored, I knew the kids must be climbing the walls. So I looked for different ways to present the material."

The three novice teachers addressed the student comprehension problem in various ways. In some cases, they changed the sequence of their instruction, opting to illustrate the workings of biologically processes through labs or demonstrations in order to achieve some measure of student understanding before the salient vocabulary terms were introduced. They increased their level of teacher-student interaction through more frequent questioning to not only check for understanding but also to determine how they were connecting with the student. During instruction, they reviewed more often, not simply for the purpose of repeating the lesson's important points, but to ensure comprehension. They drastically changed the way they perceived the task of teaching by changing their focus from the content to the student. As referenced earlier in the section on pedagogical sophistication, Emily, Rhonda, and Gloria were moving into the third stage of the Gunstone, et al. (1993) model of successful first-year teaching. This changing view on the task of teaching, however, did not simply happen overnight. It was accompanied by a fundamental change in their teaching philosophy along with an increase in their pedagogical sophistication. The participants already possessed a rather complex content knowledge, which tended to foster the use of structural PCK but inhibited the development of functional PCK. Conversely, once a commitment was made to conceptual understanding, with the accompanying pedagogical sophistication, the use of functional PCK accelerated.

The three primary participants illustrated varying levels of growth throughout their first year of teaching (Figure 4). Emily, who had the highest level of content knowledge, also exhibited the greatest use of structural PCK. But, even though she was struggling with the concept of "connecting with the student," her pedagogical sophistication had not developed to the point where she routinely used functional PCK. At the opposite extreme, Rhonda demonstrated a high level of both pedagogical sophistication and content complexity. She had been successful in fostering a greater degree of teacher-student interactions and she was very much committed to teaching for conceptual understanding. Because her content knowledge was quite high, she utilized a number of structural PCK devices in her presentations. But also, since she had achieved greater pedagogical sophistication, her ability to implement instances of functional PCK was also much better than the other two participants. Of the three main participants, Gloria probably "connected" with the individual student better than anyone. She seemed to be genuinely concerned with what her students were thinking and learning. But because of her weaknesses in content, her structural PCK was relatively low, and even though her pedagogical sophistication was improving, her functional PCK development was also limited.

It should also be noted that during the various aspects of teaching, depending on the concept being presented, the participants' degree of development in some of the major categories, like "teaching commitments," would appear to fluctuate. For example, all three participants seemed to return to a "commitment to teaching content" approach when they assessed their students at the end of instructional units. Upon examining their types of test questions, Emily, Rhonda, and Gloria continued to use very low-level, basic recall types of questions, even when their instructional approach focused on conceptual understanding. This situation is illustrative of the many components of functional PCK that must be addressed before a truly high level of development is possible.

