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ABSTRACT

This paper focuses upon the process of using curriculum and instructional frameworks to develop a curriculum unit in the earth sciences. The work stems from a graduate level seminar in science education which required participants to use a curriculum framework to design a unit of individualized science instruction. This research was guided by Duschl's thesis that the growth and development of scientific theories can guide decisions about what the most important content is. The paper focuses upon three issues: (1) the need for a thinking curriculum; (2) the rationale behind the curriculum and instructional frameworks; and (3) the rationale behind selecting content for the specific curriculum: the development of theories for the earth's interior structure. The proposed curriculum places the evaluation of six historical models of the earth's interior structure as the focal point of instruction. It includes individual, collaborative, and classroom activities centered around the evaluation and debate of the dynamic roles which evidence, technology, and aims of research have played in the development of scientific models. It offers opportunities for related laboratory and research work, classroom dialogue and presentation, and the individual and social construction of multiple models so as to foster conceptual change in learners and meaningful understanding of the goals and products of scientific endeavor. Contains 34 references. (Author/MDH)

Using Curriculum Frameworks to Incorporate the History and Nature of Science and Technology into Earth Science Instruction

by

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Abstract

This paper focuses upon the process of using curriculum and instructional frameworks to develop a curriculum unit in the earth sciences. The work stems from a graduate level seminar in science education which required participants to use a curriculum framework to design a unit of individualized science instruction. Curriculum frameworks commonly contain a rationale behind what knowledge, skills, and values they recommend be addressed, some explication of content to be covered, and suggestions as to where and how such recommendations be implemented. Curriculum frameworks are, by their very nature incomplete, requiring added effort and materials to develop a complete scope and sequence, select topics and activities, and resolve issues of management and materials. To answer the curriculum question "What to teach?," this research was guided by Duschl's (1990) thesis that the growth and development of scientific theories can guide decisions about what the most important content is. Thus, the curriculum unit developed here merged Duschl's epistemological perspective - that the procedural guidelines that philosophers of science have proposed for explaining the structuring and restructuring of scientific theories can be a tool for classroom teachers - with the curriculum and instructional framework for incorporating the history and nature of science and technology into science instruction jointly developed by BSCS and SSEC (1992). This paper focuses upon three issues: 1) the need for a thinking curriculum, 2) the rationale behind the curriculum and instructional frameworks, and 3) the rationale behind selecting content for the specific curriculum: the development of theories for the earth's interior structure. The proposed curriculum places the evaluation of six historical models of the earth's interior structure as the focal point of instruction. It includes individual, collaborative, and classroom activities centered around the evaluation and debate of the dynamic roles which evidence, technology, and aims of research have played in the development of scientific models. It offers opportunities for related laboratory and research work, classroom dialogue and presentation, and the individual and social construction of multiple models so as to foster conceptual change in learners and meaningful understanding of the goals and products of scientific endeavor.

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Introduction

Curriculum reform proposals (AAAS/Project 2061; 1993; NSTA Scope and Sequence, 1992; British National Curriculum, 1989; NARST/NSF Curriculum Reform) have served to expand what ought to be a part of the science curriculum through recommendations to include topics that explore the growth of scientific knowledge; that is, topics in the history and philosophy of science. For example, the recommendations of Project 2061, composed in the book Science For All Americans (Rutherford and Ahlgren, 1990) include the following statement:

> *Science for All Americans* is based upon the belief that the scientifically literate person is one who is aware that science, mathematics, and technology are interdependent human enterprises with strengths and limitations; understands key concepts and principles of science; is familiar with the natural world and recognizes both its diversity and unity; and uses scientific knowledge and scientific ways of thinking for individual and social purposes. (p. ix, preface)

Rutherford and Ahlgren (1990) propose that essential elements of science instruction include the nature of scientific endeavor as human enterprises, some of the great episodes in the history of the scientific endeavor, and some crosscutting themes that can serve as tools for thinking about how the world works.

This call for change as to what constitutes meaningful knowledge in science classrooms requires a creative effort which blends cognitive theories of learning and domain-specific content within a curriculum framework which teachers can employ for instructional design. Bybee, Giese, Ellis, and Parisi (1992) provide such a framework. Curriculum frameworks commonly include a discussion of the goals and rationale for teaching the knowledge, skills, and values recommended by the framework, some explication of the content to be covered, and suggestions as to where and how the recommendations should be implemented within schools. Bybee et. al. (1992) describe curriculum frameworks as an intermediate step between the general idea for a curriculum and the specific curriculum. A curriculum framework is a flexible guide for curriculum developers, who must add materials and effort to outline a complete scope and sequence, situate concepts and skills, and resolve practical matters of management and materials. While such flexibility is desirable, there is always the chance that the resultant curriculum may vary from the framework.

