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Eurasia Journal of Mathematics, Science and Technology Education

Volume 2, Number 1, February 2006

PRESERVICE AND EXPERIENCED BIOLOGY TEACHERS' GLOBAL AND SPECIFIC SUBJECT MATTER STRUCTURES: IMPLICATIONS FOR CONCEPTIONS OF PEDAGOGICAL CONTENT KNOWLEDGE

Fouad Abd-El-Khalick

Received: 08.01.2006, Accepted: 29.01.2006

ABSTRACT. This study aimed to describe preservice and experienced secondary biology teachers' global and specific subject matter structures (SMSs) and elucidate the relationship between these structures and teaching experience. Teachers' global and specific SMSs respectively designate their conceptions and/or organization of their disciplines and of specific topics within those disciplines. Two preservice and two experienced secondary biology teachers were chosen to participate in the study. Participants were administered two open-ended questionnaires and were individually interviewed to assess their conceptions of biology and photosynthesis. The data were qualitatively analyzed through several rounds of category generation, confirmation, and modification. Teachers' global SMSs fell on a continuum from poorly articulated to well integrated and thematically organized. Contrary to global SMSs, specific SMSs separated the participants into their preservice and experienced groups. Unlike their preservice counterparts, the experienced teachers did not emphasize the details of photosynthesis and viewed the process as part of larger biological processes and systems. Analyses indicated that teaching experience and attention to student needs explained these latter differences. The present results indicate that the role of teaching experience in developing teachers' pedagogical content knowledge (PCK) should be emphasized and incorporated into theorizing the construct of PCK.

KEYWORDS. Pedagogical Content Knowledge, Subject Matter Structures, Science Education, Teacher Education.

INTRODUCTION

Current efforts to reform teacher preparation programs continue to emphasize the centrality of teachers' knowledge of subject matter (e.g., National Commission on Mathematics and Science Teaching for the 21st Century, 2000; National Research Council, 2000). Renewed emphasis on teachers' subject matter knowledge had gained momentum in the 1980s through efforts that aimed to professionalize teacher education (e.g., Carnegie Forum, 1986; Holmes Group, 1986). During the latter period and on a conceptual level, Shulman (1986, 1987) attempted to accentuate the focus on the role of subject matter knowledge in teaching by

ISSN: 1305-8223

advancing several categories of what he considered to be the knowledge base needed for teaching. Among these categories was pedagogical content knowledge (PCK), which he believed identify "the distinctive bodies of knowledge for teaching" (Shulman, 1987, p. 8). Shulman (1987) also presented a model of teaching centered about the process of pedagogical reasoning, which he believed guides teacher decisions and behaviors both prior to instruction and inside the classroom.

Since the introduction of this construct, many researchers have studied the PCK of teachers, including science teachers (e.g., Clermont, Borko, & Krajcik, 1994; de Jong, van Driel, & Verloop, 2005; Geddis, Onslow, Beynon, & Oesch, 1993; Hashweh, 1987; Smith & Neale, 1989; van Driel, de Jong, & Verloop, 2002). Researchers have focused on various aspects of Shulman's PCK and/or model of teaching. Several of these research efforts, however, were based on some assumptions, such as that PCK is a separate domain of knowledge and that teachers' knowledge of subject matter directly translates into their teaching practices. These assumptions have been challenged by empirical research (e.g., Gess-Newsome, 1999; Gess-Newsome & Lederman, 1993, 1995; Lederman, Gess-Newsome, & Latz, 1994). Recently, more work has been directed toward re-conceptualizing the originally vague construct of PCK (e.g., Bromme, 1995; Gess-Newsome, 1999; Mulhall, Berry, & Loughran, 2003; van Driel, Verloop, & de Vos, 1998) and empirical research has, to some extent, taken these assumptions into consideration albeit indirectly (e.g., de Jong et al., 2005). Still, such assumptions linger on and before proceeding to discuss them, a brief description of Shulman's knowledge base, PCK, and teaching model is presented.

The Knowledge Base for Teaching

Shulman and his colleagues (e.g., Grossman, Wilson, & Shulman, 1989; Shulman, 1986, 1987; Wilson, Shulman, & Richert, 1987) enumerated several categories of the professional knowledge base needed for teaching. Their categories included content knowledge; general pedagogical knowledge; curricular knowledge; knowledge of learners (their characteristics, cognition, motivation, and development); knowledge of educational contexts; knowledge of educational aims, goals, and purposes; and PCK.

Shulman (1987) noted that the "key to distinguishing the knowledge base of teaching lies at the intersection of content and pedagogy" (p. 15). Content knowledge was defined as knowledge of the substantive and syntactic structures of a discipline. Substantive knowledge refers to knowledge of the global structures or principles of conceptual organization of a discipline. It includes knowledge of facts, concepts, and principles within a content area and knowledge of the relationships among these foundational ideas (Wilson et al., 1987). Syntactic knowledge, on the other hand, refers to knowledge of the principles of inquiry and values inherent to the field, and of the methods with which new ideas are added and deficient ones are replaced by those who produce knowledge in that field. Under general pedagogical knowledge, Shulman and his colleagues included knowledge of the theories and principles of teaching, and strategies of classroom management and organization that transcend subject matter. Curricular knowledge was defined as knowledge of the "programs designed for the teaching of particular subjects" (Shulman, 1986, p. 10) and knowledge of alternative curriculum materials. This knowledge also included lateral curricular knowledge (knowledge of the various subjects being taught within a certain grade level in a given year) and vertical curricular knowledge (knowledge of what has been and what will be taught in the same subject in earlier and following years). It should be noted that the way these categories interrelate was, however, not explicated. In fact, Shulman and colleagues noted that "how these kinds of knowledge relate to one another remains a mystery to us . . . they are just [terms] floating on a page" (Wilson et al., 1987, p. 118).

Pedagogical Content Knowledge

Of all the categories of the knowledge base for teaching advanced by Shulman, PCK was the one that gained the greatest attention from researchers. PCK was defined as the "special amalgam . . . [or] the blending of content and pedagogy into an understanding of how particular topics, problems, or issues are organized, represented, and adapted to the diverse interests and abilities of learners, and presented for instruction" (Shulman, 1987, p. 8). PCK was presented as a separate domain, "a new type of subject matter knowledge" (Wilson et al., 1987, p. 114). Nevertheless, the above definition seems to be more consistent with the contention that PCK lies at the intersection of content and pedagogy as it is used in teaching, rather than it being a separate domain of knowledge. Under PCK, Shulman included "the most regularly taught topics in one's subject area" and the alternative and useful ways of representing those topics to make them understandable to students. These alternative representations include "analogies, illustrations, examples, explanations, and demonstrations" (Shulman, 1986, p. 9). Also included under PCK was knowledge of students' misconceptions about the topics most commonly taught and the "instructional conditions necessary to overcome and transform those initial conceptions" (Shulman, 1986, p. 10).

However, Shulman and his colleagues noted that PCK is not limited to a representational repertoire of the subject matter to be taught. It rather is characterized by a way of thinking that allows teachers to transform their subject matter knowledge into forms that students can understand. This way of thinking was labeled "pedagogical reasoning" (Wilson et al., 1987, p. 118) and was presented as central to Shulman's (1987) model of teaching.

Shulman's Model of Teaching

Shulman (1987) presented a model of pedagogical reasoning and action that he considered necessary if teachers were to transform their personal understandings of subject matter into forms that are comprehensible to students. The process of pedagogical reasoning and action features six aspects of teaching: comprehension, transformation, instruction, evaluation, reflection, and new comprehension. Teaching begins by comprehension. Teachers should first understand the subject matter for themselves and should understand it in several ways. They should understand how the ideas within their discipline are inter-related and connected (substantive knowledge). Teachers should comprehend what is to be taught, and how to teach it. Comprehension also comprises an understanding of the aims and purposes of teaching. Transformation follows comprehension. Teachers should be able to transform their understanding of the subject matter into forms that are attainable by the students and that are simultaneously "pedagogically powerful" (Shulman, 1987, p. 15). This will allow students to grasp an undistorted and non-isolated portion of the subject matter being taught. Shulman (1987) noted that at least two aspects of transformation are directly related to content knowledge. Preparation or interpretation of the ideas to be delivered, and the representation of these ideas. Preparation and representation are achieved by restructuring and segmenting the material, by "cloth[ing] it in activities and emotions, in metaphors and exercises, and in examples and demonstrations" that are suitable to the students' level (Shulman, 1987, p. 13). This movement from the teacher's personal comprehension to "preparing for the comprehension of [students] is the essence of the act of pedagogical reasoning" (Shulman, 1987, p. 16).

