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Biology and Geology Teachers' Domain-Specific Pedagogical Content Knowledge of Evolution

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Why and how evolution is taught has been the subject of an often heated debate in the United States throughout the last century. The debate has influenced the teaching of science curricula at all levels. The science/religion debate was rekindled in 1999 when the Kansas Board of Education passed new testing standards that minimize the importance of evolution. The Creation Science Association for Mid-America (CSAMA) developed for a member of the Kansas Board of Education a draft of the state science standards in which evolutionary science was not mentioned. In a similar fashion, Kentucky's Department of Education deleted the word "evolution" from its standards and replaced it with "change over time." These events at local and state levels and their effect on curriculum and instruction suggest a need to develop an increasingly robust understanding of how to teach evolution. This study was designed as one step in this process of increased understanding.

Specifically, this investigation used the philosophy of science, sociocultural theory, and pedagogical content knowledge (PCK) to understand the similarities and differences displayed by prospective and inservice secondary biology and geology teachers who introduce and modify their curriculum to include the common topic of evolution. The purpose of this study was to understand how and why geology and biology teachers approach the teaching of evolutionary curricula from different paradigms even though curricular topics are similar in the distinct domains of science. Ultimately, this understanding will influence how science teachers view and implement curricula.

Efforts and debates for and against the inclusion of topics related to evolution in the high school curriculum are not new; in fact, they date back to the turn of the 20th century.[1] The teaching and inclusion of evolution in the science curriculum is controversial mainly because of its alleged contradictions of strongly held religious beliefs.[2] The evolution conflict as it relates to a standards-based curriculum can be separated into two dissonant propositions. One advocates that both creation science and evolution should be given equal time in schools in as much as some critics of evolution claim that both topics are unproven theories. The second proposition argues that creation science is a religiously based belief, whereas evolution is not a belief but rather is a factually supported generalization. This latter position justifies the inclusion of evolution and the exclusion of creation science on First Amendment grounds. That this conflict has persisted throughout the 20th century indicates that the issue of science and religious beliefs likely will not subside, and that teachers who implement the curriculum will feel the impacts of these divergent positions. The issues are related to other curriculum issues such as free speech, human rights, and diversity (e.g., multiculturalism, identity, and pluralism).

Evolutionary Controversies in Education

Evolution is central to the content standards in the National Science Education Standards (NSES) and is part of one of the program's five unifying concepts and processes for the biology curriculum.[3] The basic underlying theme in modern biology is that life began at some point after the Earth was formed approximately 4.6 billion years ago. The theme contends that this life was simple, and, across time and processes (e.g., mutation, variation, and natural selection), multifaceted organisms arose. Evolution is a complex concept that brings to education a broad perspective of natural phenomena and of the nature of science.

Bizzo reports that science students have a poor understanding of evolutionary theories, particularly as they relate to the human species.[4] Moreover, researchers have revealed that many teachers have come to the profession ill prepared emotionally and conceptually to teach evolutionary concepts.[5] Many studies have reported reasons for teaching evolution,[6] why teachers refused to teach or ignored evolution,[7] and how and why preservice teachers changed their perceptions about teaching evolution.[8] Several studies have reported inconsistent outcomes with respect to teaching biological evolution using traditional pedagogical approaches,[9] whereas some studies have noted that students were able to understand evolutionary concepts and their applications better following an inquiry approach to teaching.[10]

Not surprisingly,[11] only a few studies report the teaching of geological evolution.[12] Zook reviewed educational literature and highlighted key themes that were geologically or biologically based, and others that were common to both of these domains of science.[13] Zook argues that the teaching of biology and geology content is skewed to show only the “misconception and content” from 10 percent of the geologic time scale—basically, the Cambrian era. The teaching of such a restricted period of time within the entire history of Earth appeared to permit students to develop conceptual problems about evolution.