This paper stems from a graduate level seminar which asked participants to design a unit of indivdualized science instruction from a curriculum framework. Having decided to use the BSCS curriculum framework, a perspective was needed to guide the decision-making process during the move from the curriculum framework to the specific curriculum. The approach taken here to resolve the curriculum dilemma of deciding what to teach in the earth sciences gathered much from the epistemological perspective of Duschl (1990, 1992). Duschl (1992) illustrates how cognitive psychology has revealed to educators that expert knowers use both declarative or domain-specific knowledge and procedural or strategic knowledge. He describes psychologists, philosophers, and science educators as achieving a consensus concerning the parallels that appear to exist between the growth of scientific knowledge in a discipline and the growth of knowledge in individuals. Duschl (1990) held the thesis that the analysis of the growth of scientific theories can guide decisions about what the most important content is. Duschl argues throughout his book that epistemological (knowledge growth) models for curriculum development maximize the processes used in the teaching and learning of science because they ensure that the procedures for designing and implementing instructional content are congruent with the procedures students are asked to employ in learning the content.

The aim of this paper is to show that analysing the growth of scientific theories can aid curriculum planners and teachers make a meaningful transition between a curriculum framework and effective practice in science classrooms. Additionally, that the implementation of such practice will also satisfy the broader science education curriculum reform proposals by meshing history and philosophy of science with cognitive research. It will be argued that through the approach taken here, the individual student, through interaction with peers, teacher, and materials, can develop an improved conceptual understanding of the growth of scientific knowledge and then use that knowledge as empowerment toward enhanced thinking about science. Before this framework is revealed, I will review perspectives on how we can help students develop meaningful, conceptual understanding in science classrooms. Afterall, the development of a thinking curriculum for an earth science classroom was the impetus behind this entire study.

Purpose: Developing a thinking science curriculum

The essence of modern cognitive theory is to format instruction in such a way that it puts learning in its proper perspective. Specifically, Resnick and Klopfer (1989) call for learning that that is thinking- and meaning-centered, while insisting on the centrality of knowledge and instruction. The modern constructivist theory of learning views learners not as information compilers but rather as builders of knowledge structures (Resnick and Klopfer, 1989). Because cognitive research demonstrates that learning requires knowledge and that knowledge must be constructed by students, instructional sequences must be designed so as to give children opportunities to assess their prior knowledge within a domain, examine the legitimacy of scientific knowledge claims, build knowledge structures, and evaluate their own models and structures in the face of anomalous data or conflicting arguments. Providing instructional opportunities which answer all the traditional demands of science education yet emphasize the proposed self-regulated, constructivist theory of learning is very challenging. Instruction must be manageable for teachers and students, provide opportunities for assessment, integrate laboratory activities, be reflective, and motivate and stimulate students. However, science education research is providing increasingly glowing accounts of how placing individual learning and the construction of conceptual understanding of scientific knowledge in perspective works toward accomplishing these goals.

Minstrell (1989) suggests that rooting physics concepts in common, everyday experience has led to greater responsiveness in his students because it builds an intellectual climate that fosters concept development. Minstrell views laboratory activities as having greater significance to individuals when they are designed to allow students to test and evaluate their own ideas. He also suggests that teachers must provide not only the situations, but the time necessary for students think about the inconsistencies between their ideas and the results of laboratory demonstrations and activities. Larkin and Chabay (1989) address factors which affect student motivation in science learning. They describe the importance of intrinsic motivation, or the willingness to engage in activity for its own sake. Larkin and Chabay (1989) state that intrinsic motivation is determined by finding an optimal level in three aspects of intrinsic motivation: 1) challenge in a task, which promotes the desire for achievement; 2) the sense of control that the student has in a learning situation, which includes being an active participant and having choices of tasks or approaches to tasks, and; 3) curiosity, wherein novel or counter-intuitive elements can provide a sense of intrigue which motivates individuals toward exploration and resolution of conflict.

Lemke (1990) states that in order to place thinking about science in its proper perspective in science education, students need greater opportunity to use the language of science. Lemke thoroughly documents the restrictions placed upon student thinking and participation that result from the dominance of the triadic dialogue in science classrooms (Lemke, 1990). The triadic dialogue (teacher question-student response-teacher evaluation/elaboration) is teacher-controlled, not student-controlled, and is high on quantity while low on quality. Rather, Lemke calls for giving students opportunities to speak at length through student questions, individual and group presentations, cross-discussion, and small-group work. The role of the teacher must shift from speaker to listener. Lemke also suggests that teachers have students write more about science topics. These changes shift the role of the teacher from one of predominantly talking science to students to that of teaching students the skills of using scientific language.