This process of pedagogical reasoning does not end when the act of teaching begins. It rather is integral to the whole process of teaching. After comprehension and transformation comes instruction, which includes the most important forms of pedagogy: classroom management and explanation. Evaluation follows instruction and requires a firm grasp of subject matter. The final step is reflection on all of the aforementioned activities. Shulman (1987) suggested that such reflection is not a disposition, nor is it a set of strategies. Content-specific analytical knowledge is needed to reflect on the teaching activities. This process ends by reaching a new comprehension: A new cycle of teaching then commences at a higher level of understanding and performance. It should be noted that central to all of the above actions, as Shulman (1987) contended, is content knowledge. It was thus assumed that a teacher's subject matter knowledge would directly translate into his/her classroom teaching practices.

Pedagogical Content Knowledge and the Axis of Experience

Attempts to articulate the construct of PCK and to explicate the relationship between the categories of the knowledge base of teaching were the focus of the 'knowledge growth in teaching' project spearheaded by Shulman. In that project teachers were followed from being "teacher education students to becoming neophyte teachers" (Shulman, 1987, p. 4). Moreover, case studies of experienced teachers were accumulated. This latter effort was undertaken with the intent of informing the articulation of the knowledge base of teaching and the sources of that knowledge. In describing one veteran teacher, the subject of one of the case studies, Shulman (1987) noted that she "seemed to posses a mental index for [the] books that she taught so often . . . . Her combination of subject-matter understanding and pedagogical skill was quite dazzling" (Shulman, 1987, p. 2). Such a statement, among others, makes clear the impact that observing experienced teachers has had on shaping the concept of PCK. Furthermore, experience seems to play a major role in developing a teachers' PCK. Wilson et al. (1987) noted that PCK "emerges and grows as teachers transform their content knowledge for the purpose of teaching" (p. 118). As novice teachers plan their lessons, teach, adapt instruction to meet student needs, and reflect on their classroom experience, they seem to develop "a new type of subject matter knowledge, . . . pedagogical content knowledge" (Wilson et al., 1987, p. 114). Shulman and his colleagues, however, did not explicitly explain the role of experience in developing a teachers' PCK.

Before taking this argument further, it is important to emphasize the distinction between teaching experience and teaching expertise. The years of teaching experience are not necessarily a good measure of teaching expertise. Gess-Newsome and Lederman (1995), as a result of their study of experienced science teachers, concluded that the kind and quality of experiences in which teachers are involved, and the opportunities and disposition they have to reflect on their content knowledge during their careers affect their conceptions of subject matter more than the number of years they have taught. This contention is supported by other research studies. For instance, in their study of novice and experienced science teachers, Hoz, Tomer, and Tamir (1990) reported that teachers' subject matter and pedagogical knowledge did not improve with their years of teaching experience.

The above distinction, however, was not overlooked by Shulman. His model of teaching emphasized the importance of the quality of the teaching experiences in developing teachers' PCK. PCK develops as teachers comprehend and transform their subject matter knowledge for the purpose of teaching, and then as they evaluate and reflect on their teaching. In other words, active and reflective teachers develop PCK as they experience teaching their content area firsthand. This is the case, of course, if those teachers have a good grasp of their content knowledge. This point was clearly emphasized. But Shulman and colleagues did not make the point that teaching experience plays a major role in the development of PCK.

Many researchers agree that the construct of PCK as presented by Shulman (1986, 1987) and later articulated by his colleagues (e.g., Grossman et al., 1989; Wilson et al., 1987) was, at best, vaguely defined and lacking at the theoretical level (Bromme, 1995). In an attempt to address some of these concerns, Gess-Newsome (1999) advanced two different models to theorize PCK. The first is integrative and suggests that PCK results from the interaction between subject matter knowledge, and knowledge of context and pedagogy. This first model, it could be argued, is somewhat lacking in terms of explanatory power because it does not articulate a mechanism for how such interaction leads to the development of PCK. The second model is transformative and explicitly introduces the axis of experiences into conceptualizing PCK. Gess-Newsome suggested that PCK develops as knowledge of subject matter, context, and pedagogy are assimilated as a result of teaching experience. Empirical evidence in support of one or the other model remains to be presented.

Nevertheless, if teaching experience proves to be significant in the development of PCK, then questions about the implications that this added axis of experience would have for conceptions of PCK and its usefulness in preparing teachers gain special significance. It can be argued that a first implication is that PCK would seem less likely to be a separate domain of knowledge. This is in line with some empirical evidence (e.g., Gess-Newsome & Lederman, 1993; Lederman et al., 1994). Content knowledge and pedagogical knowledge appear to be prerequisites to PCK: PCK appears to be what distills of a teacher's content and pedagogical knowledge as these are utilized to plan, deliver, reflect on, and adapt instruction. A second implication has to do with the role Shulman (1987) ascribed to a case-study-of-exemplary-teachers approach to informing our knowledge of PCK. It would be difficult to assume that 'a PCK' for a certain content area, or for a specific topic within that content area for that matter, can be explicated. As teachers transform their content knowledge of a certain discipline (or of a specific topic within that discipline) for the purpose of teaching it in different contexts and for different goals and as they tailor that knowledge to meet the needs and abilities of various students, they are more likely to develop distinct PCKs (if the plural can be appropriately used here) rather than a single, manageable body of representational and instructional repertoires.

Moreover, even if it is manageable to collate such knowledge for a specific content area (or for a specific topic within that content area), the question to follow would be: Is it desirable, or even possible, to add another body of knowledge to the list of things student-teachers have to learn during their teacher preparation? But some may argue, as Wilson et al. (1987) would, that PCK is characterized by a way of thinking (pedagogical reasoning) rather than being a repertoire of representations. However, taking into account that pedagogical reasoning is directly related to a set of teaching acts (comprehension, transformation, instruction, etc.), the question to follow would be: Is it possible to provide student-teachers during teacher preparation programs with the experiences and opportunities that experienced teachers have had as a result of years of active, reflective teaching?

The implications presented above are not exhaustive, nor are they assertive in any respect. They are meant to be suggestive in nature; questions to be asked of the construct of PCK and its usefulness for the purpose of preparing teachers as the axis of experience is assumed to be integral to its development. Such questions become more urgent as more items are added to an already extensive list on the agendas of teacher education programs. Answering all of these questions is beyond the scope of this study, or any single study for that matter. However, preservice and experienced teachers' content knowledge and its relationship to their teaching and teaching experience remains a central issue to all that has been presented. As far as science teaching is concerned, preservice and experienced teachers' substantive knowledge of their disciplines and their knowledge of specific topics within those disciplines are intimately related and equally relevant both to early (e.g., Shulman, 1987) and more recent (e.g., Gess-Newsome, 1999) discussions of the categories of the knowledge base of teaching in general, and to the categories of content knowledge and PCK, in particular.

PURPOSE

The present study aimed to describe preservice and experienced secondary biology teachers' global and specific subject matter structures (SMSs) and elucidate the relationship between these structures and teaching experience. The guiding research questions were: How do the global and specific SMSs of preservice and experienced teachers look like? Are the global and specific SMSs of preservice and experienced teachers different? If yes, in what ways? If not, in what ways are they similar?

The study focused on preservice and experienced secondary biology teachers in an attempt to shed light, given the preceding arguments, on teachers' content knowledge and the role that reflective teaching experiences may play in developing teachers' PCK. For the purposes of the present study, science teachers' global SMSs designate their conceptions and/or organization of their discipline (Gess-Newsome & Lederman, 1993). On the other hand, teachers' specific SMSs are conceived of as their conceptions and/or organization of specific topics within their disciplines. To assess teachers' specific SMSs, their conceptions of the topic of photosynthesis was assessed. The choice of this topic was based on its centrality and importance to the discipline and on the fact that it is regularly taught in high school biology.

