Jour. Korean Earth Science Society, v. 32, no. 5, p. 494–503, September 2011
http://dx.doi.org/10.5467/JKESS.2011.32.5.494

A Review of Teachers' Pedagogical Content Knowledge and Subject Matter Knowledge for Teaching Earth System Concepts

Gillian H. Roehrig and Younkyeong Nam*

Department of Curriculum and Instruction, University of Minnesota, Minnesota, 55108, USA

Abstract: During the last three decades, earth science has been re-conceptualized as an interdisciplinary discipline entitled Earth System Science (ESS), which is based on knowledge of the physical earth system and human impact on the earth. While there is increasing effort to teach earth as a system in K-12 education, teachers' preparedness of to teach earth system is still in its infancy. This article focuses on reviewing the literature of teachers' knowledge of earth systems and of how teachers' knowledge of subject matter affects their teaching practice and pedagogical content knowledge (PCK). First, the study investigated a literature of PCK in general as well as in science teaching. Then this study duscuss what teachers' subject matter knowledge (SMK) is and what it means to be in teaching earth system science. Third, a literature of teachers' knowledge of earth system was reviewed. Finally, a number of suggestions and implications are made as to what teacher education program should do to better prepare future teachers to teach earth systems.

Keywords: Subject matter knowledge, Teacher education, Teacher knowledge, Pedagogical content knowledge.

Introduction

Over the last two decades, scientists have recognized the necessity of studying the earth as an integrated system in order to explain complex and unpredictable natural phenomena. Consequently, knowledge of the physical earth system generated by traditional earth science disciplines was integrated to form a new discipline, Earth System Science (ESS), the concept of the earth as a set of systems (Johnson et al., 1997). However, there has been increasing concern about the K-12 Earth Science teaching and teachers' understanding of earth as a system.

A recently published survey of Earth Science standards across the United States was pessimistic about the state standards of K-12 Earth Science education in the U.S. (Hoffman and Barstow, 2007). The report opens with a call to action in that "understanding Earth's interconnected systems is crucial to the future of our nation and the world. Yet our nation's schools have a mixed record of effective Earth science education" While the national standard documents (American Association for the Advancement of Science (AAAS, 1993) address "system" as one of the important themes in understanding scientific concepts, the standards (national as well as the state standards) do not directly present how to use a system-based approach to teach earth science (Hoffman and Barstow, 2007). Due to the lack of consensus on the central ideas of ESS and what teachers should teach about it, interpreting and addressing earth science knowledge using systems ideas has always been extra work for teachers in the classroom, curriculum developers, and assessment designers.

Knowing how to effectively teach particular ideas is impacted considerably by the nature of the teacher's subject matter knowledge (Barnett and Hodson, 2001). In other words, Earth Science teachers need to possess earth systems knowledge as well as understand effective ways to teach this knowledge to support K-12 students in developing their own earth systems knowledge. Subject matter knowledge encompassed another crucial component of knowledge base for teaching (Shulman, 1986). The concept of "Pedagogical Content Knowledge (PCK)" has been introduced by Shulman to fill the gap between content and pedagogical knowledge (Veal et al., 2001). Shulman

*Corresponding author: namxx020@umn.edu
Tel: +1-651-587-7773
Fax: +1-612-626-0993

(1986) defined "Pedagogical Content Knowledge" (PCK) as "subject matter knowledge for teaching". While researchers argue the importance of teachers' subject matter knowledge for developing their PCK and classroom practice (Gess-Newsome and Lederman, 1993; Lederman et al., 1994), little research has been done about how much science teachers know about earth systems and how to assess science teachers' conceptual understanding of earth systems. This literature review delineates the relationship between teachers' topic- specific subject matter knowledge (knowledge of earth system) and their teaching practice. The literature reviewed in this paper includes both studies of teacher knowledge domain (specifically about PCK) and teachers' subject matter knowledge (and its relationship with teaching practice). Based on the literature review, we also propose the important aspects that teacher educators need to consider for preparing teachers to teach topic-specific content knowledge.

This article follows three steps: first, we reviewed literature about PCK, in general. In this step, we described definitions of PCK from different studies. Then we reviewed literature of PCK in science education to understand the themes in the current research on teachers' conceptual knowledge in a specific topic earth system knowledge and its relationship with their teaching practice. Finally, we suggest directions of teacher preparation about teachers' subject matter knowledge for teaching earth system.