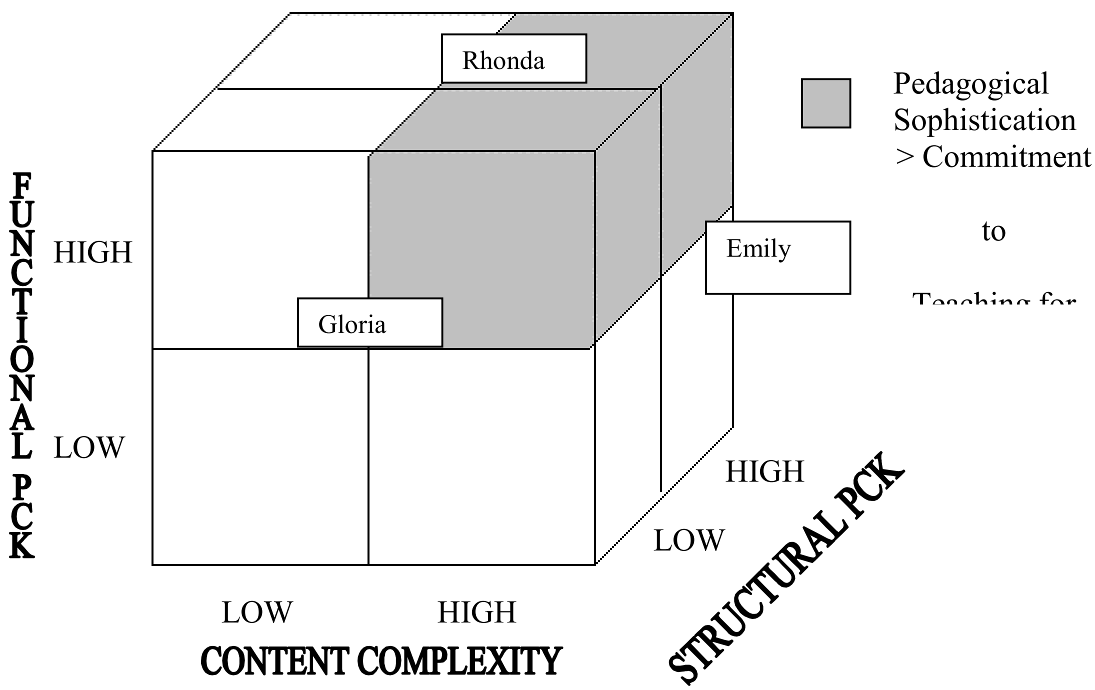

Figure 4. The participants' development at the end of the first year.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

Introduction

The final chapter of this dissertation will begin with a brief summary of the study, with comments concerning the initial pilot study, followed by an explanation of the primary investigation involving Emily, Rhonda, and Gloria. A section on conclusions will then follow in which several inferences based on the results will be discussed. This section is followed by a brief discussion of the research questions. Since this was a qualitative study, the generalizability of the conclusions was not a primary concern in the investigation; however, the substantive model of pedagogical content knowledge development may in fact have a broad application in the training of teaching professionals. This idea is further expanded in "Implications," in which the potential impact of this study's findings on the field of science education is explained, with special emphasis on the role of content classes and teaching methods courses in teacher education programs. Finally, the recommendations for further research will be addressed by examining possible future applications of this investigation's findings.

Summary of the Structure of the Study

The purpose of this investigation was to develop a substantive theory on the development of pedagogical content knowledge in teachers pursuing alternative certification. The central question for this study was concerned with how provisionally certified teachers, with adequate content but little or no pedagogical training or experience, developed pedagogical content knowledge. A pilot study was conducted with three novice, provisionally certified teachers to determine the types of PCK devices they utilized in their first year of teaching. The data from classroom observations, coupled with informal, semi-structured interviews, resulted in a listing of various types of PCK instructional strategies and tactics. Also, interviews with a small theoretical sample of experienced teachers were conducted to expand upon previously identified categories.

At the beginning of the following academic year, three new teachers, who were provisionally certified and enrolled in an alternative certification program, were recruited from a pool of twenty-nine candidates. After numerous classroom observations, interviews, phone calls, and emails, the collected data was analyzed using a sophisticated coding protocol devised by Barney Glaser and Anselm Strauss. This methodology, referred to as grounded theory, was employed for the purpose of creating a substantive theory, grounded in the data, to explain the phenomenon in question; in this case, pedagogical content knowledge development. A visual representation of the theory, or model, was then constructed to depict the relationships among the concepts. In addition to how PCK developed in these participants, the sources of this knowledge were also explored. Once again, a small theoretical sample of more experienced teachers was employed to add dimension to the emerging concepts.

Conclusions

The pilot study was instrumental in providing numerous categories and examples of pedagogical content knowledge. The three participants, Brenda, George, and Marjorie, were all very much committed to delivering the content in a comprehensive and effective manner, and although they were very enthusiastic about their new profession, their pedagogical sophistication was quite low. The only exception to this was Brenda, who not only possessed a graduate degree in physics, but also, as discovered in a subsequent interview, had taught introductory college physics for several years as a graduate assistant. Because of this experience with students who were very close in age and academic potential to the students she was now teaching, Brenda displayed a remarkable degree of pedagogical sophistication. It is also possible that this more advanced development was due to the fact that physics concepts, because of their inherent problem-solving nature, may better lend themselves to teaching opportunities that foster pedagogical sophistication and promote PCK. During the discussion of a physics problem, it is not unusual for the teacher to have to formulate alternative explanations. Those teachers who are the most proficient at accomplishing this difficult task rely on their ability to interact with the student, which is a crucial factor leading to pedagogical sophistication. For example, when faced with the problem of teaching students that the horizontal component of force is completely independent of the vertical component in projectile motion, Brenda devised a metaphor, on the spur of the moment, in which a comparison was drawn between the force components and a couple involved in a rather nasty divorce proceeding. The two components, just like the husband and wife, were divorced from each other and therefore had nothing to do with each other. Brenda's ability to interact with her students allowed her to react to their comprehension problems with an effective PCK device. Even though this association had very little explanatory power, it did help to clarify the concept and to fix it in the minds of the students. With her primary goal being the solving of problems related to projectile motion, Brenda also focused on understanding the mathematical procedures that would lead to a correct answer, and the reasons for following those procedures. This problem-solving approach forced her to reflect upon her instructional effectiveness and to frequently modify her teaching. Therefore, how the individual teacher perceives the nature of the discipline can actually affect the degree of pedagogical sophistication and the development of PCK.