The present study gains significance in light of the fact that very few studies have simultaneously focused on preservice and experienced secondary science teachers' global and specific SMSs. For instance, Gess-Newsome and Lederman (1993), Lederman et al. (1994), and Lederman and Latz (1995) focused on preservice secondary science teachers' global SMSs. Gess-Newsome and Lederman (1995) studied experienced secondary science teachers' global SMSs. Lederman and his colleagues, however, have not focused on preservice or experienced teachers' specific SMSs. By comparison, de Jong et al. (2005) and van Driel et al. (2002) focused on preservice secondary chemistry teachers' knowledge of the particulate theory of matter but not on their global SMSs. Smith and Neale (1989) investigated teachers' specific SMSs of light and shadows as well as their PCK. Their study, however, focused on elementary teachers. Hashweh (1987) focused on experienced secondary science teachers' conceptions of their disciplines (biology and physics) and of specific topics within those (photosynthesis and levers). However, several criticisms of his approach of using card sort tasks to assess teachers' conceptions of subject matter have been advanced (see Gess-Newsome & Lederman, 1993). In particular, it was argued that card sort tasks restrict respondents' conceptions of their subject matter to a list of ideas pre-determined by the researcher. Moreover, Hoz et al. (1990) attempted to investigate the relationship between experienced science teachers' content knowledge and years of teaching experience. However, the same criticisms that were advanced in the case of Hashweh's study apply to this study in which structured concept mapping tasks were employed to assess teachers' content knowledge.

More importantly, seeking relationships between preservice and experienced science teachers' SMSs may shed some light on the implications and questions that were suggested with respect to emphasizing a role for teaching experience in the development of teachers' PCK. This investigation was undertaken with the hope of informing conceptions of the construct of PCK and its usefulness for the purposes of preparing science teachers.

METHOD

This study was qualitative and exploratory in nature. Open-ended questionnaires and semi-structured individual interviews served as instruments for data collection (Bogdan & Biklen, 1992).

Participants

Purposive sampling was used to identify two preservice and two experienced secondary biology teachers to participate in the study (Bogdan & Biklen, 1992). Sampling focused on creating the needed variance in terms of teaching experience and equivalence in terms of subject matter taught to answer the guiding research questions. The preservice teachers, Pam and Paula (all names are pseudonyms), were enrolled in the final semester of a fifth-year, Master of Arts in Teaching (MAT) program in a mid-size state university in the Northwestern United States. Pam, 26 years of age, holds a BS degree in microbiology and had completed two years of graduate coursework in molecular and cellular biology. For one term during her graduate work she was a teaching assistant in both undergraduate and graduate biology courses. She discontinued her graduate studies to pursue certification to teach secondary biology. Paula, also 26 years old, holds a BS degree in zoology. She joined the teacher education program two years after her graduation. During those two years she worked in a non-educational establishment.

The two experienced biology teachers, Eric and Ellen, teach in a mid-size high school in a small rural region in the same state. Eric is 50 years old. He earned his BS degree (with special emphasis on marine biology and ecology) about 10 years before he went back to get his teacher certification. Between graduation and formal teaching he worked as a forest ranger, tree surgeon, farmer, and substitute teacher. He has taught high school biology (mainly botany) for 12 years. His knowledge of botany is primarily self-taught as his interest in this field came after formal college studies. Ellen is 34 years old. She holds a BS degree in general science with coursework in chemistry, microbiology, and geology. She also has completed about 70 graduate hours in marine biology, botany, and microbiology. She taught middle school biology and high school mathematics for one year after graduation, during which she completed coursework needed for certification. Since then she has taught high school biology for eight years.

Procedures and Instruments

Participants were first briefly interviewed to collect the demographic data necessary to develop a general profile for each. They were then individually administered two questionnaires consecutively: One to assess their global SMSs and the other their specific SMSs. The order of administering the two questionnaires was counterbalanced among the two groups of teachers. One preservice and one experienced teacher were randomly assigned to respond to the questionnaire on global SMS first, followed by that on specific SMS. This order was reversed for the other two participants. A few days after the administration of the questionnaires, the participants were clinically interviewed. They were asked to explain and clarify their responses to each questionnaire. Again, the order of discussing the questionnaires in the interview was counterbalanced. This was achieved by reversing the order of filling the questionnaires on the initial administration and discussing them in the interview for each participant. This counterbalancing was intended to assess the effect (if any) of the order of administering the questionnaires or discussing them in the interview.

The questionnaires. The open-ended questionnaire used by Gess-Newsome and Lederman (1993) and Lederman et al. (1994) was used to assess participants' global SMSs. A similar questionnaire was utilized to assess their specific SMSs. On the first questionnaire, participants were asked to respond to the following questions: (1) What topics make up your primary teaching content area (biology)? If you were to use these topics to diagram your content area, what would it look like? (2) Have you ever thought about your content area in the way you were asked to do above? The second questionnaire asked the participants to respond to the following questions: (1) What concepts and/or ideas make up photosynthesis? If you were to use these concepts and/or ideas to diagram photosynthesis, what would it look like? (2) Have you ever thought about photosynthesis in the way you were asked to do above?

As noted above, photosynthesis was chosen to assess participants' specific SMS because of its centrality to the discipline (its role in the transformation and flow of matter and energy, etc.) Moreover, photosynthesis is a regularly taught topic in high school biology. While experienced teachers are most likely to have taught photosynthesis, preservice teachers will most probably be asked to do so when they start teaching.

Participants were given up to 30 minutes to complete each questionnaire. Before responding to the questionnaires, the researcher explicitly informed participants that the terms 'topics' and 'concepts' should not be limiting in any respect. It was emphasized that they were free to use themes, procedures or any other context to represent their knowledge structures. Participants were also asked to use any form they wished to diagram these topics, themes, etc. No specific form like concept mapping or otherwise was suggested or required. Participants were overtly assured that they had the liberty to choose their own topics and or concepts and arrange them in which ever ways they deemed appropriate. This methodology was intended to provide as clear a portrait of participants' conceptions of biology and photosynthesis as possible. More importantly, this methodology was undertaken with the intent of ameliorating, though by no means completely eliminating, the problems associated with other approaches, like card sort and structured concept mapping tasks, that were employed by other researchers (e.g., Hashweh, 1987; Hoz et al., 1990). Such approaches were criticized for limiting the nature and form of the participants SMSs (Baxter & Lederman, 1999; Gess-Newsome & Lederman, 1993). The second item on the questionnaires was intended to assess whether the participants have had any previous opportunities in which they have thought about their content area or photosynthesis in the way required by the questionnaire.

Clinical Interviews. A few days after the initial administration of the questionnaires, the researcher individually interviewed each participant. The interview aimed to clarify participants' responses to the questionnaires and was guided by a set of general questions. Participants were first provided their completed questionnaires, one at a time, and then were asked to respond to the following questions (Gess-Newsome & Lederman, 1993, pp. 29-30): (1) Describe what you have written/diagrammed in your questionnaire; (2) What did you mean by each of the topics (or themes, concepts, etc.) that you have chosen to include in your diagram? (3) Why did you select these topics (or themes, concepts, etc.)? (4) What do these lines (or arrows, etc.) between the topics (or themes, concepts, etc.) represent? (5) You indicated that you have (have not) thought about your content area (or photosynthesis) before in the way asked of you on the questionnaire. If you have, when and why? If you have not, why? Digressions in the interviews were common. Participants' lines of thought on relevant ideas were pursued. An interview was typically one hour long. All interviews were audio-taped and transcribed verbatim for analysis.

Some methodological qualifications are in order. Asking participants to construct diagrams served two major purposes. First, the diagramming activity partially addressed concerns associated with over-reliance on quick recall, which might compromise the validity of assessing teachers' SMS. Indeed, diagramming was intended to provide participants ample time to think about the topics that make up their discipline or topics within the discipline and then contemplate ways in which those topics were interrelated. Second, the diagram itself provided a meaningful context to discuss participants' ideas during individual interviews rather than asking participants to (a) come up with the topics they deem important, (b) think about ways in which these topics connect, and (c) explicate their thinking about these connections, all in the same interview. Thus, in a sense, the diagrams were more of a means to an end. It is true that participants' diagrammatic representations could shed some light on their SMS. However, these representations can only be meaningfully interpreted in light of participants' discussions of, and reflection on, the diagrams. For instance, as noted below, some participants generated seemingly complex and integrated representations, but were not able to meaningfully elucidate the connectedness and integration of their knowledge of the discipline or specific topics within the discipline.

Data Analysis

All data analyses were was conducted after data collection was concluded. This was intended to avoid limiting or directing data collection during the interviews in any fashion as a result of preliminary analysis of any questionnaire or another interview. The questionnaires and interview-transcripts were qualitatively analyzed. In this analysis, each participant was treated as a separate case. Data for each participant was searched for patterns or categories. The generated categories were checked against confirmatory or otherwise contradictory evidence in the data and were modified accordingly. Several rounds of category generation, confirmation, and modification were conducted to satisfactorily reduce and organize the data (Auerbach & Silverstein, 2003). These categories were employed to describe each participants' global and specific SMSs. The categories and patterns were compared and contrasted within and across the two groups (preservice and experienced) and within and across the SMSs (global and specific). Relationships, patterns, similarities, and differences were sought.