Pedagogical Content Knowledge (PCK)

What teachers know about the earth system is an important factor in determining how they teach it. We usually assume that teachers with strong content knowledge easily draw upon this knowledge in teaching situations. Most university-based teacher education programs are based on the assumption, or hope, that subject matter knowledge can inform knowing how to teach (Rovegno, 1992). However, what earth science teachers teach about earth systems is not always determined by what they know about earth system. Pre-service and novice teachers' application of their content knowledge to the classroom situation were found to be difficult in many studies (Rovegno, 1992; Gess-Newsome and Lederman, 1993; Lederman et al., 1994; van Der-Valk and Broekman, 1999). This is because teachers' selection of subject matter knowledge for teaching is not only affected by their content knowledge but also by other knowledge domains such as pedagogy knowledge, knowledge of the students, knowledge of the curriculum, and so on. In the early 1980s, Shulman and his colleagues argued that teaching effectiveness is much more related to the content the teacher is teaching, or domain-specific rather than general (Shulman, 1986, 1987). Shulman (1986) used the term, "the missing paradigm," which indicates that the study of teaching has ignored the interaction between content knowledge and pedagogy. Teachers' specific pedagogical practice cannot be separated from their content knowledge as well as their pedagogical knowledge. Shulman (1987) introduced the "knowledge base for teaching" which consisted of seven categories: content knowledge, general pedagogical knowledge, curriculum knowledge, PCK, knowledge of learners, knowledge of educational context, and knowledge of educational purposes. Shulman (1987) defined PCK as a unique form of teacher knowledge and the ways of representing and formulating subject matter that make it comprehensible to others and also, including an understanding of what makes the learning of specific topics easy or difficult.

In his earlier work, Shulman (1986) categorized PCK under the content knowledge domain but ultimately PCK plays an essential role in integrating pedagogical knowledge and curricular knowledge. Following Shulman's (1986) ideas about PCK, other researchers developed their own categories of teacher knowledge (e.g. Borko and Putnam, 1996; Grossman, 1990; Adams and Krockover, 1997). Particularly, Adams and Krockover (1997) develop a framework for investigating teacher knowledge by synthesizing

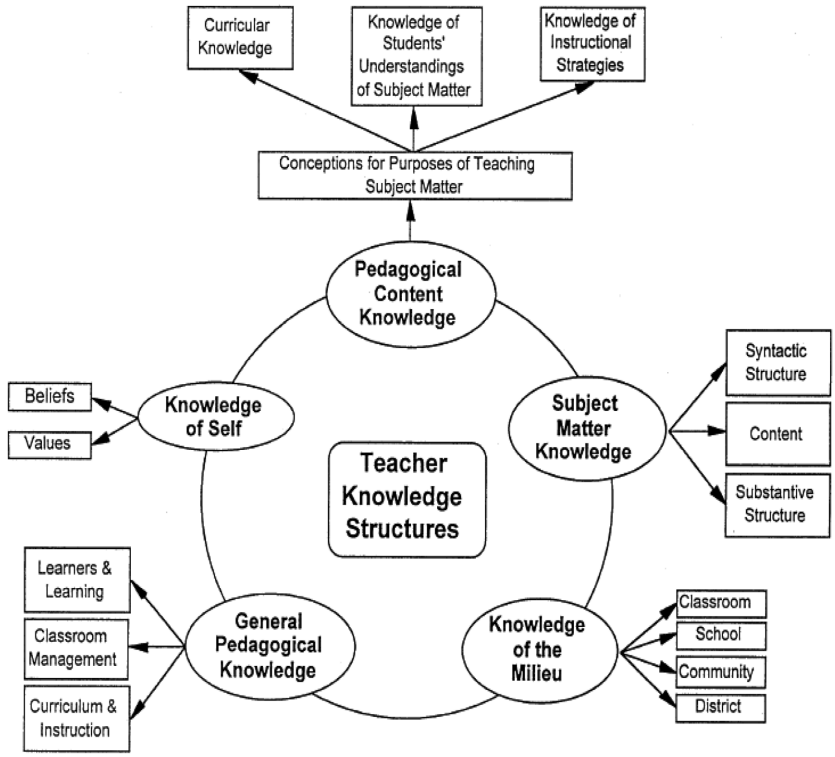

Fig. 1. Adams and Krockover's (1997) model of teacher knowledge (p. 636).

Elbaz's (1983) unique category of teacher knowledge, "knowledge of self" and Grossman's (1990) definition of teacher knowledge. Adams and Krockover's (1997) model includes five important categories of teacher knowledge that are referred to in teacher knowledge literature: (a) pedagogical content knowledge (PCK), (b) subject matter knowledge, (c), general pedagogical knowledge, (c) knowledge of the milieu, and I knowledge of self (Fig. 1).

