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Middle School Students' Understanding of the Natural History of the Earth and Life on Earth as a Function of Deep Time.

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MIDDLE SCHOOL STUDENTS' UNDERSTANDING
OF THE NATURAL HISTORY OF THE EARTH
AND LIFE ON EARTH AS A
FUNCTION OF DEEP TIME

A Dissertation

Submitted to the Graduate Faculty of the
Louisiana State University and
Agricultural and Mechanical College
in partial fulfillment of the
requirements for the degree of
Doctor of Philosophy

in

The Department of Curriculum and Instruction

by

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ABSTRACT

The purpose of this study was to use deep time, that is geologic time, as a mechanism to explore middle school students' understanding of the natural history of the earth and the evolution of life on earth. Geologic time is a logical precursor to middle school students' understanding of biological evolution. This exploratory, mixed model study used qualitative and quantitative methods in each stage of the research to explore sixth grade students' understanding of geologic time, their worldviews (e.g., conceptual ecology), and conceptual change.

The study included fifty-nine students in the large group study and four case studies. The primary data collection instrument was the Geologic Timeline Survey. Additional data collection instruments and methods (e.g., concept evaluation statement, journal entries, word associations, interviews, and formal tests) were used to triangulate the study findings. These data were used to create narrative modal profiles of the categories of student thinking that emerged from the large group analysis: Middle School (MS) Scientists (correct science), MS Protoscientists (approaching correct science), MS Prescientists (dinosaur understanding), and MS Pseudoscientists (fundamental religious understanding). Case studies were used to provide a thick description of each category.

This study discovered a pattern of student thinking about geologic time that moved along a knowledge continuum from pseudoscience (fundamental creationist understanding) to prescience (everyday-science understanding) to science (correct or approaching correct science). The researcher
described the deep-seated misconceptions produced by the prescience thinking level, e.g., dinosaur misconceptions, and cautioned the science education community about using dinosaurs as a glamour-science topic. The most limiting conceptual frameworks found in this study were prescience (a dinosaur focus) and pseudoscience (a fundamental religious focus). An understanding of geologic time as Piaget’s system of time (e.g., chronological ordering of events, before and after relationships, duration or evolutionary time) was a necessary conceptual framework for students to develop a scientific understanding of deep time.

An examination of students’ worldviews and the interface of science and religion indicated that students often successfully applied a demarcation between science and religion in their public thinking (e.g., the formal classroom setting), but in their private thinking, the demarcation was often blurred.
CHAPTER 1

INTRODUCTION

The discovery of deep time is geology's greatest contribution to human thought. The ensuing restructure of human understanding was as profound as the Galilean/Copernican revolution when humanity realized that the earth was not the center of the universe; or the Darwinian revolution, when man acknowledged that he was not specially created, but descended from the animal world (Gould, 1987, pp.1-8). Hutton, in March of 1785, introduced a novel and incomprehensible sense of time, deep time, to a world that thought it was 6,000 years old. He disclosed his intent to investigate this new notion of time in his opening statement to the Royal Society.

The purpose of this Dissertation is to form some estimate with regard to the time the globe of this earth has existed (cited in McPhee, 1981, p. 100).

In a synopsis of his rudimentary theory of the earth, which he presented to the Royal Society at that same time, Hutton posited

- The present land on the surface of the earth is not original land but has been formed by secondary causes.
- Before this present world, there was another world of land and sea in which plants and animals lived and present-day forces, tides and currents, operated.
- There is a regular system in which the present land is formed at the bottom of the ocean and raised above the surface of the sea.
- It required an indefinite space of time to produce the present land and an equal space of time to produce the former land (McPhee, 1981, pp. 100-103).
McPhee additionally reports that Hutton’s work

...would gradually remove the human world from a
specious position in time in much the same way
that Copernicus had removed us from a specious
position in the universe (McPhee, 1981, p.100).