RESULTS

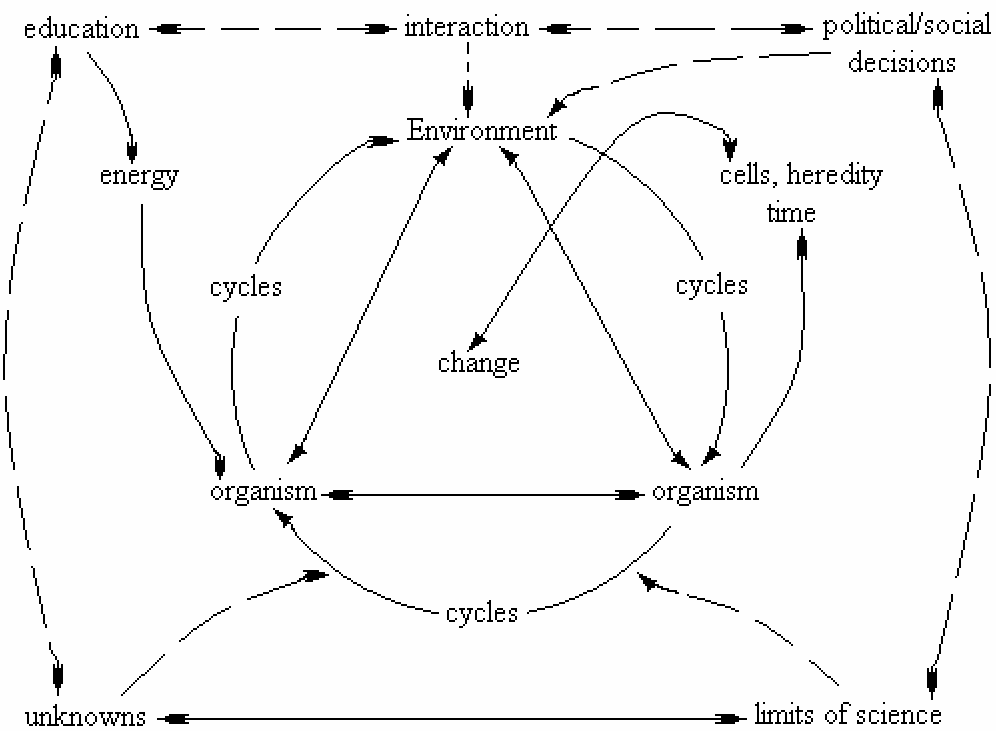
Participants' conceptions of biology and photosynthesis are presented in separate sections. Participants' views are elucidated, and differences and/or similarities between and among preservice and experienced teachers' conceptions, where evident, are also presented. Computer-generated replicas of participants' diagrams for global SMSs are also included (see Figures 1-4). The original format and substantive content (including spelling errors) of the diagrams were maintained.

Global SMSs: Conceptions of Biology

Conceptions of biology fell on a continuum with Paula's (preservice) and Eric's (experienced) on the two extremes. Structures provided by Pam and Ellen were in-between. On one end, Paula's views were ad hoc and represented isolated bits of information retained from some undergraduate biology courses. The structure provided by Pam was fluid and comprised a list of discrete college biology courses with related sub-topics arranged in a web-like format. Connections were, however, very few and themes were absent. Ellen presented a topical structure of biology that mirrored the linear organization of high school biology textbooks. Although Ellen claimed her views were connected, she was unable to elucidate interrelationships between the listed topics and concepts. On the other extreme, Eric's conceptions of biology were well integrated and organized about a few themes.

Eric. Two overriding themes characterized Eric's conceptions of biology: Interactions and nature of science (NOS). The theme of interaction was evident in Eric's diagram (see Figure 1) and was elaborated during the interview. He emphasized the interaction between organisms, the interaction of organisms with their environment, and the interaction of science and society. The latter interaction highlighted several aspects of NOS. Eric was the only participant who articulated a clear, themes-based conceptual framework with which he viewed biology and approached its teaching.

Figure 1. Eric's diagram for the structure of biology



In the center of his diagram, Eric represented the content he emphasized. Under cycles, he presented his students with the cycles of matter, and the life cycles of plants and insects. Eric aimed to familiarize students with the interdependence of organisms and their interactions with the environment. The choice of which organisms to present was driven by Eric's emphasis on interaction and student interest. Entomology figured prominently in his class as it offered students with opportunities to study interactions: Human interactions with insects which brought to light issues about health and disease, and insects interactions with crops which highlighted issues in plant management. Students' interest in entomology was also a major factor in stressing its study. In the school greenhouse, Eric and his students grew a lot of plants and conducted many experiments. Selling the grown plants also helped finance Eric's science class. Knowledge of how insects benefit or harm plants helped students to care of their plants.

The interaction between organisms and their environment was also explored at the microscopic and molecular levels. Students explored DNA, cells, heredity, and evolution (presented as "change over time"). Eric noted that the interaction between DNA and the environment (e.g., random mutations) is essential in shaping the development of species through evolutionary mechanisms like natural selection.

The interface between science and society was a major component of Eric's conceptions: The manner in which the content that students learn related to their everyday societal life and informed their interactions with the environment. Eric believed that science can inform students' decision making. It can help them make or support social and political decisions that are consistent with a healthier interaction with nature. Energy use was a case in point. Eric felt that students should understand that biological systems are driven by energy, that the available energy is finite, and that it can be appropriately used, misused or overused. Such an understanding, he continued, can help students make conscious, and more responsible decisions regarding energy expenditure as future citizens. Eric believed that although science can inform decision making in issues of social and political importance, it nevertheless does not provide definite, absolute answers. Factors other than scientific knowledge always play a role in such decision making. Policy makers may choose either to completely adopt what scientists say or to ignore it altogether depending on other economic and political factors. Eric thought that scientists themselves usually take different sides on the same issue depending on where they come from and what stakes they have in the issue debated.

Science as a way of knowing was another component in Eric's views. He aimed to convey an accurate image of science by emphasizing several aspects of NOS. He wanted his students to understand that science has limits, and that questions of great importance cannot be resolved through scientific investigations. Religious and philosophical issues, where people have different belief systems, served as examples. Moreover, science has a limited ability to explain and predict human experience and behavior. Eric also emphasized the tentative NOS by highlighting the role of models and unknowns. Science makes use of models which are not necessarily correct depictions of nature. And even though those models are functional, many unknowns, of which we are unaware, may be at work. As these unknowns become apparent, or as new models more consistent with the phenomena studied are devised, old conceptions are dropped and new ones are adopted. Eric also demonstrated understanding of the theory ladenness of observations when he noted that scientists might interpret the same data differently.

Ellen. Ellen emphasized that her views of biology and the way she teaches it were different. Student needs figured highly in this incongruity. She claimed to maintain an integrated view of the discipline. Her approach to biology, however, was linear and resembled the organizational structure of many high-school level biology textbooks. Her views, in general, lacked connectedness. It is noteworthy that Ellen did not diagram the concepts that she thought were important. She rather presented a topical list of those concepts (see Figure 2).

Figure 2. Ellen's response to the questionnaire on biology

The topics that make up my primary teaching content in biology include:

a. Ecosystems: specifically streams, forest, wetland.

b. Survey of Kingdoms and comparisons between organisms. As we survey kingdoms we look at:

- populations
- communities
- adaptations
- evolution
- animal behavior
- classification

c. Skills: microscope use, lab techniques, scientific writing.

d. Cells: within this unit we look at:

- Cell structure and function
- DNA / Protein synthesis
- Genetics
- Respiration / Photosynthesis

e. Entomology: Unit is designed to look at how insects impact humans and environment in a positive way. Also the unit ties in concepts learned through the year to a specific class of organisms.

If I were to use these topics to diagram my content area, my diagram would center around DNA as the main theme hoping the idea that living organisms are genetically related would be evident. I would include ecosystems as units coming from the DNA strand and show ecosystems as interrelated. In various ecosystems I would incorporate more specific topics. There are some topics that might not fit in this diagram . . . specifically the "skills" content. But, most content areas would fit this diagram.

2. I have though about the idea that most of the biological science concepts are taught are very interrelated, but I have not actually formed a mental picture or diagram of my content area as described above.