During the last 20 years, scholars in teacher education have tried to identify this unique form of teachers' knowledge for teaching subject matter as well as to define the differences between the subject matter knowledge of the professional community and the subject matter knowledge for teaching (e.g. Ball et al., 2008). Yet there is no agreement between scholars about PCK. In much of the literature, PCK has been described using a variety of different components: teaching beliefs, pedagogical orientation, reasoning, or even epistemological understandings. The problem of defining PCK is exacerbated by its complex nature and that it is unique for individual teachers. Furthermore, it is developed through cognitive reasoning processes or pedagogical reasoning in a specific teaching practice or context (Shulman, 1987). For the purpose of this review, we review PCK in the domain of science teaching.

PCK within the Context of Science Teaching

What are the specific discussions of PCK within the context of science teaching? As Shulman noted, knowing how to effectively teach particular ideas in science is not solely a pedagogical question; it is impacted very considerably by the nature of the science discipline and content knowledge in science (Barnett and Hodson, 2001). There are several models of PCK that are specifically developed for science teaching. Based on Grossman's (1990) model of

teacher knowledge, Magnusson et al. (2001) developed a model of PCK for science teaching which is composed of five components: orientations toward teaching science; knowledge of science curricula; knowledge of students' understanding of science; knowledge of assessment in science; knowledge of subject specific and topic specific strategies. Barnett and Hodson (2001) also proposed a modified model of PCK in science teaching called, "Pedagogical Context Knowledge", as a synthesis of a number of models, metaphors, and notions already described in the literature about teachers' knowledge. They emphasized that what good science teachers know, do and feel is largely situated in minutiae of everyday classroom life (classroom context and teacher's micro-worlds).

The definition of PCK in science teaching is not much different from general definitions of PCK in other content domains. However, the literature focusing on PCK in science teaching could be summarized using three unique aspects of the domain of science teaching: 1) science teachers particular views of teaching and learning within a science discipline, 2) science teachers' understanding of the domain specific content knowledge, 3) and the subtleties of their practice in response to learning science and demands of their students (Loughran et al., 2004). My discussion about PCK in science will narrow to the second aspect of PCK in science teaching that particularly includes the discussion of how science teachers' understanding of the domain specific content knowledge (subject matter knowledge, or SMK) affects their teaching practice.

While there is evidence that teachers' content knowledge is not sufficient to ensure effective teaching of a subject, some critical amount of content knowledge seems to be necessary to develop the PCK (Magnusson et al., 2001). In the science teacher education literature, studies on teachers' science subject matter knowledge (SMK) and its impact on science teaching practices have increased during the last 20 years. Teachers' SMK has been considered a core factor that contributes to their selection of particular curriculum (e.g. Gess-Newsome, 2001), to their critiques of specific curriculum (e.g. Grossman, 1990), to their decision to use specific instructional strategies, and consequently to students' opportunities to communicate in classrooms (e.g. Carlsen, 1991). In reviewing literature on science teachers' SMK, Gess-Newsome categorized the studies in five groups: 1) teacher's conceptual knowledge of concepts or facts that have been accumulated and developed in a certain discipline (e.g. Carlsen, 1991; Hashweh, 1987); 2) teachers' understandings of subject matter structure in a discipline (e.g. Gess-Newsom and Lederman, 1993; Lederman and Zeidler 1986); 3) teachers' understandings of the nature of a discipline (science) (e.g Brickhouse, 1990; Lederman et al., 1994; Lederman, 1999); 4) content specific orientations to teaching that focus on teachers' ideas about content and how the content should be taught (e.g. Gudmundsdottir, 1990); and 5) contextual influences on curricula implementation such as grades, text books, or school context. In this article, we discuss the first two categories, teacher's understanding of content knowledge (or conceptual knowledge) and their understanding of subject matter structure of a science discipline. we focus on these two categories because the purpose of this article is first to discuss teachers' conceptual knowledge of earth systems and its impact on their teaching practice and then to suggest teacher preparation in the specific subject matter knowledge, earth system knowledge. Teachers' understanding of earth systems is not about their knowledge of a single concept in earth science. Instead, it is about teachers' understanding of how the concepts of earth systems are interconnected and structured with related scientific concepts to explain earth system phenomena. Therefore, if we want to discuss the relationship between teachers' ESS content knowledge and their practical knowledge for teaching earth system (PCK) more in-depth, we need to discuss both their understanding of ESS content knowledge and their understanding of the relationships of the content knowledge, which is structure of the content knowledge in ESS.