The pilot study also consisted of a small theoretical sample of experienced teachers. Again, the purpose of theoretical sampling is to add properties and dimensions to those categories identified during the open coding phase of the initial interview data. Through theoretical sampling, the importance of teacher-student interactions in promoting student understanding was established. It became apparent that even a well-organized and enthusiastic instructional presentation might not promote understanding if a connection with the student has not been established. And the only way to check for this level of understanding, according to one of the teachers in the theoretical sample, was to take the time to interact with the student. This finding from the pilot study was a crucial piece of information in interpreting subsequent instructional events of the primary participants and ultimately in formulating the model of PCK development.

The data from the primary investigation clearly indicate that pedagogical content knowledge development in first-year teachers is strongly dependent on the individual's philosophical orientation and their potential for pedagogical sophistication. The type of individual currently entering the teaching profession with a provisional certificate usually possesses an advanced degree and has considerable work experience, sometimes even research experience. Consequently, these novice teachers are very committed to presenting the content. They are content specialists with a strong affinity for their subject matter, and subsequently, they want to deliver this wealth of information to their students in a superior manner. They therefore employ a very teacher-centered, transmissive form of instruction, which is not surprising since that is the mode of content delivery they thrived on as they sought their advanced degrees. Their classroom presentations are extremely well organized, resulting in an extensive coverage of information. During one particular visit to Emily's life science class, she started out with a lecture on cell structure and function, and almost ninety minutes later (block scheduling), she was still going strong on protein synthesis. Surprisingly, the majority of the class was still attempting to stay up with her. Without exception, before they gave their first major test, these novice teachers were quite confident that their students would excel. When the grades were posted, however, this was obviously not the case. Every teacher interviewed for this study was appalled at how poorly his or her students achieved. The reason for this lack of achievement, according to the students, was insufficient study. And this excuse seemed to satisfy both the teacher and the students for a short period of time. After several more episodes of poor grades, however, the participating teachers sensed that the problem might actually be with the instructional approach. How and when this revelation specifically came about is somewhat difficult to pinpoint, but a definite shift from a teacher-centered approach to more student-centered activities was occurring over the course of the semester. There was also a greater incidence of teacher-student interaction, especially during labs and group activities, as the teacher directed questions to specific students in an attempt to check for understanding. Once this cycle of interaction began, the participants began to question their own instructional effectiveness, and this naturally led to thinking about ways to make concepts more understandable.

When the participants started the school year, they were very much locked into using structural forms of pedagogical content knowledge. This type of PCK took the form of simple tactics that could be used to remember precise bits of information. For example, during a class lecture on protein synthesis, Emily helped the students remember one of the start codes, AUG, by relating it to the start of school, which happens in August. Even though this PCK device certainly helped to clarify a small portion of the process, it probably did not contribute very much to the overall understanding of protein synthesis. As the year progressed, however, the participants felt the need to interact with the students to a greater degree. The initial reason for this interaction, according to Emily, was for the purpose of classroom management. She had noticed that teachers who questioned their students and promoted more student interaction maintained better classroom control. Eventually she realized that this strategy could also be used to evaluate the effectiveness of her instruction. Once Emily realized that, in many cases, she was not making that critical connection with the student, she began to rethink her classroom presentations. Rhonda arrived at this same conclusion somewhat earlier than Emily and was instrumental in helping to identify some of the key subcategories associated with functional PCK, such as sequencing, relevancy, and students' prior knowledge. But without question, the foundation of a well-developed functional PCK is based in the exchanges that occur between the teacher and the student as they both struggle toward conceptual understanding. It is precisely this type of intellectual conflict that eventually leads to a form of pedagogical content knowledge that attempts to integrate several aspects of a process into a coherent structure; what has been termed functional PCK.