Furthermore, Hutton’s discovery of **deep time** (Gould,
1987, p. 96) and the resulting challenge to the Christian
Bible’s account of creation fostered direct antagonism
between science and theology as did both the
Galilean/Copernican and Darwinian revolutions. Gould
(1987, p. 6) writes, “The discovery of **deep time** becomes
one of history’s greatest triumphs of observation and
objectivity over preconception and irrationalism.”

Wicander and Monroe, within today’s scientific purview,
amplify the influence of **deep time** on human thought.

Time is what sets geology apart from most other
sciences and an appreciation of the immensity of
geologic time is fundamental to an understanding
of both the physical and biologic history of our
planet (1993, p. 54).

**Deep time** is defined as **geologic time**, the vast amount
of time in geology which records and recounts the natural
history of earth and life on earth (Gould, 1987, pp. 1-19;
Wicander & Monroe, 1993, p .53; Gould, 1996, p. 18; Plummer
analogy of **deep time**, “The earth is billions of years old,
receding as far into time as the visible universe into
space.”

This study uses **deep time** as a mechanism to explore
middle school students’ personally constructed theories of
the natural history of earth and life on earth. Geologic
time interfaces with many science domains including
cosmology, historical geology, biological evolution,
paleontology, and more broadly, Earth Science, Life Science, and Physical Science in the middle school science curriculum. The National Science Education Standards (1996, pp. 6-7) state a major goal of the middle grades.

... for students to develop an understanding of earth and the solar system as a set of closely coupled systems.... In this holistic approach to studying the planet’s physical, chemical, and biological processes acting within and among the four components (geosphere, hydrosphere, atmosphere and biosphere) on a wide range of time scales to change continuously earth’s crust, oceans, atmosphere, and living organisms.

Origins of the solar system, earth, and life on earth are a major focus of students’ middle school science experience. These origins are framed within the time scale of deep time (Rutherford & Ahlgren, 1990, p. 141-142; NRS, 1996, pp. 158-160; Morrison et al. 1997, p. S184; NRS, 1996, pp. 158-160; NAS, 1998, pp. 33-38). In the proceedings from Evolution Education Research Conference (EERC); Good, Trowbridge, Demastes, Wandersee, Hafner, and Cummins (1992) identified students’ understanding of geologic time as a needed area of research. Other studies, as well, direct researchers to this inquiry. Trowbridge (in Good et al. 1992, p. 201) wrote, "The idea that biological evolution is possible, given the amount of time that has passed, is necessary to acceptance of evolutionary theory." Duane Keown (1988) advised teachers to target concepts of a) Geologic time, b) The natural transitions of earth environments, c) The variability and alteration of genetic makeup, and d) The biological potential of the species. Roseman (in Good et al. 1992, p. 218) informed the science education research community that there is little research
on “how kids’ understanding of notions of systems, scale or models develops ....” Thus, the research literature supports this study’s premise that understanding the vastness of geologic time is a logical precursor to students’ understanding biological evolution.

The method of observing phenomena is different in the historical sciences (e.g., geology, astronomy, and anthropology) than in the experimental sciences (e.g., chemistry and physics). The experimental sciences are based on phenomena that are not expected to change over time. However, the historical sciences deal with evidence which is based on the reconstruction of a sequence of events in which each event is dependent upon the previous one. These events cannot be repeated and must be viewed through the filter of deep time. The students in this study have a parallel problem: to sequence index time-events in the natural history of the earth and life on earth through the filter of deep time.

Research Questions

RQ 1. What are middle school students’ conceptual understandings of the science concept of deep time, geologic time?

1a. What are middle school students’ personal theories about the natural history of earth and life on earth?
1b. What arguments do students state to support their theories?
RQ 2. What conceptual changes occur in students' understanding of the natural history of the earth and life on earth as a result of instruction using a geologic time curriculum?

2a. What conceptual change occurs within grade level 6, by age?
2b. What conceptual change occurs within grade level 6, by gender?