Conceptual knowledge and subject matter structure

Gess-Newsome (2001) defined teachers' conceptual knowledge as "the facts, concepts, principles, and procedures that are typically taught in secondary school classrooms" (p. 55). She also emphasized that teachers' conceptual knowledge is different than "declarative knowledge," which she had studied earlier in regards to the relationship between teachers' subject matter knowledge and students' achievement. In her definition, teachers' conceptual knowledge is "knowledge that is rich in relationships" or "richly integrated knowledge" that is distinguished from the knowledge that has traditionally been tested in achievement tests in the past (p. 55).

Gess-Newsome (2001) also defined subject matter structure as networks of relationships between conceptual knowledge. In the following, she describes how the subject matter structure is different than conceptual knowledge:

> Conceptual knowledge is assumed to be organized in long term memory in a manner that is structured, integrated, and facilitates the storage and retrieval of information (Gagne and Glasser, 1987; Hiebert andCarpenter, 1992). Such networks of relationships, more formally called knowledge structure, are unique to the individual, may be contextually bound, and are emotionally more neutral than beliefs (Champagne et al., 1981; Roehler et al., 1988). It is intuitive to assume that teachers would have a knowledge structure for their subject matter (p. 56).

Gess-Newsome distinguished the literature of teachers' knowledge of subject matter structure from the literature on teachers' conceptual knowledge because they each describe teachers' content knowledge in two different ways: in- depth knowledge on a certain topic or concept (conceptual knowledge) and broader knowledge around the certain concept as it relates with other concepts in a discipline (subject matter structure). However, it is difficult to separate the concept of conceptual knowledge from the concept of subject matter structure in terms of their influence on teaching practice. Both teachers' conceptual knowledge and knowledge of subject matter structure were interpreted very similarly in the literature of science teachers' SMK and its impact on the teaching practice. For example, in Gess-Newsome and Leaderman's (1993) study of five biology teachers' subject matter structure, the concept of the teacher's subject matter structure was used to describe "levels of content knowledge" (p. 317). They assume that if teachers have more knowledge in a discipline, they have more complex subject matter structure in a discipline. The definition of teachers' subject matter structure seems to be highly related to the depth of the teacher's conceptual knowledge in a discipline in science teachers' SMK literature. In other words, teachers' conceptual knowledge of an earth system concept includes both conceptual knowledge (in-depth knowledge about a concept) and subject matter structure (knowledge of the relationship between a concept and the bigger concept of earth system).

In general, the relationships between science teachers' conceptual knowledge and their practice have been studied in various aspects. Generally, as the teachers gain more content background, they have more confidence in regards to the content and consequently rely less on officially approved materials (Lantz and Kass, 1987), present more knowledge of related concepts (Chung, 2011; Harshweh, 1987), use more lectures to present new information (Carlsen, 1991; Dobey and Schafer, 1984), and ask high-level questions in problem solving situations (Barba and Robba, 1992; Carlsen, 1991; Lee, 2010).

Some of the studies specifically address the relationship between teachers' depth of knowledge in certain disciplines and its relationship with their lesson planning. Harshweh (1987) studied science teachers' conceptual knowledge of physics and biology and their lesson planning using this conceptual knowledge. Harshweh (1987) found that teachers who possess minimal subject knowledge followed the textbook structure closely for their lesson planning. Harshweh (1987) also found that teachers who were knowledgeable in a certain discipline were organized and related given lesson topics to an important discipline

conceptual scheme. Also, the knowledgeable teachers were more flexible in choosing concepts for their lesson planning. The knowledgeable teachers deleted concepts from a given textbook if the concept contradicted their prior knowledge and the theme they chose for the lessons. There are also other studies that support the idea that teachers who have more content background knowledge rely less on officially approved material when they choose lesson content and topics (e.g. Hollon et al., 1991; Lantz and Kass, 1987).

Teachers' depth of content knowledge has been also investigated in a way that presents the relationship between content knowledge or subject matter structure (e.g. Gess-Newsome and Lederman, 1993; Lederman et al., 1994; Lederman, 1999). These studies found that teachers who possess more complex subject matter structures of a discipline, for example biology, can translate a more coherent view of biology to students and select the most appropriate topics to be included in the curriculum.