The difference in studies that include biological or geological perspectives of evolution indicates a separation or dichotomous bifurcation in the science education literature between the understanding, teaching, and conceptualization of evolutionary topics. The ongoing debate in public arenas and among science educators and scientists fails in many ways to address the epistemological aspects central to understanding the teaching of evolutionary topics. That issue does not center on the appropriateness of teaching evolution. Rather, the question appears to be, Why do differences exist in how geology and biology teachers view the teaching of a similar topic in these two domains of science?

Theoretical Framework

The philosophy of science, sociocultural theory, and a taxonomy of PCK served as the epistemological underpinnings of this research study. Separately, these perspectives explain how science teachers understand the multiple aspects of teaching science curriculum. United, these perspectives provide a common understanding of specific qualities and conceptions about science teaching within a context using specific content.

Postpositive philosophers of science[14] have described knowledge as a personal mental construction of the world that is actively constructed by the knower, rather than direct representations of an external reality independent from the knower (e.g., empirical tradition). Thus, subjective, tentative, and relative observations of the world are regarded as being an "untrue" reality. The viability and usefulness of observations of the world and the generation of knowledge remain for individual knowers to contemplate and to integrate into communities of science. Science teachers, as a distinct community, must develop the connections among personal and world experiences so that science students can acquire knowledge in a personal manner. Some teachers become responsible for helping students develop connections by providing learning situations and activities that promote dissonance in students' perceived observations of the world reality.[15]

Sociocultural theory holds that communities are developed and created by individuals who participate in them.[16] Within the sociocultural realm of understanding the world, communities of practice have developed separate ways of viewing the world. Their members (e.g., biology and geology teachers) participate in activities that promote and justify their "home" communities. The participants in these communities are active agents who make decisions about their participation in the community. This view differs distinctly from the empiricist approach traditionally found in the communities of science. Hence, the knowers or participants view the world in a more subjective manner by their creation of a community based upon consensual agreement and actions rather than from an accepted external reality. For example, Hepburn and Gaskell used sociocultural practice theory to study why a physics teacher and a technology teacher implemented the same curriculum differently.[17] The difference in implementation, they observed, was due to the teachers' communities of practice and membership.

Shulman first proposed the concept of PCK.[18] He described it as the "most useful forms of representation of these ideas, the most powerful analogies, illustrations, examples, explanations, and demonstrations—in a word, the ways of representing and formulating the subject that make it comprehensible to others." Geddis added that PCK in every curricular area includes special attributes that enable teachers to transfer the knowledge of content to others.[19] The concept of PCK also differentiates a science teacher from a scientist.[20] Some research that has stemmed from the introduction of PCK has addressed the question of how preservice and inservice teachers learn to teach subjects that they already know or are in the process of learning.[21]

Veal and MaKinster developed a taxonomy of PCK in which they defined three types of pedagogical content knowledge.[22] General PCK constitutes the first level within this taxonomy and implies a sound understanding of pedagogical concepts. They claim that general PCK is more specific than pedagogy because the concepts and strategies employed are specific to the relevant disciplines (e.g., science, mathematics, history, art). Their second level is domain-specific PCK—more specific than general PCK—and relates to the specific and different curricular studies of science (e.g., chemistry, biology, and geology). Domain-specific PCK is positioned between disciplines and domains of science and represents a different level and specificity of subject matter and pedagogy.

The third and most specific level of the general PCK taxonomy is topic-specific PCK. Theoretically, a teacher who develops topic-specific PCK at this level could have a solid repertoire of understandings and skills in the previous two levels. Although some concepts unique to each domain are taught similarly, other common concepts reasonably are taught differently on many pedagogic occasions because of the science teachers' differing sociocultural communities of practice. For example, heat and temperature are common concepts in both physics and chemistry. Although each of these concepts is found in both domains, the teaching styles, methods, and approaches to representing these topics usually differ as a function of the epistemology of the individual teachers' underlying disciplines. These substantial differences legitimate the needs of both prospective and inservice science teachers to develop topic-specific PCK as an instructional paradigm when they implement science curriculum and when they routinely reinforce the sociocultural perspective of their specific and distinctly different communities of inquiry.