RQ 3. How do students' conceptual ecologies/worldviews influence their understanding of the history of the earth and life on earth?

3a. What are middle school students' conceptual ecologies/worldviews about natural history?
3b. What do students' drawings and interviews reveal about their understanding of natural history?
3c. What analogies, metaphors, examples, models, or stories do students use to explain concepts in natural history?

**Definitions**

For the purposes of this study, the following definitions will be used:

1. **Deep time:** Geologic time from the formation of the earth (4.6 bya to the appearance of the first prehistoric humans (2 mya), which recounts the natural history of earth and life on earth.

2. **Dinosaur theory:** Dinosaurs are used as the dominant concept to organize the student's thinking about the events in the natural history of the earth and life on earth.
3. **Evolutionary time**: The student’s understanding of geologic time-events is expressed as change-over-time or change-over-particularly-long-durations.

4. **Mixed-model design**: A study that uses a "mixed form" in all stages of the research: (a) design (naturalistic inquiry and experimental), (b) measurement (qualitative data and quantitative data, (c) analysis (content and statistical) (Tashakkorri & Teddlie, 1998)

5. **Modal profile**: A technique to combine quantitative and qualitative data by creating narrative profiles of the individual or group being studied. A modal profile is a "detailed narrative description of a group of people based on the most frequently occurring attributes of the group.... " (Tashakkori & Teddlie, 1998, pp. 130).

6. **Organizing concept (OC)**: A dominant theme or idea that a student uses to organize or guide her/his thoughts about **deep time** (geologic time).

7. **Relational time**: The student’s understanding of geologic time is expressed by using the before and/or after relationship of index time-events.

8. **Schema**: An underlying organizational pattern or structure (Webster’s, 1991); conceptual framework used by an individual.

9. **Sequential/Relational time**: The student’s understanding of geologic time is expressed in a chronological series and in a before/after placement of index time-events.

10. **Sequential time**: The student’s understanding of geologic time is expressed in a chronological series.
11. **Special Creation**: An organizing concept that the students used to explain events in *geologic time*. The doctrine that the universe and all that is in it was created by God essentially in its present form at one time. However, in this study, Special Creation beliefs do not include the notion of a young earth, but a very old earth. The young, inexperienced students think of the earth being created at the beginning of time or at a time greater than twenty billion years ago.

12. **Theory**: A coherent group of general propositions used as principles of explanation for a class of phenomena (Webster's, 1991) developed by the consensus of the scientific community.
Primary Questions

1. What are middle school students’ conceptual understandings of the science phenomenon of deep time, geologic time?
2. What conceptual change occurred in students’ understanding of the natural history of the Earth and life on Earth as a result of instruction using a geologic time curriculum?
3. How do students’ conceptual ecologies/worldviews influence their understanding of the history of the Earth and life on Earth?

Secondary Questions

4. What are middle school students’ personal theories about the natural history of the Earth and life on Earth?
5. What arguments do students state to support their theories?
6. What conceptual change occurred within grade-level by age and by gender?
7. What do student drawings & interviews reveal about their understanding of geologic time?

Methodology

Conceptual Thinking

Worldview
Science is a body of knowledge and a way of knowing that describes an objective reality.

Philosophy
Scientists individually construct their knowledge and build the body of knowledge by group consensus.

Scientists seek to create the “truth” about the scientific phenomenon as close as possible.

Scientific theories do change over time when anomalous findings falsify the existing theory.

Theories
Biological evolution Conceptual Change Theory
Cosmology Misconception Theory
Geologic time Metacognition
Time (Piaget) Cognitive Psychology

Scientific Development

Understanding Geologic time is closely correlated to students’ understanding Evolution Theory.

Geologic time is a concrete illustration of “change over time” in Evolution Theory.

Students’ personally constructed science theories range from nonscientific to scientifically correct.