While teachers develop their conceptual knowledge through various ways, it appears that they developed it as a rich relationship between concepts through their teaching experience. According to Gess-Newsome (2001), "Experienced teachers are more likely than novices to hold subject matter structures that are coherently structured and rich in relationship" (p. 69) Abd-El-Khalick's (2006) study also supports the idea that teaching experience can influence teachers' development of their content knowledge as more systemic and more complex relationships between content knowledge. By comparing pre-service and experienced biology teachers' conceptual knowledge, he found that experienced teachers did not emphasize the details of a concept but viewed the concept in relation with bigger concepts of the specific subject knowledge. Other studies also describe the differences between experienced and novice teachers in terms of the relationship between conceptual knowledge developments and teaching experience. Barba and Ruba (1992) compared pre-service and in-service teachers' content knowledge in earth science and their problem solving skills. In this study, Barba and Ruba (1992) found that pre-service teachers' conceptual knowledge is less structured or "organized for retrieval", whereas in-service teachers' conceptual knowledge is more structural and ready to solve problems using the conceptual knowledge (p.1030). Experienced teachers who have rich and highly structured content knowledge also tend to structure a unit that includes more structured and rich information (Gess-Newsome, 2001).

In summary, science teachers' conceptual knowledge of specific concepts as well as their knowledge of the relationship between the concepts and other related concepts are important in order for them to present a more coherent view of a science discipline and to be more flexible in choosing and organizing topics and related content knowledge. Moreover, science teachers' conceptual knowledge and understanding of the relationship between the important concepts in a science discipline is affected by the science discipline they were trained in and developed throughout their teaching experience. In the following section, we review literature on teachers' content knowledge of earth systems. This includes their understanding of specific content knowledge in earth systems as well as their understanding of the earth system that shows complex relationships between content knowledge in earth systems.

Teachers' Understanding of Earth System

The study of teachers' understanding of earth science concepts has occurred most recently in teachers' SMK literature (Abell, 2007). Particularly from the perspective of an earth system approach, the study of earth science concepts held by K-12 teachers has been slow to shift from a focus on separate sub-disciplines to a focus on an integrated earth system. While some research focuses on teachers' understanding of more complex natural phenomena such as global warming (e.g. Dahl et al., 2005; Ekborg, 2003; Khalid, 1999; Kikas, 2004; Summers, 2000, 2001; Trend, 2001), most of the research on teachers' understanding of

earth science has been repeatedly investigated as small, isolated concepts such as causes of day and night, seasons (e.g. Atwood and Atwood,1996: Schoon and Boone, 1998; Schoon, 1995), moon phases (e.g. Trundle et al., 2002; Schoon, 1995; Suzuki, 2003), astronomical distance (Jeong and Han, 2010), and plate tectonics (e.g. Libarkin and Anderson, 2005; King, 2000).

The current body of research demonstrates teachers' lack of understanding of earth science concepts as well as their lack of awareness of the earth as a system. For example, many of the teachers surveyed believe that Earth's core is liquid or molten (Libarkin and Anderson, 2005), the Earth's mantle is solid (King, 2000), there is a large portion of carbon dioxide in the atmosphere (Summers et al., 2000), and the ozone layer is composed of dust or liquid (Dove, 1996). Many teachers also believe that ozone layer depletion is a form of large-scale pollution related to acid rain, the greenhouse effect, and marine pollution (Boyes, 1995; Dove, 1996). Most of the teachers in these studies were unaware that natural events could also cause environmental problems. For example, volcanic activity can cause both a depletion of the ozone layer and acid rain (Boyes et al., 1995; Dove, 1996). In their research about teachers' understanding of the carbon cycle, ozone, and global warming, Summers et al., (2000, 2001) argue that teachers have little awareness of the earth as a system and do not connect these phenomena with the concept of earth system interactions. For example, teachers are uncertain about energy exchange between the sun, earth and space (Summers et al., 2001) and they do not understand how human activities increase the concentration of greenhouse gases and the feedback effect of the increase of greenhouse gases on human life (Summers et al., 2000).

However, the current studies do not address how teachers' limited understanding of certain earth science concepts is related to their understanding of the ESS perspective of earth systems. The earth system concept is very complex because it requires an understanding and familiarity with many interdisciplinary scientific concepts. Teachers' understanding of the concept of earth system, specifically, earth system interactions or behaviors, concepts of scale of time and space in system interactions, have not been studied. A lack of research on pre-service and in-service teachers' knowledge of earth systems is problematic. Moreover, few studies involved in-service teachers, who will do most of the K-12 earth system teaching. Instead, the majority of the current studies were conducted with pre-service elementary teachers. This lack of research is problematic because it influences the teachers' practice, their selection of curricular activities and their critiques of specific curriculum (Grossman, 1990; Kinach, 2002; Sperandeo-Mineo et al., 2006).