This research uses ideas from the philosophy of science and sociocultural theory to study the applicability of the PCK taxonomy at the topic-specific level on the teaching and implementation of evolutionary curriculum. Differences in the science communities of biology and geology were viewed from a sociocultural perspective and used to aid in the interpretation of differences in teaching similar curriculum. In particular, the research question that guided this investigation is straightforward: How and why do geology and biology teachers implement the same curricular concepts of evolution from distinctly different perspectives?

Methods

The inquiry process that guided this study was qualitative in nature; it was a case study in both theory and action.[23] We conducted this case study with 12 secondary preservice and inservice teachers who were substantially grounded in either the geological or biological science communities of inquiry. These cases represented the unit of analysis for the study, and we gave each educator a pseudonym in order to protect anonymity. We chose earth and environmental science and biology teachers based on distinctions within their sociocultural communities. From a sociocultural perspective, the two groups of teachers represented different communities of practice, even though both groups shared the overall framework of the collective science education community. The concept of evolution served as a common identifiable theme central to the curriculum of each discipline, a platform from which both groups of teachers were able to participate, and a common denominator for the researchers to use in the examination.

For the purposes of data collection, we chose a convenience sample from a geographically accessible area. The sample consisted of eight prospective and four inservice secondary biology and geology teachers. Preservice teachers were enrolled in the first author's secondary science curriculum class and a subsequent student-teaching field experience. All teachers in the sample volunteered to take part in the study. The inservice teachers who volunteered to participate taught either biology or earth and environmental science in local suburban area high schools and had an average of 25 years of teaching experience. Both novice and experienced teachers were chosen because they represented diversity within their ascribed sociocultural communities. The cadre of educators making up the case study afforded us both richness and depth of analysis.

Data Sources

The inquiry focused on the differentiation of instructional methods used for topics and concepts of evolution. We used multiple data sources throughout the research. First, we observed educators teaching evolutionary concepts in the classroom setting. During these observations of the preservice and inservice instructors, we took field notes and then summarized those notes. A second data source consisted of semistructured interviews with each preservice and inservice teacher. The semistructured questions allowed participants to offer explicit responses to designed questions, and they provided opportunities for the interviewer to probe the implicit nature of the participants' knowledge. The questions we used were informed by our experiences in teaching biology and earth science in secondary schools and by knowledge of previous research on science teachers' learning and teaching. We audio-recorded and transcribed all interviews for completeness. A third data source consisted of unstructured conversations with inservice teachers in informal settings. The main purpose of these conversations was to solicit teachers' verification of our understanding of the interview data; it also permitted a deeper investigation of indistinct topics we identified. We also collected documents pertaining to the secondary science methods course (e.g., philosophy statements, journals, and assignments) and used them in generating questions asked during interviews.

Data Analysis

We analyzed all text data (e.g., interview transcripts, documents, field notes, assignments, and journal entries) using qualitative content analysis. We each independently established emic categories based upon the units of meaning and their relationship to the research questions. Together, we discussed these derived categories and clustered them to form larger categories.[24] We both determined subcategories to organize the data further. Some of the emergent broad categories served as the foundation for questions in the participants' unstructured conversations.

In addition to establishing broad categories, data analysis was also consistent with the sociocultural theory underlying this inquiry. As transcripts from the interviews and field notes were read, we coded units of analyses based upon communities of teaching experience—

preservice or inservice—and on PCK—biology or geology.

Results

This section focuses mainly on the interview results, augmented with data from field notes, assignments, and journal entries. Two major themes—instruction and curriculum—guide the presentation of results. Within each theme and subtheme, data reflect the sociocultural communities of the preservice and inservice biology and geology teachers.