Concepts
Cosmology: Big Bang, age of universe.
Historical Geology: History of the formation of Earth, principle of uniformity, fossil record.
Evolution: Development of life on Earth.
Time

Events
Students respond to survey.
Pretest declarative knowledge.
Instruction on geologic time.
Case study interviews: drawings, journals, story of events in history of Earth, fossil time line, word association.
Post survey and test.

Value Claims

The level of public illiteracy in America suggests that educated people may be seriously confused about evolution and the nature of science.

Major teaching goals of science in the middle grades: Earth and solar system as a closely coupled system.

Interactions of Earth’s physical, chemical, and biological processes on a wide range of time scales.

Origins of the universe, solar system, Earth and life.

Knowledge Claims

Earth’s history provides students with evidence about the co-evolution of the planet and life on earth.

Students’ understanding of geologic time may resemble the historical precursors of current scientific theories.

Student misconceptions interfere with their learning.

Data Transformations
Whole class Pre/post tests (Quantitative analysis).
Whole class Pre/post surveys (Quantitative & qualitative analysis).
Concept Evaluation Statements (Quantitative & qualitative analysis)
Student drawings, (Quantitative & qualitative analysis)
Interviews of case studies (Qualitative analysis)

Record
Audio and visual recordings
Pre/post tests and surveys
Student artifacts: journals, drawings, field notes

Figure 1. Vee diagram of deep time study’s design.
Duschl and Hamilton (1992) asserted that students are natural theory builders. These theories, however, are often incomplete (White & Frederiksen, 1987), incoherent (Ranney & Thagard, 1988), and misguided (Caramazza, McCloskey & Green, 1981).

An effective science curriculum, according to Duschl and Hamilton, should aid students in theory-building while respecting and initiating conceptual change from the belief systems (natural theories, prior knowledge, or alternative conceptions) currently held by the students. In the process of revising their natural theories and developing correct science theories, students' understandings may resemble the way fundamental principles in a domain were developed in the history of science (Wandersee, 1986). In addition, as students change and revise their personal theories to move from descriptive prescience theories (simple description of observations or common-sense science theories) to axiomatic theory-based science (thinking about or with correct science theory), students may gain an appreciation of the nature of science. Early work in conceptual change theory was informed by the work in misconceptions research, cognitive psychology, Piaget's equilibration theory, and the writings of Kuhn and Toulmin in the history and philosophy of science.
Misconceptions

Misconceptions research was the early focus of conceptual change theory. Many researchers found that misconceptions or nonscientific thinking about science phenomena exist in both adults and children, occur frequently, and are often resistant to change (Driver, 1983; Driver, Squires, Rushworth & Wood-Robinson, 1994). Most researchers agree that students' misconceptions interfere with learning. Chin and Brewer (1993) offer one reason misconceptions disrupt learning. Individuals, whose unscientific ideas conflict with new information, often disregard or discount the new information in favor of existing knowledge rather than alter or reorganize existing schema (Chin and Brewer, 1993). McCloskey (1983), arguing from an empiricist perspective, asserts that there is a direct correlation between the phenomena and the perception or misconception; therefore, "misconceptions are generated by misperceiving the world." However, Strike and Posner (1983) found this view a superficial interpretation and presented the theory that misconceptions or misperceptions are embedded in a conceptual ecology as well as a conceptual system or network.

A misconception is not merely a mistake or a false belief. Either it must also play the kind of organizing role in cognition that paradigms play, or it must be dependent on such organizing concepts.

Concepts are not isolated artifacts, they exist in semantic and syntactical relations with one another so that they are interdependent on their meaning and are not readily appraised in isolation.
These conceptions will be quite resistant to change, if they are embedded in a web or other concepts that lend them plausibility or intelligibility (Strike and Posner, 1992, pp. 152-153).