Preparing Earth Science Teachers to Teach Earth System Concepts

Subject matter knowledge for teaching earth system concepts is a unique form of teacher knowledge that pre-service teachers have to acquire to teach earth systems during their teacher education programs (Grossman, 1990; Carlson, 1990; Peterson and Treagust, 1995; Kinach, 2002). Researchers emphasize the importance of subject matter knowledge and topic specific aspects of PCK. Grossman (1990) argued that a subject-specific methods course may be the most logical place for prospective teachers to acquire how to teach specific subject matter knowledge. Researchers have designed subject-specific methods courses and content, and evaluated the effectiveness of those through assessing teachers' PCK (e.g. Daehler and Shinohara, 2001; Peterson and Treagust, 1995, Sperandeo-Mineo et al., 2005). This calls for attention to the content-specific methods course designed for earth science teachers. Pre-service earth science teachers' subject-specific methods course needs to focus on suggesting appropriate teaching strategies to teach earth system concepts and methods for assessing students' conceptual knowledge of earth system and emphasizing the importance of the "real" practice of teaching earth systems.

Earth science teachers' classroom practice is also an

important factor for developing PCK for teaching earth systems. Rovegno (1992) suggested that PCK includes experiential dimensions and emphasizes the field-experience to transform a teacher's knowledge about something to knowledge about how to do something. Based on their year-long assessment study of pre-service biology teachers' subject knowledge structure, Gess-Newsome and Lederman (1993) also argue the importance of the actual experience of classroom teaching. They said that, until a teacher has gained experience and mastered basic classroom skills, it may be unrealistic to expect a readily accessible and useful subject matter structure to exist or to be translated into classroom practice. van Driel et al., (1998) investigated the effects of participation in an in-service workshop and conducting an experimental course in classroom practice on teachers' PCK. They found that adequate subject matter knowledge appears to be a prerequisite for developing PCK and teaching experience is the main source of PCK development. van Driel et al., (2002) also argued that the growth of PCK was influenced mostly by the pre-service teacher's teaching experience.

Discussion and Implications

In conclusion, the literature on teachers' PCK development in teacher preparation implies three important points for preparing earth science teachers to teach earth systems: (1) teacher educators need to identify earth system concepts and the related earth system concepts teachers need to teach as well as to define the depth of a teacher's understanding of the concept of earth system (Lederman et al., 1994; Ball, 2000; Loughran et al., 2001, 2004; Kinach, 2002), (2) teacher educators must provide opportunities for teachers to examine, elaborate, and integrate new knowledge and beliefs about earth system concepts and the knowledge of earth systems into their existing knowledge structure of earth systems and their beliefs about the discipline of earth system (Peterson and Treagust, 1995; Shulman, 1997; Magnusson et al., 2001; Sperandeo-Mineo et al., 2005), (3) teacher educators must provide opportunities for teachers to learn about instructional strategies and ideas in a meaningful and supportive context as well as actual classroom situations involving the teaching of earth system concepts (Rovegno, 1992; Cochran et al., 1993; Lederman et al., 1994; Mellado, 1998; van Driel et al., 1998, 2002; Barnett and Hodson, 2001).

Many researchers agree that PCK is topic-specific (Grossman, 1990; Magnusson et al., 2001; Loughran et al., 2001, 2004; Sperandeo-Mineo et al., 2005). As Magnusson et al. (2001) argues, teacher education programs can never completely address all the components of PCK that a teacher needs because teachers' experience within one topic area may not be sufficient to support them in engaging in desired practices within other topic areas. Therefore, the content for a teacher preparation program must address not only broad subject knowledge but also more focused topics, such as earth systems, to give concrete direction and description of PCK development for pre-service teachers.

References

Abd-El-Khalick, F., 2006, Preservice and experienced biology teachers' global and specific subject matter structures: Implications for conceptions of pedagogical content knowledge. Eurasia Journal of Mathematics, Science and Technology Education, 2, 1-29.

Abell, S.K., 2007, Research on science teacher knowledge. In Abell, S.K. and Lederman, N.G. (eds.), Handbook of research on science education. Lawrence Erlbaum Mahwah, NJ, USA, 1105-1149.

Adams, P.E. and Krockover, G.H., 1997, Beginning science teacher cognition and its origins in the preservice secondary science teacher program. Journal of Research in Science Teaching, 34, 633-653.

America Association for the Advancement of Science, 1993, Benchmarks for science literacy. Oxford University Press, NY, USA, 400 p.

Atwood, R.K. and Atwood, V.A., 1996, Preservice elementary teachers' conceptions of the causes of seasons. Journal of Research in Science Teaching, 33, 553-563.