Instruction

Nature of Science. The preservice biology teachers mainly directed their instruction according to positivist and traditional ways of teaching. It is reasonable to believe that their practice may have related to their lack of experience in understanding the content topics, students' backgrounds, and multiple pedagogies. For example, Katie stated that potentially controversial issues could be dealt with at the outset of a class. She told her students that "evolution is a fact." She then tried to engage her students in dialogue about the meaning and interpretations of fact versus theory by asking "if you can think of anyone who would say that's not true." Based upon students' responses, Katie initiated her lesson plan on "how evolution occurred, the mechanism of it and the theory."

Experienced biology teachers, in contrast, were more likely to discuss and share ideas about interpretations of evolution with their students than were the teacher candidates. Thus, they exemplified a different community of practice based both upon teaching experience and PCK knowledge. For example, Jackie mentioned that she wanted her students to recognize that "there is evidence, that it's not just a wild theory; and [to] be systematic when they use DNA and fossil records, and . . . to independently show the same relationship." Jackie was able to engage students to weigh the meanings of fact and theory within the context of evolution.

The preservice geology teachers, like their biology counterparts, taught very didactically. Still, they differed in how they taught the evolution topics. One preservice geology teacher, Roy, possessed more content background than did the other preservice teacher, and this attribute became obvious in his approach to the teaching of evolution. "I think specifically from a geologic standpoint, I try to introduce evolution. I tell them what it strictly means; it's just change." Roy used many hands-on activities related to fossils and strata to reinforce the evolutionary concepts. On the other hand, the other preservice geology teacher, Suzie, used mostly biological analogies and stories to teach the concepts of evolution and natural selection to her earth science students. In these instances, the different amount of content background influenced the type of community in which each teacher was a participant and reinforced their participation.

The experienced geology teachers, on the other hand, approached the teaching of evolution from a more empirical manner. Sal stated, for example, "Based on the evidence we have that's scientific, this is the way we think things have occurred throughout Earth's history." He and John spoke about teaching evolution more from a factual basis than through discussion. They relied on the evidence from the fossil record to justify their positions. Their community of practice was reemphasized through the use of geologic data and evidence.

Most of the teachers used a “scientific” approach in their teaching of evolution. Nevertheless, distinctions were apparent between preservice and inservice teachers and between geology and biology instructors. The preservice teachers taught mainly from a factual perspective, whereas the experienced teachers, especially the biology teachers, used more discussion of issues as part of their instruction. Along similar lines, the geology teachers used facts from the fossil record to teach concepts, whereas the biology teachers used discussions on issues related to the evolutionary topics.

All the geology and biology teachers offered suggestions for laboratory sessions, activities, and demonstrations (see Figure 1). When asked to suggest ideas to their classmates, the preservice biology teachers tended to suggest more examples than did their geology counterparts. These biology teachers also used more inquiry and hands-on types of labs and activities. As part of the instructional sequence and choice of activities, for example, Peggy believed that

> during the whole year you have to bring in evolution into every subject because it is intertwined with everything, and then also have a unit where you concentrate just on evolution because if you can't do that, you are avoiding the issues.

Janice introduced her unit on evolution by using a cooperating teacher's hamsters. She asked her students “to make some observations about the hamsters” as she wandered around the room logging the volunteered answers regarding similarities and differences. Janice transitioned the discussion into a “short lecture” covering some of the topics in the textbook's unit on evolution. In another example, Peggy used a bowl of jellybeans to highlight the concept of natural selection. She placed the bowl of jellybeans on her desk. When students entered the class, they picked and ate all of the colored jellybeans, leaving the black ones. Peggy stated, “And that's a form of evolution, because the black jellybeans survived, and they're going to reproduce and make more black jellybeans.” Kathy exemplified the evolutionary concept of change over time in another laboratory exercise: “We did the horse lab, which was comparing the cheek span, the teeth width, in the horses over millions and millions of years. And they drew a graph of how it changed over time; over 5 million years it was 0.1 centimeters.” Through the lab she attempted to dispel the myth that evolutionary change is rapid.