The work of Paul (1991) echos Lemke's call for a move away from the triadic dialogue in classrooms. Paul distinguishes between the common method of didactic teaching, which consists mainly of teaching by telling and learning by memorizing, and a dialogical and dialectical model of teaching and thinking, which involves extended exchange between different points of view. Paul (1991) states that dialogue promotes thinking in science classrooms because, unlike a didactic monologue, students engaged in dialogue have more than one line of reasoning to consider. Paul describes dialogue as becoming dialectical when ideas or reasoning conflict, requiring that participants actively seek to assess the strengths and weaknesses of each. Paul (1991) presents a statement which summarizes his view of what students should be encountering in classrooms. Its value warrants quotation:

> "But if gaining knowledge really is a fundamental goal - and all curriculums say it is - then most students should be spending most of their time actively reasoning. That is, most of the students most of the time should be gathering, analyzing, and assessing information. They should be considering alternative competing interpretations and theories. They should be identifying and questioning assumptions, advancing reasons, devising hypotheses, thinking up ways to experiment and testing their beliefs. They should be following up implications, analysing concepts, considering objections. They should be testing their ideas against the ideas of others. They should be sympathetically entering opposing points of view. They should be role-playing reasoning different from their own. In short, they should be reasoning dialogically and dialectically (p. 281).

Paul essentially demands that students have opportunities to dialogue, to do what Resnick (1987) calls "think aloud." Thinking aloud allows students to critique and shape one another's performance by making thought processes visible, not just the results. In a review of programs designed to teach higher-order thinking, Resnick (1987) concluded that successful programs involve cooperative problem solving and meaning-construction activities. Developed from the theory of Vygotsky (1978), this line of research suggests that group problem-solving allows novices to participate in complex tasks, see skilled thinkers (the teacher and more advanced peers) modelling thinking strategies, move toward taking over more of the work themselves, and gain a greater appreciation for how individual elements in the process contribute to the whole.

These valuable insights into science learning and understanding pose a great challenge to classroom teachers. There is a challenge involved in encouraging student reasoning, talk, and writing that extends beyond the implications for a change in control, direction, or dominance of classroom discussion and activity. Lemke's call for greater student talk requires a type of controlled flexibility on the part of teachers. Teachers should encourage students to say what they mean and understand in their own way while making clear to students that scientific terms do have specific meanings. It is a challenging line to walk, but it seems essential for student thinking. It is certainly more desirable than the "parroting" of science talk all too common on test responses and in classroom discussion.

The benefits of encouraging science talk make risks and challenge worthwhile. For example, encouraging science talk is also conducive to a constructivist approach to learning. Similar to the conclusions reached by Minstrell (1989), Lemke (1990) stresses the importance of exposing students' alternative views on concepts. This entails getting students' ideas "on the table" for everyone, and then elucidating the similarities and differences between the ways students talk about science concepts and scientific ways of talking about them. Lemke asserts that teachers should be as concerned about the ideas *of* students as they are about the ideas they wish to present *to* students.

Considering what students think is an important element of successful science instruction. Numerous studies of children reveal that their curiosity and attempt to make sense of the world around means that they arrive in science classrooms with ideas about how the world works the way it does. Osborne and Wittrock (1983) describe how important it is to realize that children must actively construct or generate meaning from sensory input. Combining the notion of generating meaning with aspects of information processing theory, Osborne and Wittrock (1983) developed the generative learning model, wherein the child acquires knowledge by constructing it from within. Take, for example, a situation where a teacher says something like "there is force on a ball rolling down a hill." This must be considered for what it is, simply a set of sounds received as aural input and which itself has no inherent meaning. The child must generate links between this input and those parts of memory store which the child considers relevant, but which may not be intended by the teacher. Hearing a teacher use the term 'magnetic flux' may result in a child generating a link to soldering flux that her parents have used (Osborne and Freyberg, 1985).

Student thinking can also be encouraged through specific metacognitive strategies which require that students wonder why they are doing what they are doing the way that they are doing it. More concisely, students ask themselves "Does this make sense?" Costa (1984) defines metacognition as our ability to know what we know and what we don't know. Costa elaborates on the concept of metacognition as that of having the ability to produce a strategy or plan to obtain the information we need, and to be conscious of the steps in our strategy during the problem-solving task. In order to foster the development of metacognitive abilities in our students, Costa (1981) recommends that educators use a variety of instructional strategies which infuse self-monitoring into the learning environment. One such strategy is to have students maintain a journal in which they must actively write and illustrate as they reflect upon their thoughts, actions, and understanding.

The journal is for reflecting, sense-making, and self-assessment, and should be an on-going activity, as should be metacognition.

The sole criteria for journal entries is that they demonstrate metacognitive processes in action. Students will be expected to be questioning themselves about their understanding of the nature and quality of evidence, the status and evolution of their ideas, the beliefs that they hold in high regard and those which they feel uncertain about, the relationships between concepts, the possible reasons for successes and failures, and postulating steps that they need to take to resolve conflicts. Costa (1984) describes how the journal-writing process encourages the revisiting of initial perceptions, the comparison of changes in those perceptions, the charting of progress in strategic thinking and decision-making, and the identification and differentiation between unsuccessful and successful pathways toward individual understanding. Journals serve teachers as well as students. Journals provide a teacher with insight as to how children are making meaning of the information that they have encountered. Journals give teachers status reports on student understanding that can be used strategically to guide students.