Similar to Eric's case, student needs were prominent in shaping Ellen's approach to the discipline: "I would like to teach biology on the basis that life is genetically related as far as we all contain DNA . . . [however] . . . this might not be the best way to teach it, so I don't teach it in this order . . . [because] . . . I don't think that students will understand." Once and again, Ellen emphasized that she wanted her students to know "that things are interrelated," and that DNA was the common factor. Students, she thought, lacked the prerequisite knowledge necessary to develop an understanding of this connectedness. When explicitly asked, however, she failed to elucidate ways in which DNA can be used to connect the topics and concepts on her list if her students had the prerequisite knowledge. She rather said that: "I think that we together will come up with something as a group . . . we come up with some sort of image rather than enforcing my image down their throats." And even though the question of how things were connected came up several times during the interview, Ellen did not provide an answer.

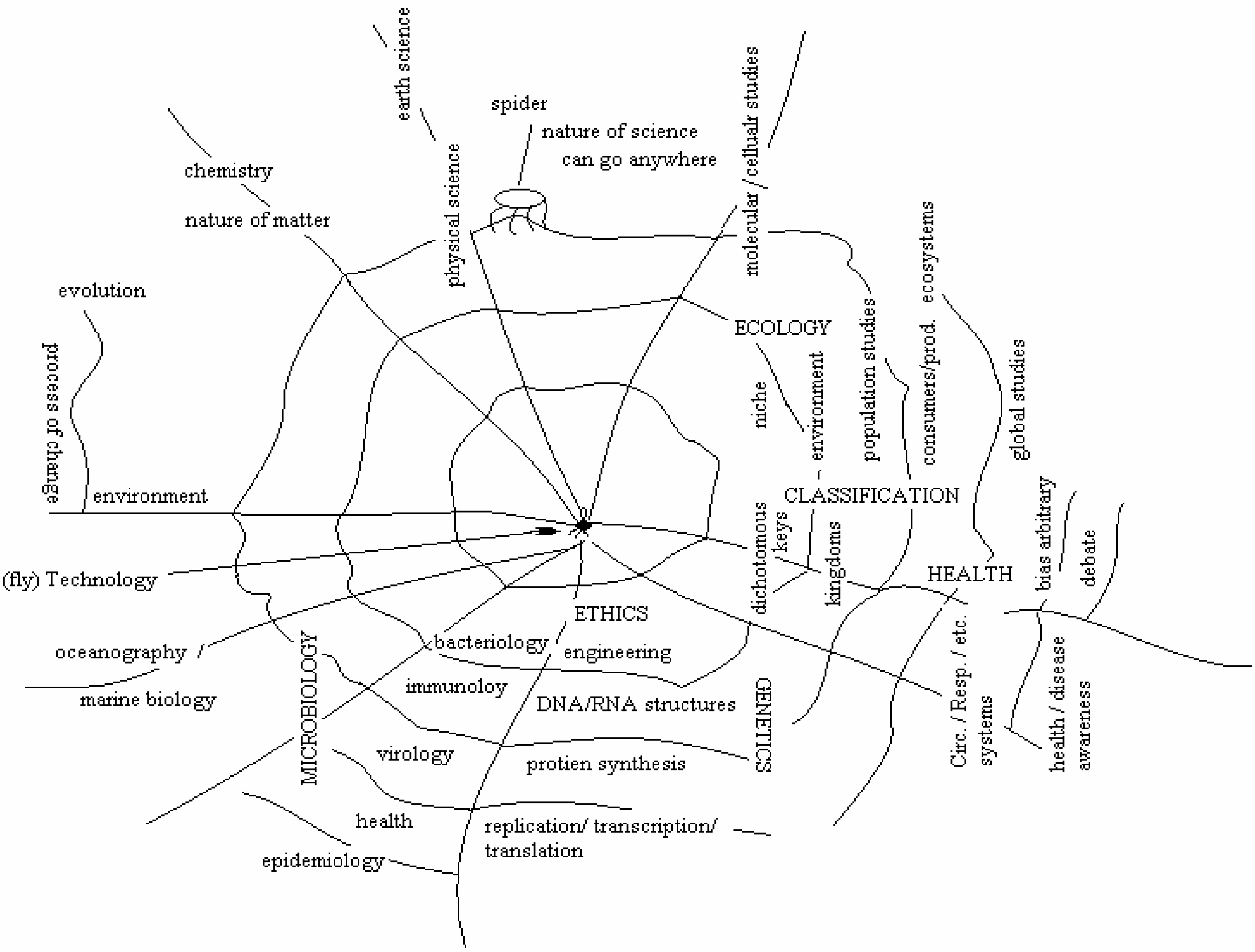
In her questionnaire, Ellen presented a topical view of biology. Her organization was consistent with the structure of many high school biology textbooks. Ellen noted that she would start with an overview of ecosystems, populations, and communities. A survey of the kingdoms followed. Again, the role of student needs was apparent. When asked about the concepts that she stressed when surveying the kingdoms, she, rather than answering the question, said they spent time covering organisms that students were not familiar with, since otherwise "they will be bored." After classification, the interaction of species within populations and communities, and the adaptation of organisms to their environments (evolution) are presented. Ellen would then move to the cellular level and then to ecosystems. The skills (e.g., lab skills, "scientific" writing) that she included are likewise usually presented in most biology textbooks.

It was evident that Ellen was only starting to articulate her conceptions of biology. She noted that she, after several years of teaching, started to look at things differently. She started to realize that topics in biology are interconnected, that themes are important, and that a sequential approach is not necessarily appropriate. However, her views in this regard were yet to be elaborated. Ellen noted that thinking of subject matter in this fashion is not possible in the early years of teaching where a teacher is usually overwhelmed with issues of classroom management: "When you first start teaching, you're busy just trying to keep order in the classroom. By the time you get to be, you know, to be in the classroom for five or six years then you start looking at things in a different way."

Ellen was not short on experience, she had been in classrooms for more than eight years. She, however, might not have had ample opportunities to reflect on her subject matter. And the opportunities she had were not consistent with developing an integrated view of biology. For instance, she noted that even though she thinks of biology thematically (not evident in the data), she had to write sequential curricular proposals (consistent with the data) because the latter were preferred by school boards.

Pam. Pam noted that she attempted to construct a diagram of biology in a course in her MAT program. She claimed to maintain an interconnected view of biology. She correspondingly used a spider web to represent this view (see Figure 3). Pam's conceptions of biology were, however, not integrated. Her lack of a conceptual, organizing framework of the discipline was evident when she was asked to explain how the topics on her web were connected. She answered, "I have a hard time with this because there is a lot of overlap . . . it is hard to represent [these relationships] in two dimensional. It is three dimensional because there is too much overlap."