Significantly, concepts function as perceptual categories. According to Kuhn (1970), they structure perception in such a way that people who have different concepts live in different perceptual worlds. People with different paradigms will not agree as to what constitutes relevant evidence for resolving their disagreement and will not perceive evidence in the same way. If one assumes that misconceptions are similar to paradigms or paradigm-like, these views provide strong arguments for why misconceptions will be resistant to change.

Schema Theory

Cognitive psychology describes the nature of an individual's knowledge as a schema. Schema consists of (1) an organized set of prototypical concepts related to a theme, (2) the strategies and rules used to evaluate new information, and (3) the procedures for using and justifying this knowledge (Rumelhart, 1980; Thorndyke, 1984). The function of schemata are analogous to the functions of theories (Duschl & Hamilton, in Strike and Posner, 1992, p.23).

In cognitive psychology, schema theory is used to describe the nature of an individual's knowledge and conceptual change in a manner that is similar to the way philosophers of science describe the development and change in science theories in the history of science.
Current conceptual change theory holds two theoretical constructs on how conceptual change may occur: revolutionary in a Kuhnian model or evolutionary in the Toulmin sense. Posner, Strike, Hewson, & Gertz (1982) integrated the revolutionary and evolutionary viewpoints. They described conceptual change learning as rational and revolutionary. In their theory, the learner adapts knowledge to suit his or her personal needs and every conception is influenced to some degree by the student's conceptual ecology: his or her rational, emotional, and metaphysical beliefs.

The revolutionary view is based on the ideas of Piaget (1968, 1970), Kuhn (1970), Lakatos (1972), and Posner, Strike, Hewson, and Gertz (1982). This cognitive model of conceptual change is based on the history and philosophy of science presented by Kuhn (1970) and on Piaget's (1986, 1970) equilibration theory of cognitive change. Kuhn interpreted conceptual change as a change in the individual's paradigm or worldview. Piaget posited the mechanism necessary for conceptual change is the individual's dissatisfaction with her/his existing concept.

Conceptual Ecology

Conceptual change, in the Toulmin sense, uses intellectual ecology as the mechanism for conceptual change. Toulmin proposed an evolutionary analysis of intellectual development in which each new conceptual variant must compete, in a Darwinian sense, with other new ideas, as well as the existing ideas of the individual's intellectual environment or ecology. Strike and Posner (1992) subsumed Toulmin's evolutionary analysis of intellectual development into conceptual change theory in the construct of the student's conceptual ecology. The student's conceptual
ecology includes, but is not limited to, an individual’s rational, emotional, and metaphysical beliefs. So, the new science concept must compete not only with existing rational or not-so-rational science concepts, but also with the individual’s emotional and metaphysical beliefs. Both notions of intellectual ecology and conceptual ecology are synthesized in the cognitive construct called an individual’s worldview.

Strike and Posner suggested that the “basic problem of understanding cognitive development is to understand how the components of an individual’s conceptual ecology interact and develop, and how the conceptual ecology interacts with experience” (1992, pp. 155-156). Hewson & Thorley (1989, p. 541) defined conceptual ecology as the context in which the conceptual change occurs and has meaning. They asserted that the cognitive artifacts of an individual’s conceptual ecology include epistemological commitments, metaphysical beliefs, recognition of anomalies; analogies, exemplars and images; motives, goals, metacognition; knowledge from other areas of inquiry, and knowledge of competing conceptions. Demastes (in Good et al. 1992, p.97) argued that “...the learner’s conceptual ecology controls any learning that can occur.” This construct is described in the conceptual change literature by multiple terms such as intellectual ecology (Toulmin, 1972), context of conceptual change (Hewson and Thorley, 1989), conceptual ecology (Strike and Posner, 1992), and worldview or Weltanschauung.