Research Questions

1. How do provisionally certified first-year teachers, with ample content knowledge but minimal pedagogical training, develop pedagogical content knowledge?

Provisionally certified teachers enter the teaching profession with a well-developed knowledge of their subject matter and a strong commitment to the teaching of content. Because they lack any pedagogical training, they exhibit an objectivist epistemology and utilize a transmissive, teacher-centered form of instruction. In their content explanations, they utilize PCK devices and strategies (structural PCK) that clarify and enhance the recall of specific facts and details but do little for promoting conceptual understanding in their students. Unless a critical incident occurs to alter this instructional approach, these teachers will more than likely continue to instruct in this manner. The critical incident that occurred with the research participants in this study was a dissatisfaction with the level of student achievement coupled with a desire to promote greater teacher-student interaction to check for understanding. This increase in pedagogical sophistication resulted in a more student-centered instructional approach as the participants attempted to use types of activities that would not only better illustrate concepts but also enhance student comprehension. Their explanations became more relevant and focused on the relationships of several components of a science concept or process (functional PCK) rather than individual facts.

2. What are the sources of this knowledge?

The research participants believed they already had well-developed powers of explanation because of their level of formal education and their informal experiences associated with their previous jobs and families. Many of their structural PCK devices were attributed to personal formulations. When they felt a need to enhance their content knowledge, they relied on the course textbook, trade books and information from the Internet. There was no evidence whatsoever that they discussed content with other teachers. The participants relied on their mentor and colleagues to provide illustrative activities, labs, and demonstrations; however, they modified these activities to accurately reflect their instructional objectives and to better adapt them to their students. Although only one participant commented on the value of the pedagogical training that they were receiving during the first semester, it is speculated that the coursework must have had an effect, either overtly or covertly, on their understanding of pedagogy, because the increase in teaching sophistication was just too dramatic in some of the cases. According to the participants, the day-in-day-out act of teaching and the experiences associated with dealing with their students was the primary impetus for developing a more advanced pedagogical content knowledge.

Implications

Surprisingly, there is a paucity of research on how novice teachers develop pedagogical content knowledge. Of course, this lack of interest in PCK may once again serve to illustrate the current trend in teaching research toward the pedagogical component and away from the content component. Although several investigations have attempted to pinpoint the unique aspects of PCK, very few have attempted to attack the question of how and why this knowledge structure develops in the first place. Perhaps the research community has concluded that the development of explanatory power is simply a by-product of experience, as the research of Bell, et al. (1998) concluded by postulating a specific-topic PCK, which develops as a result of teaching the same concept over and over again. Although several research studies have attempted to delineate the components of PCK, the work of Shulman and his concept of pedagogical reasoning remains the key theoretical explanation of how PCK develops. This process, however, is extremely complex and is based on very sophisticated forms of pedagogical behavior that must already be present in order for pedagogical reasoning to be effective. For example, under the transformational subcategory of "selection," the teacher is expected to choose "from among an instructional repertoire which includes modes of teaching, organizing, managing, and arranging" (Shulman, 1987, p. 15), while under the component labeled "evaluation," Shulman expects the teacher to be able to "check for student understanding during interactive instruction" (Shulman, 1987, p. 15). In other words, these are very advanced teaching skills, which a group of provisionally certified teachers are probably not going to possess. Subsequently, in understanding PCK development for these types of teachers, a theoretical formulation, which addresses the problem of how teachers explain difficult concepts with no pedagogical training whatsoever, was needed. This was not only the goal of this investigation but also its chief contribution to teaching research – to plot the very origins of PCK development and to determine the factors that contribute to this form of teacher knowledge.