In summary, fostering the development of understanding in students requires that provide we them ample opportunity to express what they think and know, to consider the opinions of and listen critically to the ideas of others, and to develop and use strategies which aid in the construction, representation, and assessment of their developing understanding. This is challenging, difficult work for both teachers and students. However, curricular and instructional frameworks that focus upon a student-centered, constructivist approach to science learning do exist. These frameworks can guide science educators willing to face the challenges involved in putting individual learning and restructuring in perspective in science classrooms. In this next section, I will discuss the rationale behind two such frameworks, the curriculum framework for teaching about the history and nature of science and technology of BSCS/SSEC (Bybee et. al., 1992), and the method of incorporating the evaluation of scientific theories into science instruction outlined by Duschl (1990).

Rationale behind the curriculum frameworks

The BSCS/SSEC curriculum framework emphasizes the use of major themes which integrate the history and nature of science and technology (HNST) in school programs, the contributions of women and minorities, active learning approaches for science and social studies, and an accurate presentation of the disciplines of both science and technology. A driving force behind this curriculum framework is the national concern for producing a scientifically and technologically literate citizenry. Educational researchers have argued that science literacy includes the history and nature of science and technology (Duschl, 1985; Bybee, 1986; Hurd, 1987; NSTA, 1990)[1]. However, developing curriculum programs that make HNST an aspect of science teaching has been difficult for three reasons. Bybee et.al, (1992) point out that no conceptual framework exists that describes teaching and learning strategies for HNST. Secondly, a laboratory approach to science education is often wrongly assumed to represent the nature of science and vignettes of scientists. Thirdly, science teachers often know little about the history and nature of science, so that they include little of it during instruction. The BSCS/SSEC curriculum framework was designed to address these three issues (a companion volume of background papers to the framework was designed the address teacher education: Teaching about the History and Nature of Science and Technology: Background Papers: Bybee, Giese, Ellis, Parisi (1992).

The BSCS curriculum framework is centered around a view of scientific literacy that has two dimensions - that of understanding science and technology as human activities and that of understanding that science and technology are embedded in cultures. These dimensions stress an understanding about science and technology as it compliments understanding the products of science and technology. The framework contains goals as to what citizens should understand about the nature of science and technology. It also contains related conceptual themes that should serve as the foundation for teaching about HNST. These themes include:

- Science is a way of explaining the world
- Technology is a way of adapting to the world.
- Science and technology are activities that involve human values.
- The social, cultural, and environmental contexts within which they occur influence the conduct and context of science and technology.
- Science and technology influence the social, cultural, and environmental contexts within which they occur.
- Science and technology and their interrelationships have changed over time.

Although the goals and themes are elaborated in the BSCS document in more detail than can be provided here, an example for the first theme on scientific explanation will highlight the depth of the framework:

Scientific explanations are based on empirical observations or experiments...
Scientific explanations are made public...

[1]Six chapters of the January 1993 draft of Benchmarks for Scientific Literacy (Project 2061/AAAS) addressthe nature of science, technology and mathematics, human society, historical perspectives, and habits of mind.

Scientific explanations are tentative...
Scientific explanations are historic...
Scientific explanations are probabilistic...
Scientific explanations assume cause and effect relationships...
Scientific explanations are limited...
Science cannot answer all questions...

In general, the goals and themes of the BSCS framework are based upon the belief that knowledge of the history and nature of science and technology is a fundamental aspect of scientific literacy. There have been somewhat similar efforts which focus upon the incorporation of the history and philosophy of science in science education. Duschl (1990, 1992) stresses that an emphasis upon the development and growth of scientific theories can lead to sound instruction wherein students construct and restructure their own understanding. Duschl (1990) outlines a set of frameworks which can be used to enable scientific theory to take its proper role in science classrooms. The educational benefits of analyzing theory development are multifold. Most importantly, theory evaluation engages students in a process which has as its goal the understanding of relationships between concepts and the quality and compatibility of knowledge claims. Theory evaluation allows science educators to move away from the declarative exposition of scientific knowledge toward a procedural process in which students must identify core concepts, consider the methods and aims of research, and gain a historical perspective of the growth of knowledge (Duschl, 1990).

The rationale behind calling for such a change in instruction is the recognition that teaching knowledge about science is different than teaching scientific knowledge. Knowledge about science provides a richer portrait of the nature of science because it employs both faces of science; that is, it addresses not only *what* we know, but addresses *how* we have come to arrive at this knowledge. Duschl (1990) presents the position that science has two important faces - the product of science face and the process of science face. Furthermore, he argues when a curriculum strives to accomplish educational goals centered around the "what we know" face of science (the products of science), students miss out on the how and why we know face of scientific endeavor. Curricula which stress scientific knowledge outside of its developmental context tend to be epistemologically flat (Kilborn, 1982) because the emphasis is on the final form version of "what we know" scientific knowledge.