**Status Construct**

Hewson (1981, 1982) and later Beeth (1998) integrated Toulmin’s and Posner-Strike’s models of rational learning or conceptual change theory in the theoretical concept of
status construct. Hewson (1981, 1982) proposed that student dissatisfaction with existing knowledge results from the interaction of Intelligibility (I'), Plausibility (IP'), and Fruitfulness (IPF') of concepts. Moreover, in this interaction, these concepts must compete within the student's personal theory of the science concept for higher status as in the Toulmin evolutionary view of conceptual change.

The status construct provides a useful method for assessing changes to student conceptions, for identifying conceptual change, and for examining a student's commitment to an idea. The competition between an intuitive and a scientific conception occurs progressively at the levels of I (Intelligibility), IP (Intelligibility and Plausibility), and IPF (Intelligibility, Plausibility, and Fruitfulness). Usually the conception that achieves the higher status succeeds for the time being. If the alternative conceptions do not generate dissatisfaction as a result of status competition, the new conception may be assimilated alongside the old. Hewson calls this conceptual capture. If dissatisfaction occurs between the new and prior conception because the student finds the conceptions incompatible with each other, two things may happen. If the new conception achieves higher status than the prior conception, accommodation occurs. Hewson calls this conceptual exchange. If the old conception retains higher status, accommodation (conceptual exchange) will not proceed for the time being. However, researchers are warned that

1(I) The word and meaning of the word in the formation of a concept.
2(IP) Interaction between vocabulary and justification of concept.
3(IPF) Interaction among vocabulary, justification, and means of interpreting a phenomena.
the replaced conception is not forgotten, and the learner may wholly or partly reinstate it at a later date (Hewson & Hewson, 1984). It is the student, not the teacher, who makes the decisions about the intelligibility, plausibility, and fruitfulness of competing conceptions (Hewson & Hewson, 1984, Beeth, 1998).

Hewson's work supports the assertion that conceptual change occurs incrementally and in a piecemeal fashion (Laudan, 1984). Other researchers' findings, as well, support the premise that students' conceptions change in a gradual, piecemeal fashion over time (Albermann & Hynd, 1989; Strike & Posner, 1990; Shymansky, Yore, & Good, 1991; Duschl and Gitomer, 1991; Villani, 1992; Demastes, Good, and Peebles, 1996). Many studies investigating conceptual frameworks and conceptual change in students' understanding of biological evolution concepts demonstrate that students often do not completely change their nonscientific beliefs to scientific ones (Driver, 1981; Hallden, 1988; Bishop and Anderson, 1990; Settlage, 1992; Demastes et al. 1995). Chin and Brewer (1993) indicated six possible student reactions to contradictory information. Instead of conceptual change, the student may ignore the data, reject it outright, exclude it, hold it in abeyance, reinterpret the data, or accept the data only to make peripheral changes in their prior ideas.

The preceding discussion elaborates The Piagetian School research model in which a student's conceptual change is interpreted as a change in his/her paradigm or worldview. The Piagetian strategy that foster conceptual change, according to the equilibration theory of cognitive change, is disequilibrium, that is, discord within the individual. For conceptual change to occur, dissatisfaction must be
created between the initial conception of the student (the unscientific concept) and the conception being taught.

**Alternative Conceptions Movement**

The two epistemological bases for conceptual change, the Piagetian School and The Alternative Conceptions Movement (ACM), are discussed in the conceptual change literature (Gilbert & Swift, 1985). Cleminson (1990, pp.429-445) offered a review of ACM as a prominent learning theory research program within a constructivist framework. ACM examines and validates children's science: the intuitive ideas, concepts, and theories about the natural world children develop as they interact with the world. The ACM tenets posit that children's naive concepts and theories develop from the sensory experiences of everyday life and are used to explain science phenomena in the natural world. These naive conceptions are from a self-centered point of view and involve an intuitive understanding. Although the naive conceptions and theories are meaningful and sensible to the child, they are different from the accepted scientific explanations. The ideas of children's science are expressed in the everyday use of the language of children.