A major component of this investigation was the role of the teacher's content knowledge in the development of her pedagogical content knowledge. According to Shulman, mastery of the content occupied a paramount position in relation to pedagogy. The results of this study, however, indicated that a well-developed content knowledge might actually hinder the teacher in achieving greater pedagogical sophistication, and consequently a more advanced PCK. The problem centers on the teacher's instructional theory, or, to put it in simpler terms, how she views the task of teaching. As stated earlier, almost all of the provisionally certified teachers in this study possessed advanced degrees and had significant work experience. They felt that they were very much content specialists and, since they lacked any basic pedagogical training, their obligation was to present their subject in a manner very similar to how they had been taught in college and graduate school. By adopting this transmissive strategy, these teachers found themselves in a situation where they presented the material and the students were expected to absorb it. Only when they realized the futility of this scenario did they reevaluate their instructional strategies. Once they became aware of the importance of making a connection with the student, they began to move away from a commitment to just teaching the content to a commitment to teaching for conceptual understanding. They achieved greater pedagogical sophistication and subsequently moved from purely structural forms of PCK to functional forms. Therefore, stating that all other aspects of the teaching enterprise are secondary to the mastery of content fails to acknowledge the complexity of the problem. Content is certainly important, but if the teacher fails to "connect with the student," no amount of content knowledge will remedy that situation.

The dilemma associated with content knowledge versus pedagogical knowledge naturally leads to the question of how the findings of this investigation impact teacher preparation. Every teacher in this study expressed the desire to find better, more effective ways to present the material. They were not satisfied with some activity that seemed to break the monotony of the classroom, or simply provided the students with an opportunity to improve their grade. They wanted meaningful instructional strategies that would ultimately lead to greater student comprehension. Admittedly, their best sources for these types of activities were other teachers. As far as their teaching methods course was concerned, the participants commented that the most meaningful part of the class was the interaction it provided with other teachers who were experiencing similar difficulties. If collegial support and varied presentation strategies are, time and again, considered to be two of the most critical requirements during the first year of teaching, then these two important aspects should be a prominent part of preservice and inservice training. It was also noted in the discussion on pedagogical content knowledge development that the actual act of teaching could improve the level of content complexity. Planning, preparing, and implementing lessons can potentially expand the knowledge base of the teacher. This finding implies that methods class instruction in unique presentation strategies, such as inquiry teaching or conceptual change teaching, should focus on the use of these techniques with specific science concepts. In other words, modeling these strategies in an actual teaching format is far superior to just discussing the associated research. If, for example, inquiry learning is a worthwhile instructional approach, then the methods class should learn about it by using it. In response to the need for authentic classroom experience, many teaching methods classes have become site-based, thereby allowing the students to practice new instructional strategies in an actual classroom environment. Also, by linking these various teaching methods to specific science concepts that everyone must cover, teachers will be provided with more meaningful and effective presentations, resulting in a higher level of pedagogical sophistication and functional PCK.

It must be emphasized that a critical evaluation of teaching methods classes was not the intention of this research. Questions concerning the participants' methods coursework were solely designed to determine the role that this type of instruction played in PCK formulations. In accordance with the conclusions of this study, any experience, including traditional pedagogical training, that fosters a greater degree of pedagogical sophistication will invariably have a positive impact on PCK development.

Recommendations for Further Research

The most interesting question for further investigation would focus on how the proposed model of pedagogical content knowledge development relates to first-year teachers who have obtained certification through more traditional routes. The model was constructed using a relatively small sample of novice teachers who were seeking certification through alternative programs. And, as any practitioner of qualitative research knows, generalizability is considered to be somewhat of a weakness in these types of investigations; however, the process of theoretical sampling, an important technique in grounded theory research, does improve the model's explanatory power by expanding upon the properties and conditions of the previously identified categories. For example, Rhonda discussed how preparing and implementing lessons for her physical science class actually improved her content knowledge. During the open coding process, this concept was labeled "learning by teaching". This same category resurfaced during theoretical sampling when several veteran teachers expressed the notion that the act of teaching actually led to a greater degree of content complexity. What started out as an interesting comment by a novice teacher took on greater meaning and significance when veteran teachers in the theoretical sample identified the same concept as an important and useful informal source of content knowledge. Because these unique data collection techniques tend to enhance the explanatory power of the generated theory, the model of PCK development may be applicable to preservice teachers following more traditional forms of certification. For example, it would be of great benefit to schools of education if they could determine whether or not their graduates face the same instructional dilemmas as the research participants, and whether they pass through comparable developmental stages. If they do in fact follow a similar pathway, then how could teaching methods classes and other related coursework be modified to promote a greater degree of pedagogical sophistication and enhanced PCK? As stated earlier in the implications section, beginning teachers are extremely interested in finding new and effective ways for presenting science concepts. But the data indicate that, in order for these instructional strategies to be really beneficial, they must be content-specific. Additional research in this area would help teacher educators determine the precise mix of content and pedagogy, and how best to present effective teaching methodologies to both preservice and inservice teachers.