In contrast, a more comprehensive approach to science education is one that employs history and philosophy of science with the development of scientific theories. History and philosophy of science reveals the path of reasoning, the social and technologic influences, and the debate and conflict which occur during the growth of scientific understanding. It includes the products of science while addressing the way in which scientists have come to acquire scientific understanding. Thus, while educational goals centered around scientific knowledge have merit, we do students a disservice if we fail to educate them about the rational evolution of scientific knowledge. History of science reveals that the evolution of scientific knowledge has been centered around the growth of scientific theories. Cognitive research reveals that the development of knowledge in a scientific field parallels the growth of knowledge in the learner. Rather than stress the final products of knowledge, which in themselves do not provide understanding, we need to illustrate that scientific endeavor is laden with many false starts, incorrect assumptions, and faulty logic. Individual learners undergo similar experiences in our classrooms, primarily because they arrive with misconceptions about the world or possess a limited schemata or framework into which they must fit new knowledge. Just as scientists must structure their experiments and ideas within the framework of scientific theories, students must learn to structure new concepts within their own frameworks.

In summary, these two curriculum frameworks provide sound arguments for the incorporation of the history and nature of science and technology (Bybee et. al., 1992) and the analysis of growth of scientific theory (Duschl, 1990) into the science curriculum. This next section reviews how Duschl suggests strategies for selecting the appropriate content for the specific curriculum. It also outlines how the BSCS document provides an instructional framework for implementing that curriculum in classroom practice. The final portion of this paper will address the rationale for selecting specific content in the domain of geology

The instructional frameworks

Duschl (1990) argues that the evaluation of the growth of scientific theories allows for an analysis of the development of knowledge and of the methods and criteria for seeking knowledge can occur. While he points out that evaluating theories is difficult, an examination of the development of a scientific theory is not beyond the scope of science teachers or secondary students. Ronald Giere (1984) has proposed a workable method of testing theories with arguments. In his scheme (shown below), a theory is stated as a hypothesis which can be treated as both a true/false statement and the conclusion of an argument. The argument consists of a set of premises, represented by background knowledge (the existing knowledge claims of science which the theory must not refute), and initial conditions (the states of the system before considering the hypothesis). This framework allows one to test the theory as it stands alone and in comparison to its competitors. This is accomplished by evaluating the strengths and weaknesses of either individual premises (background knowledge or initial conditions) which support the theory (theoretical hypothesis), or by evaluating the internal consistency of a set of true premises. In this manner, a plausible theory should be free of contradictions and false premises. For the purpose of science instruction, the benefit of this method is in the way knowledge claims are broken down into parts. These pieces can be evaluated individually (in historical context) and as the pieces of a larger framework.

Schemata for testing theories with arguments (Giere, 1984)

TH_0	Theoretical Hypothesis	The theory being tested.
IC	Initial Conditions	The states of the system (known facts) before considering this hypothesis.
BK	Background Knowledge	The existing claims of science that the hypothesis should not refute.
P	Premise	The predicted occurrence of the state of some real system described by the theory.

A brief discussion of instructional frameworks will provide a basis for comparing the integrated framework to be used here with other models of teaching and learning. Renner (1982) states that the predominant method of science instruction is characterized by three stages, that of telling, confirming, and practicing. In stage one, teachers "teach" the content by telling students information. In stage two, students verify this information through observation, usually by "performing" laboratory experiments. In stage three, students apply that information by answering questions or solving problems. This hardly seems conducive to successfully implementing a thinking- and meaning-centered curriculum.

In contrast, Osborne and Freyberg (1985) outline several three-stage teaching sequences which relate closely to the five stage model to be implemented here. These models are based in a concern for the cognitive development of the learner (Renner, 1982; Karplus, 1977; Nussbaum and Novick, 1982; and Erickson, 1979). They typically consist of the following three stages: 1). exploration: children ascertain their conceptions, become exposed to alternative ideas, and interact with the concepts in concrete activities, 2). explanation: students work toward clarifying their ideas by reflecting upon their attempts to resolve conflicts raised in stage one, and 3). elaboration/application: the concept is applied to new situations and the range of its applicability is extended.

I have selcted a slightly more elaborate instructional framework because I believe that the integration of theory evaluation into science instruction is a more elaborate process. The instructional framework of Bybee et. al. (1992) stresses the individual construction of understanding and is concordant with the scientific and technologic process. Bybee et. al. (1992) view constructing understanding to be based upon providing opportunities for students to 1). assess their prior knowledge about a topic, 2). encounter a common set of experiences that invites them to examine and question their understanding, 3). encounter specific content and to find out how this knowledge applies to their previous experiences, 4). challenge themselves to elaborate upon their ideas, and 5). come to some conclusions about a certain aspect of how their world works. This five-stage instructional framework consists of engagement, exploration, explanation, elaboration, and evaluation:

Engagement identifies the learning task, makes connections between past and present learning experiences, and anticipates activities and organizes students' thinking toward the learning outcomes.

Exploration provides students with a common base of experience within which current concepts, processes and skills are identified and developed. This phase is based upon students' explanations and is connected to experiences in later stages. Teachers facilitate and monitor interaction between students and instructional material.

Explanation focuses students' attention on a particular aspect of their earlier activity and provides students with an opportunity to demonstrate their conceptual understanding, process skills, or behaviors. Teachers have the chance to introduce a concept, process, or skill.