Figure 1. Laboratories and Activities in Evolution Implemented by Biology and Geology Teachers

Laboratories/Activities	
Biology	**Geology**

DNA analysis—Gorilla, human, and chimp Hominid skull comparison Hamster comparison Fossil analysis "Barbellus" activity Horse cheek and teeth lab Geological time line construction Jelly beans activity Goldfish and Hardy-Weinberg lab Fish frequencies activity	Catastrophism vs. uniformatarianism debate Geological time line construction Stream lab with cross-bedding Rope or string time line activity Colored toothpicks in grass activity Hamster/rabbit breeding lab

The experienced biology teachers appeared better prepared to explain evolution in "different ways" so their students did not "shut down immediately." For example, all of the biology teachers at one high school used the same fossil inquiry lab because they knew students would respond well to the content. Students studied fossils and were asked "little questions, like 'How do you think this is formed?'" Another biology teacher at a different high school suggested a bead activity that demonstrated the close alignment of human, gorilla, and chimpanzee DNA. Teachers used the hominid skull and barbellus labs to emphasize the concepts of natural selection, adaptation, mutation, and survival of organisms. The barbellus lab was a favorite among many of the respondents, as Jackie's interview account demonstrated:

> One that a lot of the kids seemed to get into a lot was this activity . . . dealing with this fictional organism called "barbellus." Students were given part of the handout, [which] was just kind of a cross-section of a fictitious creek somewhere with all the strata and with the locations where all the little fossils were found. And then on all the other sheets they had pictures of all these little fossils. And then the students had to arrange those and make connections and kind of trace an evolutionary family tree of this; they had to make the connections.

The preservice geology teachers employed few analogies or activities, but they did emphasize specific activities that focused on the fossil record and time. In addition, these geology teachers used more examples with biological terms in their explanations of historical events than the biology teachers used examples with geologic terms. For example, Roy used a debate about the demise of the dinosaurs as a way of contrasting gradual and cataclysmic change. "That ties biology into geology because of the idea of volcanism actually changing the environment of the earth, causing the demise of 70 percent of all species." Suzie used a similar lab to emphasize the evolution of the earth system, change over time, and fossil records in rock strata. “There is a pile of sediment from phosphate mines in the eastern part of the state that contains a wealth of fossils (shark's teeth, bivalves, even fecal pellets) that Mr. Ham allows the students to dig through and identify.” Both biology and geology teachers believed that a fossil lab was ideal for emphasizing different evolutionary concepts. The main curricular difference between the fossil laboratories was the geology teachers' exclusion of a hominid focus.

Many of the activities used by experienced biology and geology teachers were shared with preservice teachers and had been learned, in many instances, in the preservice teachers' content development in college science courses. In essence, the biology teachers were introduced to more activities, labs, and analogies, and these subsequently were translated into their teaching practice. The use and implementation of laboratories and activities emphasized the biology teachers' repertoire of vocabulary terms and concepts. The geology teachers used fewer terms, concepts, and analogies during their instruction. Figure 2 compares the number of terms used by the preservice biology and geology teachers. Although the same content was taught in each curricular domain, few terms are duplicated. The difference in number and type of words used reflects differences in the communities of inquiry to which the preservice teachers belonged.