Ball, D.L., Thames, M.H., and Phelps, G., 2008, Content Knowledge for teaching: What Makes It Special? Journal of Teacher Education, 59, 389-407.

Ball, D.L., 2000, Bridging practices: Intertwining content

and pedagogy in teaching and learning to teach. Journal of Teacher Education, 51, 241-247.

Barba, R.H. and Rubba, P.A., 1992, A comparison of preservice and inservice earth and space science teachers' general mental abilities, content knowledge, and problemsolving skills. Journal of Research in Science Teaching, 29, 1021-1035.

Barnett, J. and Hodson, D., 2001, Pedagogical context knowledge: Toward a fuller understanding of what good science teachers know. Science Education, 85, 426-453.

Boyes, E., 1995, Trainee primary teachers' ideas about the ozone layer. Environmental Education Research, 1, 133-145.

Brickhouse, N.W., 1990, Teachers' beliefs about the nature of science and their relationship to classroom practice. Journal of Teacher Education, 41, 53-62.

Broko, H. and Putman, R., 1996, Learning to teach. In Berliner, D. and Calfee, R. (eds), Handbook of educational psychology. Macmillan, NY, USA, 673-708.

Carlsen, W., 1991, Subject-matter knowledge and science teaching: A pragmatic perspective. Advances in Research on Teaching, 2, 115-143.

Carlson, R.E., 1990, Assessing teachers' pedagogical content knowledge: Item development issues. Journal of Personnel Evaluation in Education, 4, 157-163.

Chung, D., 2011, The effects of prior knowledge and development procedure to teaching materials developed by the pre-service earth science teachers-focused on the teaching materials in the schoolyard. Journal of Korean Earth Science Society, 32, 140-151.

Daehler, K.R. and Shinohara, M., 2001, A complete circuit is a complete circle: Exploring the potential of case materials and methods to develop teachers' content knowledge and pedagogical content knowledge of science. Research in Science Education, 31, 267-288.

Dahl, J., Anderson, S.W., and Libarkin, J.C., 2005, Digging into earth science: Alternative conceptions held by K-12 teachers. Journal of Science Education, 12, 65-68.

Dobey, D.C. and Schafer, L.E., 1984, The effects of knowledge on elementary science inquiry teaching. Science Education, 68, 39-51.

Dove, J., 1996, Student teacher understanding of the greenhouse effect, ozone layer depletion, and acid rain. Environmental Education Research, 2, 89-100.

Ekborg, M., 2003, How student teachers use scientific conceptions to discuss a complex environmental issue. Journal of Biological Education, 37, 126-132.

Gess-Newsome, J., 2001, Secondary teachers' knowledge and beliefs about subject matter and their impact on instruction. In Gess-Newsome, J. and Lederman, N.G. (eds.), Examining pedagogical content knowledge; The construct and its implications for science education Dordrecht. Kluwer Academic Publishers, The Netherlands, 55-94.

Gess-Newsome, J. and Lederman, N.G., 1993, Preservice biology teachers' knowledge structures as a function of professional teacher education: A year-long assessment. Science Education, 77, 25-45.

Grossman, P.L., 1990, The making of a teacher: Teacher knowledge and teacher education. Teachers College Press, Teachers College, Columbia University, USA, 185 p.

Gudmundsdottir, S., 1990, Values in pedagogical content knowledge. Journal of Teacher Education, 41, 44-52.

Hashweh, M.Z., 1987, Effects of subject-matter knowledge in the teaching of biology and physics. Teaching and Teacher Education, 3, 109-120.

Hollon, R.E., Roth, K.J., and Anderson, C.W., 1991, Science teachers' conceptions of teaching and learning. In Brophy, J. (ed.), Advances in research on teaching (2nd ed.), JAI, Greenwich, CT, UK, 145-186.

Hoffman, M. and Barstow, D., 2007, Revolutionizing earth system science education for the 21st century: Report and recommendations from a 50-state analysis of earth science education standards. National Oceanic and Atmospheric Administration. Washington, DC, USA, 59 p.

Jeong, J. and Han, S., 2010, The Conceptions of Astronomical Distance of Elementary School Teachers. Journal of Korean Earth Science Society, 31, 827-838.

Johnson, D.R., Ruzek, M., and Kalb, M., 1997, What is earth system science? Paper presented at Remote Sensing-A Scientific Vision for Sustainable Development, 1997 IEEE International, 2, 688-691.

Khalid, T., 2003, Pre-service high school teachers' perceptions of three environmental phenomena. Environmental Education Research, 9, 35-50.

Kikas, E., 2004, Teachers' conceptions and misconceptions concerning three natural phenomena. Journal of Research in Science Teaching, 41, 432-448.