Elaboration extends students' conceptual understanding and skills through new experiences. Students present and defend their explanations and identify and complete several learning experiences related to the learning task.

Evaluation encourages students to assess their understanding and abilities and provides teachers with opportunities to evaluate student progress toward achieving objectives.

Selecting a topic:

The historical significance of knowing about the earth's interior

The presentation of the development of theories for the interior structure of the earth in earth science curricula can provide an historically-rich introduction to the ways in which scientists attempted to explain large-scale earth processes and features. Some may feel that the development of plate tectonic theory should be the first topic of consideration for earth science instruction. Indeed, the January 1993 draft of *Benchmarks for Science Literacy* (AAAS, 1993) includes the development of the theories of continental drift and plate tectonics as its focal problem in a chapter on the history of science. However, while plate tectonic theory is probably viewed as the frontier theory in earth science, an appropriate pun would be to simply state that knowledge of the interior underlies plate tectonic theory. Lest we forget, plate tectonics suffered a near-death during the early 20th century at the hands of scientists who could not rationalize the mechanism for plate motion (continental drift) within the context of their understanding of the earth's crust and interior. Reasoning in geology did not begin in the 20th century - a rational and understandable restructuring of our view of the earth's interior has occurred over the last 200 years. An examination of this restructuring can provide an opportunity to make scientific and individual change part of the earth science curriculum and serve as an excellent foundation for understanding the deeper context of the debates within the development of continental drift and plate tectonics.

Furthermore, I propose that there is inherent "danger" in the beauty of the global theory of plate tectonics. Plate tectonic theory encompasses so many large-scale geologic processes and events so conveniently that it can be easily trimmed into a declarative statement of knowledge. Plate tectonic theory is typically used in science texts to neatly account for the distribution of land masses, earthquakes, volcanoes, hot spots, and major mountain ranges. In addition to the drawbacks inherent in presenting such a final form and covering law version of science, much of the rich history of the development of earth science is eliminated from instruction, mainly because plate tectonic theory is relatively young. In a poll by Hazen and Trefil (1991) which asked earth science-educators to reveal the fundamental ideas in earth science, the layered structure of the earth was among the eight key ideas they listed. The authors stressed that the interior structure is "an integral part of the presentation of plate tectonics" (Hazen and Trefil, 1991).

Scientists have long recognized that knowledge of the earth's interior provides answers to many different kinds of questions. One of the primary reasons for attempting to model the earth's interior is that the physical and chemical properties of the earth's interior control processes and features at the earth's surface. Thus, geologists proposed theories or models of the internal structure of the earth in order to explain geologic phenomena, such as volcanoes, earthquakes, magnetism, and folded mountains. Similarly, physicists and seismologists proposed theories to help them understand geophysical phenomena, such as the behavior of elastic waves as they travel through the planet, or the origin of the earth's magnetic field.

Another source of speculation about the earth's interior stemmed from cosmology. The condition of the interior is a product of the energy and forces which have acted upon it since its formation. Thus, many early models of the interior came from the application of physics, mathematics, and astronomy to cosmology. Geologic phenomena were the physical evidence used to support a model of an interior structure which resulted during the origin of the planet. For example, the rise in temperature with depth in mines supported the cosmogenic theory that the earth originated as a cooling star (Descartes, 1644). The intertwining of observation and interpretation of geological and geophysical phenomenon with cosmology is of great importance to any model of the interior. If the temperature inside the earth depends upon its history, then it is important to know if it originated as a cold body or as a hot ball of gas (Gutenberg, 1959).

Lacking an eyewitness view of the earth's interior, the effort to identify its structure and properties required the efforts of scientists from many different scientific disciplines, including astronomy, cosmogony, chemistry, physics, and many subdisciplines of geology and geophysics, such as seismology, vulcanology, mineralogy, and structural geology. Researchers in different disciplines built a partial or whole model of the earth's interior which either lent support to or was required by the specific observations which their model attempted to explain. As a result, scientists have proposed no fewer than six models of the earth's interior structure over the last 300 years (Figure 1). The piecemeal approach to a theoretical model isn't always the most efficient way to solve a problem, but it certainly isn't atypical in science. The product of science, scientific understanding, involves explanation, debate, evaluation, competing theories, feedback, and hopefully, resolution. That is why an examination of the development of models of the earth's interior structure should be incorporated into earth science curriculum.

Our knowledge of the earth's interior has grown over time, and we have developed and used increasingly complex technologies in order to acquire this knowledge. However, our understanding of the interior structure can by no means be described as one of linear progression. In fact, a more appropriate statement would be to point out that the advances in both technology and knowledge were brought about by a desire to understand the interior. Scientists in different disciplines gathered and viewed evidence in many different ways. Because the scientific evidence was not centered around one discipline, nor could one line of approach resolve and satisfy all the conditions for which a theory about the earth's interior must account, the piecemeal observations and resulting theory often conflicted with rival theories or different observational viewpoints. While our knowledge of the interior grew, our understanding of the interior evolved. The history of this evolution in understanding is rich with fascinating scientific and philosophical debate.