Figure 2. Vocabulary Used to Teach Evolution in Biology and Geology Classes

Biology		**Geology**	
Theory	Mutation	Series of events	Natural selection
Evidence	Natural selection	Earth's history	Survival of fittest
DNA	Microevolution	Slow change	Paleoclimatic event
Fossils	Macroevolution	Cataclysmic	Adapt

Geology time scale	Human evolution	Uniformitarianism	Fossil record
Monkeys	Adaptation	Erosion	Metamorphism
Mechanism	Relatedness	Dinosaurs	Change over time
Change over time	Evolutionary tree		
Morphology	Populations		
Niches in ecology	Biochemistry		
Viruses	Species		
Genetics	Classification		
Frequencies			

Contextualization. The setting and the school community in which these teachers taught influenced some of their decisions on what, how, and why to teach evolutionary topics. Ultimately, for some teachers, their perceptions of community pressures led them to fear teaching and learning about evolution. Most of the biology teachers, in fact, were apprehensive about teaching evolution. An exception was Janice, who believed that issues or controversies surrounding the instruction of evolution were not present in the school district in which she taught. Her instruction took place in a “very progressive community,” and even though “there may be people who didn't agree with evolution, at least they listened.” On the other hand, Peggy recognized the controversy and did not want to marginalize her students' views or beliefs; she also believed that she would alter her instruction and curriculum in evolution based on her local community. Katie believed that a reasonable criterion was what “is acceptable within your community." She also suggested allowing students to talk about the issues surrounding evolution and to get the "preconceptions of what evolution is" out in the open through discussion.

Geology teachers had fewer concerns about teaching evolutionary topics because they perceived the topics as being more historical and inanimate. Roy explained why evolution was not a fearful topic to teach or to learn in geology: "You get into evolution of the Earth, which doesn't seem to . . . strike as much fear into [students] as with biology." The secondary school students' fear focused on the realization that "we're only two steps ahead of chimpanzees." This fear resulted from their misconception that evolution occurred over only a short period of time. Even though fossils were used, explained, explored, and defined in geology, their relationship to human life was not explicated. As Suzie stated, "We evolved from apes, and within geology, that's not even touched really."

Each participant's parent discipline had a different view of teaching evolution within the context of the local population. The biology community of practice had more concerns due to the perceived focus on hominid evolution, whereas the geology community of practice was able to focus instruction on nonhominid vertebrate fossils and geologic time.

Curriculum

This section focuses on two aspects of the evolution curriculum—unifying framework and students' knowledge. Biology and geology teachers had differing perceptions of evolution as a unifying framework. In addition, the incorporation and consideration of the students' knowledge in their instruction clearly differentiated biology teachers from geology teachers. On the other hand, preservice and inservice teachers displayed little difference around these two curriculum themes. In discussing these themes, we consider only the sociocultural perspective of the distinct science domains.

Unifying framework. All geology and biology teachers believed that evolution should be taught as the underlying theoretical framework for their individual discipline, but the extent of their arguments differed. Biology teachers incorporated evolutionary concepts during units on genetics, biochemistry, evolution, and classification of species. For instance, Peggy linked genetics to the theory of evolution by showing how "biochemistry shows the relatedness between species" and noted the "99 percent shared relationship between human and monkey chromosomes." Peggy also taught a unit that covered the theory extensively, or, in her words, "concentrated just on evolution." Janice considered evolution in her curriculum not as an "arching concept" and not as "just something [she has] to cover," but "somewhere in between." She perceived evolution as both "a theme that covers many things" and a topic to "make relationships." Katie dispersed the concept of evolution throughout her entire curriculum. She believed that "almost everything that you talk about in biology can be traced back to adaptation." From her standpoint, "It is the basis of biology."

In most cases, teachers explicitly referred to evolution. One biology teacher mentioned that she could not "teach biology without talking about evolution or believing that evolution is the unifying framework." Another biology teacher stated:

> That's the unifying theory, so I don't see how you can talk about genetics and evolution, back-to-back units, without incorporating it. And then when you go to invertebrates it is presented in a systematic manner based on evolution . . . this is the order of progression thus far, instead of just saying we move from sponges to barbarians now. So they know it's not just some arbitrary linkage of things.