Kinach, B.M., 2002, A cognitive strategy for developing pedagogical content knowledge in the secondary mathematics methods course: Toward a model of effective practice. Teaching and Teacher Education, 18, 51-71.

King, C.C., 2000, The earth's mantle is solid; Teachers' misconceptions about the earth and plate tectonics. The School Science Review, 82, 57-64.

Lantz, O. and Kass, H., 1987, Chemistry teachers' functional paradigms. Science Education, 71, 117-134.

Lederman, N.G., GessNewsome, J., and Latz, M.S., 1994, The nature and development of preservice science teachers' conceptions of subject matter and pedagogy. Journal of Research in Science Teaching, 31, 129-146.

Lederman, N.G. and Zeidler, D.L., 1987, Science teachers' conceptions of the nature of science: Do they really influence teaching behavior? Science Education, 71,

721-734.

Lederman, N.G., 1999, Teachers' understanding of the nature of science and classroom practice: Factors that facilitate or impede the relationship. Journal of Research in Science Teaching, 36, 916-929.

Lederman, N.G., Gess-Newsome, J., and Latz, M.S., 1994, The nature and development of preservice science teachers' conceptions of subject matter and pedagogy. Journal of Research in Science Teaching, 31, 129-146.

Lee, H., 2010, A Qualitative Case Study of an Exemplary Science Teacher's Earth Systems Education Experiences. Journal of Korean Earth Science Society, 31, 500-520.

Libarkin, J.C. and Anderson, S.W., 2005, Assessment of learning in entry-level geoscience courses: Results from the geoscience concept inventory. Journal of Geoscience Education, 53, 394-401.

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

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

Magnusson, S., Krajcik, J., and Borko, H., 2001, Nature, sources and development of pedagogical content knowledge for science teaching. In Gess-Newsome, J. and Lederman, N.G. (eds.), Examining pedagogical content knowledge. Kluwer Academic Publishers, Boston, USA, 95-132.

Peterson, R. and Treagust, D., 1995, Developing preservice teachers' pedagogical reasoning ability. Research in Science Education, 25, 291-305.

Rovegno, I.C., 1992, Learning to teach in a field-based methods course: The development of pedagogical content knowledge. Teaching and Teacher Education, 8, 69-82.

Schoon, K.J., 1995, The origin and extent of alternative conceptions in the earth and space sciences: A survey of pre-service elementary teachers. Journal of Elementary Science Education, 7, 27-46.

Schoon, K.J. and Boone, W., 1998, Self-efficacy and alternative conceptions of science of preservice elementary teachers. Science Education, 82, 553-568.

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

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

Sperandeo-Mineo, R., Fazio, C., and Tarantino, G., 2006, Pedagogical content knowledge development and preservice physics teacher education: A case study. Research in Science Education, 36, 235-268.

Summers, M., Kruger, C., and Childs, A., 2001, Understanding the science of environmental issues: Development of a subject knowledge guide for primary teacher education. International Journal of Science Education, 23, 33-53.

Summers, M., Kruger, C., Childs, A., and Mant, J., 2000, Primary school teachers' understanding of environmental issues: An interview study. Environmental Education Research, 6, 293-312.

Suzuki, M., 2003, Conversations about the moon with prospective teachers in japan. Science Education, 87, 892-910.

Trend, R., 2000, Conceptions of geological time among primary teacher trainees, with reference to their engagement with geoscience, history, and science. International Journal of Science Education, 22, 539-555.

Trend, R., 2001, Deep time framework: A preliminary study of U.K. primary teachers' conceptions of geological time and perceptions of geoscience. Journal of Research in Science Teaching, 38, 191-221.

Trundle, K.C., Atwood, R.K., and Christopher, J.E., 2002, Preservice elementary teachers' conceptions of moon phases before and after instruction. Journal of Research in Science Teaching, 39, 633-658.

van Der Valk, T. and Broekman, H., 1999, The lesson preparation method: A way of investigating pre-service teachers' pedagogical content knowledge. European Journal of Teacher Education, 22, 11-22.

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

Van Driel, J.H., Jong, O.D., and Verloop, N., 2002, The development of preservice chemistry teachers' pedagogical content knowledge. Science Education, 86, 572-590.

Veal, W.R., van Driel, J., and Hulshof, H., 2001, PCK: How teachers transform subject matter knowledge. International Journal of Leadership in Education, 4, 285-291.

Manuscript received: July 4, 2011
Revised manuscript received: August 29, 2011
Manuscript accepted: September 15, 2011