Figure 3. Pam's diagram for the structure of biology



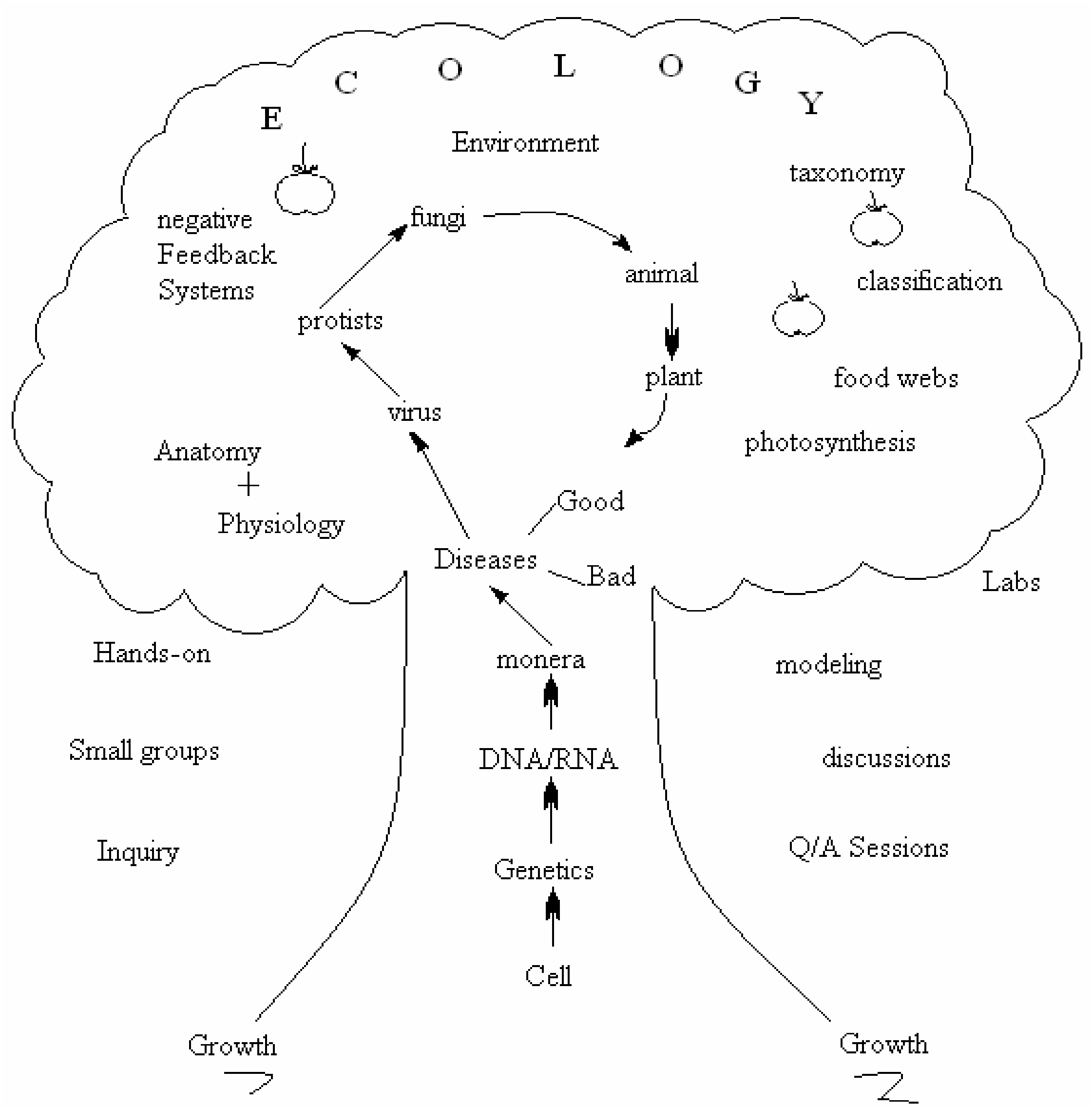
Pam often struggled when attempting to verbalize relationships. She felt overwhelmed, and just like Ellen, she expressed the view that everything in biology is interconnected but was not able to elucidate these connections. In fact, a closer look at her web reveals that the concepts and terms included depict topical listings of discrete college biology courses. These elaborate listings were consistent with Pam's extensive coursework in both undergraduate and graduate studies in biology. When asked to explain what she meant by the topics on her web, she typically listed sub-topics that were related to a certain term. For instance, to the question: "What do you mean by microbiology?" she replied: "In microbiology we have bacteriology, immunology, radiology, health, epidemiology and I think that molecular studies go here also." The same thing was repeated when asked about other terms and/or topics.

Moreover, Pam's conceptions were fluid. As she was tying to explicate the relations between pairs of concepts or topics, she often shuffled the concepts and moved one concept from one part of the web to another. For instance, in the above example, when asked whether she would include molecular studies under microbiology or not, she answered: "Yes. Or separate!" As expected, it was apparent that Pam has not thought about these concepts and the relations that may exist between them. In fact, when asked why she chose to include these topics, she noted that these were the concepts current in her mind at the time.

The effect of text-driven, college coursework was also evident when Pam explained how she would go about teaching biology. The sequence that she suggested was typical of most introductory college biology textbooks: Starting with basic chemistry, moving to cellular structure and function, then to organisms, and next to ecology. Finally, Pam noted that she used the spider on her web (see Figure 3) to represent NOS because it affects all the disciplines. She, however, was not able to explicate her views about NOS, which as it turned out, was not a pervasive theme in her conceptions of biology. When asked about it, Pam said that she would start her teaching with a discussion about NOS, "just a little bit about what it is about and . . . some demonstrations to practice observation versus inference."

Paula. Paula's conceptions of biology were ad hoc and not well thought out. When asked in the interview to describe her diagram, she replied: "Since this was a few days ago, I don't remember what I was thinking . . . so I guess your guess is as good as mine." She was not able to justify her choice of the concepts that appeared in the diagram or explicate many of the relations that she mapped between those concepts. Paula used a tree analogy to represent biology (see Figure 4). When asked about the reasons for her choice, she replied: "Because we did this in one of the classes and because the tree represents life, something growing and using energy." The tree, Paula continued, represented her attempt to start with 'smaller' concepts and move to 'larger' ones along lines of structural complexity. This, she noted, was the way the central concepts on the tree were organized (cell, genetics, DNA/RNA, Monera, diseases, viruses, Protists, fungi, animals, and plants-in this order). She explained: "I have put these in a circle because they can follow one another and they are related." Paula, however, was not able to explain how these terms were related. For instance, she was not able to explain the link between DNA/RNA and the kingdom Monera, or why she moved from Monera to viruses and then to Protists. The way she arranged these terms was not even consistent with her intent to represent

Figure 4. Paula's diagram for the structure of biology



an increasing level of complexity. For example, in her diagram, cells came prior to DNA and RNA. In fact, the center of the tree mirrored the five-kingdom classification system proposed in 1957 by Robert Whittaker (Whittaker & Margulis, 1978). Whittaker's five kingdoms are Monera, Protista, Fungi, Plantae, and Animalia. There certainly are serious doubts about Paula's conception that these kingdoms were organized on the basis of increasing structural complexity. The tree analogy, as it turned out, did not reflect any conceptual framework of biology. It rather represented isolated chunks of information that Paula has retained from her undergraduate course work. This claim is especially plausible in light of the fact that Paula majored in zoology where she was necessarily exposed to classification systems.

Ecology, Paula noted, was the encompassing concept in the diagram. When asked why, she answered: "Because ecology is the largest concept . . . Anything you talk about should be related to ecology [italics added]." She, however, was not able to elucidate any relations between ecology and several other concepts/topics in her diagram. On the tree Paula also included several concepts (e.g., food webs, photosynthesis, negative feedback systems) that were not connected to any other concepts. These concepts, Paula noted, were essential for understanding the larger picture. When asked to elaborate on this idea, and after a long pause, she answered briefly: "These are concepts that I have kind of thought of." Paula was unable to even give examples of these concepts. When asked about the inclusion of photosynthesis among these concepts, she said: "I have done photosynthesis [on the first questionnaire] and it was still in my mind." It is noteworthy that this was the only instance in which the order of administering the questionnaires had an effect on the views elucidated by participants.

Around the tree, Paula put several pedagogical concepts related to teaching (e.g., hands-on, inquiry, small groups). When asked how these concepts fit with what she has diagrammed, she answered that these were needed to teach biology. Overall, Paula felt inadequate about her conceptions. She pointed out that teaching experience would have made things easier: "I guess that one of the biggest problems is having to do this [diagram] and you are not an experienced teacher. Everything I would put here would of course come out of a textbook."

Specific SMSs: Conceptions of Photosynthesis

All four teachers, preservice and experienced, shared some elements as far as conceptions of photosynthesis were concerned. First, they all emphasized the essentials: Knowing the inputs and outputs of the process. In photosynthesis, light energy from the sun is utilized to convert carbon dioxide "from the atmosphere" and water "from the soil" into energy-rich, carbon-based compounds. Second, all participants limited their discussion of the process to green plants. They did not mention that photosynthesis also occurs in cyanobacteria and algae.

The differences, however, were more substantial than the above similarities. The first difference was the level of detail that teachers in the two groups considered. The preservice teachers, Pam and Paula, emphasized various structural and chemical details of photosynthesis. They included the specific sites (e.g., thylakoids, grana) where the process occurs, and the various chemical reactions (e.g., light and dark reactions, electron transport chain) and intermediary molecules (e.g., ATP, NADPH) involved in photosynthesis. On the other hand, the experienced teachers, Eric and Ellen, presented a much simpler account, an account limited to inputs and outputs. The second difference was that Eric and Ellen viewed photosynthesis as part of a larger picture. They emphasized the critical role of photosynthesis in providing the food supply and oxygen necessary for the survival of the most familiar life forms on earth: Plants and animals. This role was only partially emphasized by Pam (who stressed the importance of the byproduct oxygen in cellular respiration) and was not mentioned by Paula. What is more important was that teaching experience and student needs were the most important factors in the data to explain these differences.