Geology teachers also believed that evolution was an underlying component, but their reference to evolution was more subtle and continued to be used as a point of reference throughout the year. As one teacher put it,

> [Students] need to understand that anything that they study in geology—whether it's metamorphism, whether it's how rocks are changing, how structures are changing, how the oceans change, how the makeup of continents change—it's all tied into a geologic evolution.

The focus here was more on the concept of "change over time" than on adaptations of species of animals or plants. The language and vocabulary used differed in reference to the curriculum. The geology teachers maintained a different knowledge community by emphasizing what they had learned in their content preparation.

Some of the geology teachers did not perceive evolution as the complete theoretical framework for their content as did the biology teachers. The main reason for this difference seemed to be the perceived difference in how the two domains of science view the concept of time. Evolution was seen to occur more quickly in biology than in geology. For example, the biology teachers used examples of viruses, bacteria, and plants to demonstrate evolution, whereas geology teachers employed field trips to a stream basin to demonstrate that change in species occurs very slowly. The biology examples focused on microevolution (e.g., gene expression in phenotypes and point mutations), whereas those from geology focused on macroevolution (e. g., fossils, rock strata, and uniformatarianism).

The geology teachers seemed to interpret change over time quite differently than did the biology teachers. For example, Sal stated, "It's just that things change over a long period of time." "By the definition of geology, we know that things change very slowly." "I think that it's important for students to understand that geology is not static. It is something that changes, but it's very slow." On the other hand, biology teachers mentioned that evolution just occurred over time. They did not emphasize the duration of the time period, as did the geology teachers.

Knowledge of students. Because of the perceived emphasis on teaching hominid evolution in biology, the biology teachers' responses revealed a more in-depth understanding of student misconceptions about evolution. One misconception that most of the biology teachers noticed was that students "thought that they would change the environment. They didn't realize that the changes occurred first, and depending on what happened to you . . . you survived." As an example, Peggy asked her students, "When you get colder, what do you do? And I said, 'Yeah, but do you grow hair? Your hair doesn't . . . grow and you get warm.'" Another teacher believed that students had to get their hands on something so that the new concept "wasn't too abstract."

Another misconception identified by both biology and geology teachers was that students thought that change occurred in a relatively short time period. John said, “A lot of students don't have any concept about just how long a time that [4.6 billion years] is.” To correct this misconception, biology and geology teachers used geologic time line activities and analogies such as a rope, a calendar, a book, and sand on a beach. For example, Janice used the rope analogy in her biology class to dispel the “misconception that all of this is happening in a relatively short period of time.” Peggy added that analogies such as this one allowed her students to “get an understanding of how everything evolves over time and how miniscule humans are” relative to the age of the Earth. In her activity, students learned that human life makes up only a millimeter in their time line, and the analogy “makes something abstract, concrete to them.”

One biology teacher, in particular, believed that determination of students' prior knowledge of evolutionary topics would be beneficial. With this information, she believed, she would be better able to alleviate students' initial concerns. “I would have started by having just a one-on-one conversation with them, asking them to tell me what they know about evolution; what evolution makes them think of.” She continued: “I think a lot of the problem is that the kids really don't know what the problem is with evolution.” By beginning with a discussion and then progressing to a time line activity, Peggy was hoping to engage students into the science content rather than the religious or emotional aspects of evolution.

When confronted with teaching evolution, the biology teachers anticipated more of the students' concerns and worries about evolution than did the geology teachers. The theme of evolution or change over time was more seamless in the geology curriculum and instruction. In biology, however, few teachers emphasized evolutionary concepts throughout the year through periodic integration with different biology topics. In the geology classes, time and evolutionary processes were less important aspects of the content than they were in biology, thus reinforcing the idea that the two communities of inquiry differed epistemologically.

Discussion

The guiding question for this study concerned the processes through which science teachers taught differently even though their curricular content was similar. Preliminary findings and thoughts focus on four areas that define biology and geology as separate epistemological communities of practice. We make no claim, however, that all teachers (preservice and inservice) within a community are situated similarly. Variance within each community surely influences how the teachers viewed specific topics.