All three of the primary participants in this study became more pedagogically sophisticated throughout the course of their first year, and demonstrated the potential for developing a greater degree of functional PCK. It is obvious, however, that a large percentage of teachers do not exhibit a similar degree of progress. Why were the novice teachers in this study so successful during their first year of teaching? What aspects of their academic backgrounds, their prior work experiences, and their personalities and attitudes, allowed them to so successfully reflect on and then modify their instructional approaches? Continued research along this line might help in understanding why so many teachers seem to falter and stagnate at certain points on the model of PCK development and why we find ten year veterans who are still teaching science as a body of factual information with little or no concern for facilitating conceptual understanding. Answers to these and other questions concerning PCK development in veteran teachers could be used to improve the many graduate programs currently available to teachers. So many teachers have lost that enthusiasm for "connecting with the student" and simply view an advanced degree as a means of obtaining a pay increase. A revitalized graduate program, grounded in research on promoting student understanding, could provide teachers with the opportunity to improve their pedagogical sophistication and ultimately their pedagogical content knowledge.

A Final Comment

The teaching profession has undergone countless changes in the last ten years, and it will continue to do so. As so many county administrators and principals like to say, “if we’re not trying to get better, then we’re getting worse.” And in most cases, the individual teacher is the one who suffers rather than benefits from the effects of change in the form of increased workloads and extended days. In virtually every interview, participants expressed frustration with the coverage of material as dictated by the standards. And although standards-based education certainly has its positive side, many of the participants felt that the amount of material to be covered prevented them from going into depth, thereby promoting greater student understanding. Of course, one of the advantages of reform is that it discourages complacency and prevents teachers from getting too comfortable with the day-to-day routine of teaching. But no matter what direction the teaching profession may go, nothing can replace that special feeling the teacher gets when a struggling student finally says, “oh yes, I understand it now.” Without question, to facilitate student comprehension is the ultimate goal of the teaching profession. The obligation of educational research is to provide the knowledge and the means for ensuring that all teachers are fully capable of achieving this goal.

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APPENDICES

Appendix A

Request for Site Access

2375 Briarwood Trail
Cumming, GA 30041
December 8, 2003

To whom it may concern,

I would like to request authorization to recruit one or two of your science teachers to participate in a research project that I am conducting as a graduate student at the University of Georgia. The purpose of the study is to determine how pedagogical content knowledge develops in novice teachers possessing adequate levels of subject matter knowledge but little or no formal teaching preparation or classroom experience. The primary research participants will be teachers who are seeking alternative means of certification, such as the PACCS program (Program for Alternative Certification in Secondary Science) at UGA. An important contribution of this research would be to determine how novice teachers promote student understanding, even though they may not possess a full array of pedagogical skills.

The principle form of data collection will involve an interview and observation format that deals only with the teacher participant. Neither students, nor any student work will be used to generate data.

I have had the opportunity to visit your school during the fall semester as a supervisor for one of your teachers who is seeking alternative certification. I would like to continue working with this individual as both a mentor and educational researcher.

Please feel free to notify me of any questions you may have concerning my research. My home phone number is 770-887-1659. I look forward to hearing from you.

Sincerely,

Paul F. Baldwin

Appendix B

Consent Form

I agree to take part in a research study titled, “The Acquisition of Pedagogical Content Knowledge by Provisionally Certified Science Teachers”, which is being conducted by Paul F. Baldwin, Department of Science Education at the University of Georgia (770-887-1659) under the direction of Dr. J. Steve Oliver, Department of Science Education, UGA (706-542-1763). I do not have to take part in this study; I can stop taking part at any time without giving any reason, and without penalty. I can ask to have information related to me returned to me, removed from the research records, or destroyed.

The purpose of this study is to determine how pedagogical content knowledge develops in novice teachers possessing adequate levels of subject matter knowledge but little or no formal teaching preparation or classroom experience. An important contribution of this research would be to determine how novice teachers promote student understanding, even though they may not possess a full array of pedagogical skills.