The preservice biology teachers' emphasis on the details of photosynthesis was clear in their diagrams and stressed in the interviews. This was particularly the case with Pam. She, contrary to the others, used specialized terminology. For instance, she used the term 'photons' rather than terms like 'light energy' or 'solar energy' employed by the other three teachers. She also went into many details, such as emphasizing the formation of ATP and NADPH. She thought it was important for students to understand the role of these energy carriers: that it is critical to transfer energy in infinitesimal packets in order to avoid damaging the cell through releasing all the available energy in one large packet. When asked whether she would go into these details with high school students she answered in the positive. One can argue that Pam's preoccupation with details is consistent with her elaborate background on the topic (especially her graduate studies in cellular biology). However, a comparable level of detail was also emphasized by Paula. This was the case despite the fact that Paula indicated that her knowledge of photosynthesis was limited. She had no botany courses in her undergraduate studies. Yet, Paula thought it was important to, and did, include details about the various structures and reactions involved. This was the case even though she was unable to explain most of the details she emphasized. For instance, when asked to explain the relation that she mapped between chloroplasts and thylakoids she answered "I don't know . . . I am not sure." She also erroneously included the Krebs cycle under photosynthesis. So, despite lacking specialized knowledge about the topic and the fact that she indicated having not thought about photosynthesis in this manner before, Paula did not limit herself to the basics as one would anticipate. On the contrary, she went for the details. So the inference that the tendency to include details is related to a participant's elaborate knowledge can be ruled out. Teaching experience would in fact serve as a more plausible alternative. This was quite clear in the case of the experienced teachers.

Ellen, and as was the case with her views of biology, emphasized that what she put in the questionnaire reflected her view of photosynthesis but did not represent what she would actually teach about the topic. In her questionnaire, and consistent with her elaborate background in biology, Ellen gave a detailed account of photosynthesis. She included many details such as the specialized structures that plants have evolved to allow for and enhance photosynthesis, the seasonal dependency of the process, and the various chemical reactions taking place inside a leaf. However, it turned out that in her teaching she just stressed the overall equation that sums up the reactions and did not go into the details of the light and dark reactions saver their dependency on light or otherwise. The central idea that she wanted to get across was that photosynthesis is an energy transfer system by which solar energy is converted into chemical energy. Ellen's elaborate knowledge of photosynthesis seemed to have been purposively adjusted to fit her students' needs.

That teaching experience was a major factor in placing less emphasis on the details of photosynthesis was particularly evident in Eric's case. His view of photosynthesis, as Eric noted, was rather simple: "What goes in . . . and what goes out, and the importance of it." These elements were clearly presented in his diagram of photosynthesis. Solar energy is used by chloroplasts found in the leaves of plants to change carbon dioxide and water into food, releasing oxygen in the process. Eric noted that he avoided going into the details of the various chemical reactions. He only presented "the chemistry of the reactions in the form that [he] would expect kids to understand it." He added:

> As a newer teacher I got into more details, and as I taught it just seemed that kids never could really remember too much about photosynthesis. It was too abstract for them even if you did experiments . . . I just never could get kids to really understand it, even my better students. So I simplified my expectations.

The effects of teaching and having to deal with students' needs was further evident in shaping Eric's views. In his diagram, Eric included minerals as one of the reactants in photosynthesis. Though this can be thought of as simply a misconception, another more plausible explanation has precedence. As noted above, Eric and his students grew a lot of plants in their greenhouse that serves as their laboratory. Many experiments are usually run in the greenhouse all year long. Moreover, an end-of-year sale of the grown plants helps finance the science class. So, for Eric, photosynthesis is a way to teach his students how to keep their plants healthy:

> In my botany classes this is important for kids to understand these are the requirements for plants to remain healthy . . . We need always to evaluate if a plant is not growing healthy. We look at it in terms of the things the plant requires: It doesn't have enough light, enough moisture, it doesn't have enough air circulation, it doesn't have the water, etc.

So, the practical knowledge that Eric felt his students should derive from learning about photosynthesis may explain why he thought of minerals as a reactant in photosynthesis.

The importance of teaching in shaping teachers' views of specific topics in their content areas was realized even by preservice teachers. When asked to elaborate on some aspects of photosynthesis that she has included in her diagram, Paula answered: "I don't know, I haven't taught this yet."

The second difference was that experienced teachers saw photosynthesis as one link in a larger chain of events. They also made more connections between photosynthesis and other areas in biology. That photosynthesis is "the driving force of life on earth" was emphasized by Eric. The words "food and life" and the food chain depicted (autotrophs, herbivores, and carnivores) in his diagram clearly reflected this idea. Ellen similarly stressed the point that sugars produced in photosynthesis are utilized by plants and other organisms that feed on them. This forms the basis of elaborate food chains. Ellen also depicted the reciprocal relationship between photosynthesis and cellular respiration: that the products of the former are the reactants of the latter and vice versa. She also felt it was important to compare and contrast these reactions especially in plants and humans to understand the flow of energy and the cycling of matter. While Paula did not mention any of these relations, Pam focused on the relation of photosynthesis and respiration. She, however, limited this relation to the use of oxygen produced in photosynthesis by other organisms in cellular respiration. There was no mention of other organisms using the products of photosynthesis as a food supply. Finally, it should be noted that Eric, Ellen, and Pam indicated that they have thought about photosynthesis though they have not actually diagrammed it. Alternatively, Paula had not previously thought about photosynthesis in the manner asked by the questionnaire.

DISCUSSION AND IMPLICATIONS

The results of this study were, in many respects, consistent with previous research on preservice biology teachers' conceptions of subject matter. That preservice teachers' global SMSs mainly comprised discrete listings of college biology courses (e.g., Pam) or isolated chunks of information delivered in such courses (e.g., Paula), and that these listings and bits of information lacked connectedness or conceptual organization were consistent with findings reported, for example, by Gess-Newsome and Lederman (1993), Lederman et al. (1994), and Lederman and Latz (1995). However, the authors of these latter studies reported that toward the end of the teacher preparation program, the conceptions of biology elucidated by their subjects showed evidence of connectedness and thematic integration. This was not the case in the current study. The participant preservice teachers were about to graduate from the MAT program at the time the present study was conducted, yet their global SMSs showed very few connections and a complete absence of a thematic nature. In fact, these conceptions were similar to those reported by Lederman and his colleagues to be characteristic of biology teacher-candidates as they joined teacher preparation programs. It should be noted that initially Pam and Paula's diagrams of biology conveyed an integrated view of the discipline. Further probing during the interviews, nonetheless, revealed no evidence of integrated conceptions. This was the case even though both preservice teachers noted that they had opportunities in their MAT classes to reflect on and to attempt explicating their conceptions of biology. Such opportunities, it seems, were not enough to generate an integrated view of the discipline.

The findings of this study were also consistent with previous research on experienced biology teachers' global SMSs, especially the study by Gess-Newsome and Lederman (1995). In this latter study, as well as in the present one, it was evident that experienced biology teachers' global SMSs varied greatly. While some teachers maintained a linear, topical view of biology with sequences that resembled the structure of materials in popular high school biology textbooks (e.g., Ellen), others presented more integrated views of the discipline that showed evidence of connections and pervasive themes (e.g., Eric). Gess-Newsome and Lederman (1995) reasoned that having opportunities to reflect on subject matter was crucial in developing more integrated views of one's discipline. The frequency, variety, and quality of those opportunities, they continued, were more important than years of teaching experience in explaining the observed differences between experienced teachers' conceptions of subject matter.

The explanation advanced by Gess-Newsome and Lederman (1995) serves equally well to account for the different global SMSs furnished by the experienced teachers in the present study. In fact, as he noted, Eric had several opportunities to reflect on his subject matter in his career. He often evaluated biology textbooks for adoption in his course. On such occasions, Eric contacted many publishers and reviewed as many textbooks as was possible. He literally spent a few summers going over the materials and activities in such textbooks to see whether and how these can fit his and his students' needs. Such opportunities were also augmented by his unique experiences in other fields, especially as a forest ranger, tree surgeon, and farmer. These experiences played a crucial role in shaping and focusing Eric's conceptions. This was evident in his emphasis on interactions between insects and crops, plant management, and the utilitarian approach to the study of photosynthesis. These topics were mainly geared to help his students take care of their greenhouse. Ellen's years of teaching experience (eight years) were not substantially fewer than Eric's (10 years). Ellen experiences, however, were fewer. The opportunities she had to reflect on her subject matter (e.g., writing curricular proposals), we have seen, were not consistent with developing a conceptual view of biology. These experiences, it seemed, served to reinforce her topical, linear approach to biology.

So, having opportunities to reflect on subject matter, and acting on these opportunities, seem to play a major role in developing a teacher's conceptions of his/her discipline. In addition, having ample time to do so, seems crucial. Both preservice teachers had opportunities to generate a conceptual view of biology in their teacher preparation program. These experiences were, however, short-lived and insufficient to make any significant impact on their views. After all, such views were nurtured over several years in college science courses. However, it is imperative to re-emphasize that time alone is not sufficient: Ellen's eight years in the classroom, likewise, made little impact on her global SMSs.