Many inservice and preservice teachers taught evolution by addressing it directly and in a traditional manner. Other teachers incorporated hands-on activities using an inquiry approach. When differences in instruction existed, preservice teachers relied on more direct instruction due to their lack of knowledge about the students' backgrounds within a community and lack of topic-specific activities, labs, and analogies.

Geology teachers, however, knew more about biology content topics and concepts than biology teachers knew about geology content topics and concepts. This knowledge enabled the geology teachers to integrate geologic terms and themes with those found in biology. The geology teachers also used the students' prior knowledge in biology to relate and to focus new content. The only exception to this generalization was geology teachers' general ignorance of genetics. For example, geology teachers did not have sufficient knowledge of examples and topics in genetics that they could relate to their instruction on fossils. This example highlights the topic-specific nature of evolutionary content and lends evidence to the proposition that biology and geology have separate communities of practice that are substantiated at the topic-specific level of teachers' PCK.

Biology instruction emphasized the human, life, and animate aspect of evolution, whereas geology instruction focused on rocks, earth, and inanimate objects. This distinction obviously led to discussions and criticisms of human evolution as being correct or incorrect during the biology instruction. It also led to more discussions focused on "monkeys" and religion in the biology classes. Each community of practice also maintained a different perspective of evolutionary time and the reasons for evolution, and this was reflected in teachers' knowledge of content and how it would affect their students.

The evidence supports a belief that the "nature of geology" and the "nature of biology" are distinct from each other. Just as the nature of mathematics and the nature of science differ, the results of this study offer a lens through which to view the domains of biological and geological instruction as related directly to separate communities of inquiry for the development of teachers' topic-specific PCK. A potential outcome of a related future study reasonably could be a list of attributes that explicate the differing natures of geology and biology. Precedents for such inquiries exist.[25]

The inclusion of evolutionary topics in the biological and geological sciences seems to be irrefutable. Despite the recent push to exclude evolution from the curriculum, additional educational research should seek to understand the subtle differences between domains of subjects and how these differences influence teaching and curriculum development.[26] A broader understanding of the various domains of knowledge, in which differences in curricular approaches are highlighted and learned, should lead to progress in both the teaching and learning of topics and concepts of evolution.

What implications do these findings have for classroom supervision and curriculum? Congruent with those found in related studies, these data suggest new understandings between the epistemological ideas that underlie distinct yet related domains of science. By understanding the differences in how the two groups of teachers teach the evolution curriculum, supervisors can promote a cross-domain vision of science content. Sharing ideas, instructional methods, labs, and activities among teachers and domains of science should accentuate preservice and inservice teachers' learning of the content and dispel common misconceptions.

The differences between the two domains of science and their approaches to teaching curricular topics in evolution largely are preconfigured by differences in the communities of inquiry. The communities of inquiry are the distinct domains of different science epistemologies that have been established by their members through inquiry, communication, and practices. The structure of these domains remains solid and likely can be altered only when a teacher or a member of the community undergoes a dramatic "conceptual change" in content understanding and membership in another community. Supervisors should be aware of the difference in communities of practice in all subject areas (e.g., social studies, science, and foreign language) because they impact a synthesis of agency and structure.[27] This knowledge should foster more specific recommendations and suggestions about how to teach specific content (i.e., PCK). The specific curriculum content is differentiated only at the topic-specific level. This understanding justifies, in no small measure, the PCK taxonomy within a sociocultural perspective.

Endnotes

[1] Gerald Skoog, "Topic of Evolution in Secondary School Biology Textbooks: 1900–1977," *Science Education* 63 (May 1979): 621–640; Gerald Skoog, "The Coverage of Evolution in High School Biology Textbooks Published in the 1980s," *Science Education* 68 (February 1984): 117–128.

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