The benefits that I as a participant may expect from this research are an enhanced understanding of the relationship between content knowledge and pedagogical knowledge. Ultimately, any research dialogue that clarifies how a teacher’s knowledge and abilities impact learning has significant potential to improve instruction.

The research procedure includes both observations and interviews. Classroom observations will involve the researcher, in a non-participatory manner, collecting data by means of audiotaping and field notes. The informal, one-hour interviews will be conducted in a private setting at a convenient time. The format of the interview will be relaxed, spontaneous, and open-ended allowing for greater in-depth discussion. To insure valid analysis, the researcher’s interpretations of the interview data will be taken back to the participant to check for agreement. No set number of interviews or member checks will be established as data analysis proceeds. The discovery of emergent themes and categories, coupled with the need for participant validation, will determine the number of data collection episodes. It is estimated that no more than three hours will be required of each participant.

No discomforts or distresses are foreseen.

Any information the researcher obtains about my participation in this study, including my identity, will be held confidential. My identity will be coded, and all data will be kept in a secured, limited-access location. My identity will not be revealed in any publication of the results of this research; however, research records can be obtained by court order.

The researcher will answer any further questions about the research, now or during the course of the project, and can be reached by phone at 770-887-1659.

Please sign both copies of this form. Keep one and return the other to the investigator.

I understand the procedures described above. My questions have been answered to my satisfaction and I agree to participate in this study. I have been given a copy of this form.

Signature of Researcher/Date

Signature of Participant/Date

For questions or problems about your rights please call or write: Chris A. Joseph, Ph.D., Human Subject Office, University of Georgia, 606A Boyd Graduate Studies Research Center, Athens, Georgia 30602-7411; Telephone (706) 542-6514; email address: irb@uga.edu

Appendix C

Survey for Theoretical Sample

1. On a scale of 1-10, with 10 being the highest level, how would you rank your knowledge of your subject area?

Why did you give yourself this particular ranking?

How did you learn about your subject area?

2. On a scale of 1-10, with 10 being the highest level, how would you rank your teaching ability?

Why did you give yourself this particular ranking?

How did you learn to teach?

3. How would you explain what pedagogical content knowledge is to a colleague?

On a scale of 1-10, with 10 being the highest level, how would you rank your pedagogical content knowledge?

Why did you give yourself this particular ranking?

4. Has your ability to explain difficult science concepts changed since you started this year?

If so, how has it changed?

Why has it changed?

5. Give an example of a specific science concept that is easy for you to present to your students?

Why is the teaching of this concept so easy for you?

How have you attempted to make this concept more understandable? What types of activities or "things" do you use to teach this concept? What types of analogies, metaphors, examples, acronyms, stories, etc. do you incorporate into your explanation of the concept?

6. Identify a specific science concept that has caused problems with student comprehension. How did you know there was a lack of understanding?

How did you change your presentation to clarify the concept?

What happened when you retaught the concept?

How would you do this differently in the future?

Appendix D

Semistructured Interview Guide

I. The nature of pedagogical content knowledge:

A. How would you describe your level of content knowledge? How well do you know your subject?
B. How have you attempted to make content more comprehensible during your initial teaching experience?
C. How effective do you think you are as a teacher? Why do you consider yourself to be an effective teacher? What examples can you think of that would illustrate this effectiveness?
D. How would you characterize the teacher who can explain things well?

II. The sources of pedagogical content knowledge:

A. What are the sources of your content knowledge?
B. How well do you think you explain difficult content to your students?
C. Give me an example of a science concept that is easy for you to present to your students. What types of activities do you use to teach this concept? What types of analogies, examples, or metaphors do you incorporate into your explanation of the concept?

III. The interaction between content knowledge, teaching experience, and general pedagogical knowledge:

A. Describe the challenges you have encountered in teaching difficult concepts.
B. What sources of knowledge are most beneficial for your particular teaching responsibilities?
C. What different teaching strategies do you use with your classes? Where did you learn about these techniques?
D. What aspects of teaching influence the way you plan and teach a concept?

IV. The development and modification of pedagogical content knowledge:

A. Tell me about a specific science concept that has caused problems with student comprehension. How did you know there was a lack of understanding? How did you change your presentation to clarify the concept? What actions on your part were involved in this change? What happened when you retaught the concept?
B. To what degree does making a concept more comprehensible involve student feedback?
C. What role does reflection play in the planning and teaching of science concepts?