While few earth science textbooks today fail to include plate tectonic theory, an unfortunate consequence of the survey approach to science is that most present our model of the interior as one which isn't likely to change and which had no rivals. Nothing could be further from reality. In fact, the idea for this work arose from a review of some of the leading geology texts of the earth twentieth century: most included more than one model of the interior structure of the earth. In contrast, the majority of current earth science textbooks indicate that seismology has provided the "X-rays" of our layered earth. It is as though scientists had no thoughts about the interior prior to the development of the seismograph (circa 1860). While seismology probably gives the most reliable evidence in support of a very plausible model of the earth's interior, has this technology removed all doubt about the world below? Does it give full treatment to the rich history of debate about the interior? Scientists and science instructors might be well-advised to heed the advice of Stephen Brush (1982), a historian of science who has examined the development of this theory:

> Today's textbooks and popular science magazines seem quite confident that we have found an answer [model of earth's interior] -- almost as confident as those of a hundred years ago were about a somewhat different answer. On the other hand, our present conception of the earth's structure is qualitatively similar to one that was proposed nearly 300 years ago but subsequently abandoned. So, in reviewing the history of the subject, we should avoid the temptation to assume that modem theories are necessarily more accurate than earlier ones or that certain facts have been permanently established. Instead, knowledge of history should make us less dogmatic in giving answer to our question. (p.)

In contrast with most current approaches, teaching the development of theories for the interior structure of the earth provides instructors with the opportunity to make theory change a part of science instruction. Change and revision has dominated our view of the interior for the last 300 years. Students can realize the rich history and interdisciplinary nature of geology by examining the path of reasoning and by evaluating the evidence crucial for theory testing for each of the six models of the interior. This process engages the learner in an analysis of the people, events, and technologies which have influenced the growth of knowledge about the earth's interior, a knowledge central to an understanding of plate tectonic theory. It also provides a much-needed view of the dynamic nature of the science of geology without excluding the products of scientific endeavor.

Within earth science, our attempts to understand the earth's interior over the past 300 years has led to great debate, changes in theoretical commitments, and subsequent growth of knowledge about the planet. As such, it serves as an excellent example for instructional purposes. This instructional sequence addresses two key questions: Why speculate about the interior of the earth, and how does an examination of this task serve students of earth science. The history of the development of theories for the earth's internal structure has been excellently documented in three papers by Stephen Brush (1979, 1980, 1982). The specific curriculum uses these works of Brush and additional sources in the history of geology to format theory development into frameworks. Given the interdisciplinary approach to earth science, it should not be surprising that Brush pointed out that at least six models/theories about the internal structure of the earth have been proposed (Fig. 1). To more easily evaluate these theories, each one was put into Giere's (1984) framework for testing theories. The themes selected for this paper include incorporating the history and philosophy of science in earth science education so that students have the opportunity to:

1. Examine both the products of science and the process of science through the application of growth of knowledge frameworks to scientific theories for the earth's interior.

2. Construct an improved conceptual understanding of the earth's dynamic and complex interior through an interactive comparison of the historical growth of knowledge regarding the interior of the earth and the growth of individual understanding of the same.

3. Work individually and collaboratively, to express and communicate personal ideas, understanding, and questions orally and in writing.

4. Actively reflect upon their thinking, learning and understanding, and use their curiosity and imagination to explore, discover, and resolve their cognitive conflicts.

5. Develop an appreciation for the dynamic trade-offs between evidence and theory, the challenge involved in investigating a realm which cannot be directly viewed, and the human elements in achieving personal and scientific understanding of the earth's interior.

Conclusions

I have presented a rationale for incorporating the history and nature of science and technology into the science classroom. This rationale meshes well with the call for a curriculum that is thinking- and meaning-centered. In delineating one of the many possible moves from a curriculum framework to the specific curriculum, I have also demonstrated how the evaluation of scientific theories can assist in that most important step. However, the resultant curriculum lies untested at this point. While it outlines a sequence of instruction, it is still largely conceptual and can certainly benefit from the response of critical readers. I would envision it best serving students at the secondary or university level. As the unit lies untested and unevaluated, let me take my last few paragraphs to make one final argument for its use in earth science classrooms.

The curriculum unit in earth science proposed here will present challenges to both teachers and learners. Teachers used to the survey approach that typifies high school science courses may be concerned about the topics they may not be able to cover. They may be concerned about the relevance of what was largely a nineteenth century debate to the everyday lives of their students, and may not readily recognize the potential for intrinsic motivation in students who are 1) provided with a challenging task, 2). given a sense of control over their learning situation, and 3). asked to resolve conflicting arguments. Teachers may also have restructure their classroom practice, shifting from the triadic dialogue that dominates most classrooms to practice that values their role as listener, coach, and manager of dialogue and debate. They will also have to take the time to gain a deeper knowledge of the history of the domain they teach.