In the present study, global SMSs did not discriminate preservice and experienced biology teachers. Their conceptions of biology, as noted earlier, fell on a continuum. This, however, was not the case with specific SMSs. Conceptions of photosynthesis clearly separated the participants into the two groups: preservice and experienced. The views presented were consistent within each group and differed from those of the other group in two major ways. First, was the level of detail emphasized. The preservice teachers emphasized various structural and chemical details of photosynthesis while the experienced teachers presented a much simpler account that was limited to inputs and outputs. Secondly, the experienced teachers viewed photosynthesis as part of a larger picture. They emphasized its critical role in supplying the food energy and/or oxygen necessary for the survival of almost all living organisms. This role was overlooked by the preservice teachers. As noted earlier, teaching experience and student needs were the most important factors in the data to explain these differences.

In the case of photosynthesis, and contrary to the discipline as a whole, participants in each group seem to have had similar experiences. Both experienced teachers did teach the topic over the course of several years to students in the same school with similar backgrounds. As they taught, they had to respond to their students' needs and abilities. And, as they made explicit, they had to modify their expectations. Their conceptions of what is worth emphasizing in their classrooms were modified accordingly. Ellen and Eric's views of photosynthesis were much more similar than their conceptions of biology. Both preservice teachers, on the other hand, probably had similar college experiences with photosynthesis, and having not taught it, their views on the topic were very similar. All this makes stronger the contention that teachers' conceptions of subject matter are affected by their reflecting and acting on it.

It should be noted that reflection on subject matter does not always guarantee depth of understanding or more accurate conceptions. As teachers respond to idiosyncratic student needs and modify their expectations accordingly, and as they read into new materials based on prior conceptions or from within certain perspectives, they may end up developing idiosyncratic conceptions. Eric's inclusion of minerals as a reactant in photosynthesis is a case in point.

Implications for Conceptions of PCK

In as far as photosynthesis is typically taught in high school biology courses, and to the extent that PCK is concerned with "the most regularly taught topics in one's subject area" (Shulman, 1986, p. 9), the results of this study were consistent with the contentions advanced by Shulman. Shulman and his colleagues argued that as teachers plan their lessons, teach, adapt their instruction to meet student needs, and reflect on their teaching, they develop PCK. This was evident in the present study. Teaching experience and student needs were the most important factors in the data to explain the differences between the preservice and experienced teachers' conceptions of photosynthesis. Thus, essential to the development of PCK, as presented by Shulman, is the component of experience (even though Shulman and his colleagues did not highlight the importance of this component). Teachers, as was the case with Ellen and Eric, would have to go through several cycles (i.e., over several years) of teaching and reflection to develop the desired knowledge of the topics they teach.

If a teacher's PCK could only be developed through teaching experience, then the usefulness of this construct for teacher education purposes would be severely limited. It is obvious that teacher preparation programs cannot provide prospective teachers with the equivalent of years of classroom teaching experience in order to develop their PCK. No doubt, a case-study-of-exemplary-teachers approach to teacher education, as advanced by Shulman (1987), can be useful. This approach, however, cannot possibly result in preparing exemplary teachers. Stories of innovative instructional strategies and activities, and vignettes of creative representations, metaphors, and analogies of subject matter devised by classroom teachers, would serve to enrich prospective teachers' experiences. Such pieces, nevertheless, cannot equip them with the kind of knowledge they will need in their own classrooms.

However, teaching experience may not be the only factor crucial to the development of teachers' conceptions of subject matter. As far as global SMSs are concerned, teaching expertise figured more prominently than teaching experience in accounting for the observed differences in the experienced teachers' conceptions of biology (also see Gess-Newsome & Lederman, 1995). Ellen's views of biology were not significantly impacted by her substantial teaching experience. As noted earlier, opportunities to reflect on subject matter are essential to the development of more integrated views of a discipline. Such interconnected views are necessary for teachers to be able to present the 'most regularly taught topics' as undistorted and non-isolated portions of a larger whole (Shulman, 1987). Thus, opportunities to reflect on subject matter should be part of teacher education. Nevertheless, the frequency, variety, and quality of those opportunities weigh heavily in developing the desired conceptions. This, we have seen, was the case with Pam and Paula. Their short-lived experiences with attempting to conceptualize their subject matter in the MAT program did not have a notable effect on their global SMSs. Teacher preparation programs cannot allocate ample time for those opportunities amidst their already packed agendas. What is alternatively needed is an explicit, theoretical model for the development of PCK. When incorporated in teacher education, such a model can help prospective teachers take responsibility for developing their own conceptions of subject matter.

As presently conceived, PCK largely remains an atheoretical construct. Even though all the components of a possible theoretical model for the development of PCK were advanced by Shulman (1987), the necessary links between the components were not explicated. This probably resulted from conceiving PCK as a separate domain of knowledge. Attempts to theorize PCK, such as those advanced by Gess-Newsome (1999), go some way in providing a viable alternative framework, but more is needed. For example, Gess-Newsome's integrative model does not provide a viable mechanism for bringing about the integration of teacher's knowledge of content, context, and pedagogy. Similarly, the results of the present study only provide partial empirical support for Gess-Newsome's transformative model. These results indicate that teaching experience is not enough to account for the development of PCK as was the case with Ellen.

The following is by no means a re-conceptualization of PCK as advanced by Shulman (1987), it rather is a minor change of perspective. This change, however, may prove to have some implications for teacher preparation programs. The idea advanced here is that PCK is not a separate domain of knowledge. PCK develops as a result of the interaction of the other components of the knowledge base as teachers use that knowledge in their teaching. It follows that the components of the knowledge base for teaching, as articulated by Shulman, are prerequisite to the development of PCK.

The above point is more evident when we consider the way Shulman and his colleagues noted that PCK develops: As teachers plan their lessons, teach, adapt their instruction to meet student needs, and reflect on their teaching, they develop "a new type of subject matter knowledge, . . . pedagogical content knowledge" (Wilson et al., 1987, p. 114). The same point is also evident in Shulman's model of teaching and the associated set of activities. In this respect we have seen that subject matter knowledge, both substantive and syntactic, is essential for comprehending what is to be taught. In addition, curricular knowledge is prerequisite to planning. General pedagogical knowledge, including knowledge of teaching strategies and classroom management, is critical for teaching. Knowledge of learners is essential for transforming subject matter and adapting instruction to meet the diverse student abilities and interests. Both evaluation and reflection, as Shulman (1987) noted are not dispositions. They rather require content-specific analytical knowledge, and knowledge of the purposes and aims of teaching. It can thus be seen that the development of PCK is crucially linked to teachers' familiarity with the other components of the knowledge base. (It should be noted that the way the various types of knowledge were assigned to the above activities is schematic. It is recognized that the various categories of knowledge overlap in their application to those activities.) In addition, Shulman noted that PCK is characterized by a way of thinking, which he labeled as pedagogical reasoning. As such, PCK develops as teachers think about and act on their knowledge for the purpose of teaching it.

The components of the knowledge base for teaching as advanced by Shulman are already on the agendas of teacher preparation programs. Capitalizing on this point to promote PCK is, nevertheless, related to explicating the model underlying its development, be it Shulman's contention of pedagogical reasoning or his model of teaching. But, what are the components of pedagogical reasoning? What kinds of knowledge about teaching and learning are demanded by Shulman's model of teaching? What does it mean for teachers to comprehend the subject matter for themselves? How can they comprehend it in several ways? What does it take for teachers to be capable of transforming their knowledge of subject matter into forms that students can attain? What is the role of reflection in developing teachers' conceptions? What are the content-specific analytical knowledge that Shulman deemed necessary to enable teachers to engage in reflection; a crucial aspect of their professional development? How do the other components of the knowledge base relate to all of the above? Further research is needed to shed light on these questions. If answers to such questions prove helpful in theorizing the construct of PCK, then teacher preparation programs would have a better chance of helping teachers develop the desired conceptions of subject matter. Equipping teachers with the kind of theoretical knowledge that can help them take responsibility for their own professional development may prove more useful than adding another type of knowledge that prospective teachers will have to know (given that we can collate this kind of knowledge in the first place), even if it comes under the attractive label of PCK.

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Fouad Abd-El-Khalick

Department of Curriculum and Instruction

University of Illinois at Urbana-Champaign

311 Education Building, MC-708

1310 South Sixth Street

Champaign, IL 61820

USA

Phone: (217) 244-1221

Fax: (217) 244-4572

E-mail: fouad@uiuc.edu