Students will also be challenged in this curriculum. They will have to adjust to a new approach to learning, one that places value on their ability to reason and explain as much as it values their understanding of factual knowledge. They will have to learn how to question assumptions, elicit and reflect upon their beliefs, and test their ideas against the ideas of others. Perhaps for the first time in their experience in science classrooms, they will have opportunitites to actively use the language of science. They will also have to consider the social and cultural aspects of science, as well as the products of science.

While this curriculum poses challenges to teachers and students, it also offers great opportunities. It offers a thinking and meaning-centered experience, an opportunity for students to work together to solve problems, an opportunity for conceptual understanding to take place, and an opportunity for an expansion of students' perceptions about the history and nature of science. Duschl (1990) writes that "a science curriculum that focuses solely upon the prevailing knowledge claims or views of science merely teaches scientific knowledge. To paint a complete picture of science, a science curriculum should address not only what is known by science, but how science has come to arrive at such knowledge" (p. 10). This curriculum unit represents a step toward putting the construction and development of scientific knowledge at the core of earth science education.

Figure 1. The six historical models for the earth's interior structure (Brush, 1979).

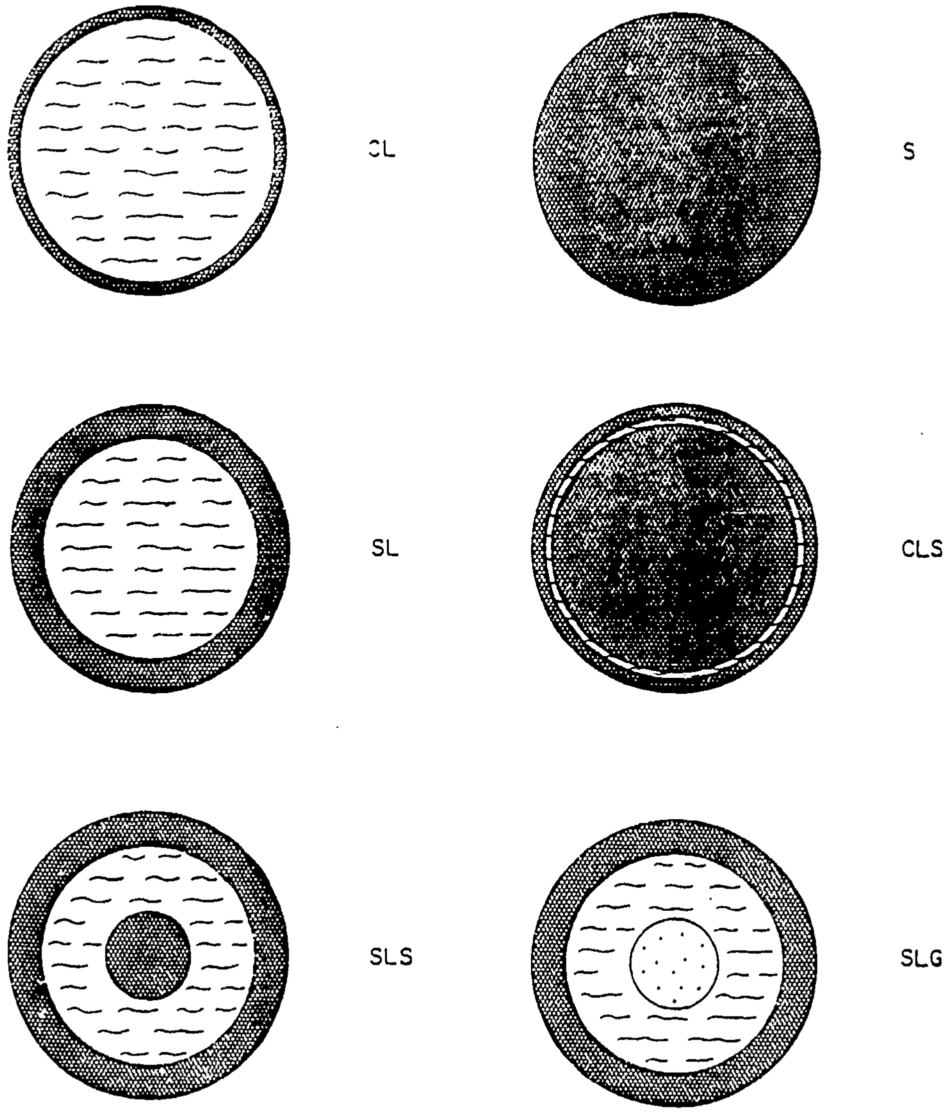

Figure 1

Schematic representation of the six models of the interior of the earth

CL model—thin solid crust surrounding hot liquid interior

SL model—thick solid shell surrounding hot liquid interior

SLS model—thick solid shell, liquid interior, and solid core

S model—completely solid

CLS model—almost entirely solid but with very thin liquid layer under crust

SLG model—solid shell, liquid interior, gaseous (supercritical) center

(Brush, 1979)

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