In formal schooling, the child is confronted with science concepts that cannot be induced from theory-free observation and are in conflict with the student's intuitive ideas about the world. Champagne, Gunstone, and Kloper (1983) found that the conflict between student's intuitive ideas and formal science adversely affected their ability to learn from instruction. Additionally, the student may hold two meanings for the same concept, one for use in the classroom and another for everyday living. As a result,
science and science concepts may seem "unreal" to the student (Osborne & Freyberg, 1985).

**Mixed-model Study**

In keeping with the philosophy of a mixed-model study, this dissertation employs a synthesis of some of the tenets of both the Alternative Conceptions Movement and The Piagetian School to examine students' understanding of deep time. Novak (1998, p. 68) argues that there are some similarities between the assimilation (conceptual change) theories of Piaget's developmental theory and Ausubel's meaningful learning theory. However, the crucial difference, he explains, is Piaget's theory refers to a general reasoning ability, whereas Ausubel posits that an individual's reasoning ability is a function of the individual's conceptual framework in a specific domain. However, this study synthesizes these differences by examining both the student's general reasoning abilities (e.g., Piaget's and Lawson's general thinking abilities) and the individual's conceptual framework (e.g., the student's web of conceptual systems). The specific tenets from ACM used in this study are (1) examining, valuing, and initiating conceptual change from the students' informal science theories, (2) analyzing student language, (3) investigating the student's conceptual framework, (4) investigating the conflict between a student's two points-of-view about a concept, and (5) examining student's informal science knowledge and formal science knowledge of science phenomenon. The conceptual change research paradigm used to frame this study is grounded in the work of Posner, Strike, Hewson, and Gertzog (1982) which is informed by Piaget's equilibration theory of cognitive change. From
these research perspectives, the researcher will investigate the student's web of conceptual systems or conceptual ecologies which include the individual's specific cognitive constructs of epistemological commitments, metaphysical beliefs, analogies, metacognition, content knowledge, worldview, rational learning, not-so-rational learning, and conceptual networks (Strike and Posner, 1983).

Summary of Literature

Status Construct

In this study, Beeth's (1998) criteria for evaluating status construct or competition between concepts will be the mechanism applied in a recursive fashion to interpret and reinterpret the components of the students' web of conceptual systems. Beeth's (1998) criteria for interpreting status construct are

- Intelligibility (I^I): Does the learner know what the words of the conception mean and do these words convey an idea?

- Plausibility (I^P): Does the learner believe the conception to be true and can he or she provide some justification(s) to support his or her conception?

- Fruitfulness (I^PF): Does the learner use his or her conception as a powerful means of interpreting phenomena that have the same scientific explanations?

The researcher moves from inductive thinking, describing incidents (groups and individual cases), to deductive thinking, analyzing with theory, as she examines students' personal science theories using I (e.g., the student's language), IP (e.g., the student's language and justifications), and IPF (e.g., the student's language, ^I = the word and the meaning of the word in a concept. ^IP = the interaction of word and the justification of a concept. ^IPF = the interaction among the word, the justification, and interpretation of the concept.}
justifications and fruitful interpretation of the science concept). First, the researcher draws from language theory (e.g., Chomsky's notions of the deep structure of language, syntax and semantics) to examine the Intelligibility (I) of the student's understanding of the science concept. Within the Chomskian themata, language provides the best model for how to conceptualize and study thought processes (cited in Gardner, 1985, p. 193). Student language, specifically science vocabulary, is also used as a measure of content knowledge. To examine the Plausibility (IP) of the student's theory, the researcher examines the student's worldview, conceptual ecology (Toulmin, 1972; Hewson & Thorley, 1989; Strike and Posner, 1992; Demastes, Trowbridge, & Cummins, 1992) and the warrants he or she uses to justify the answers. The Fruitfulness (IPF) of the individual's science theory is explained by Rumelhart's schema and is confirmed by the student's organizing concept, content knowledge, and general reasoning abilities. The theoretical concepts of Intelligibility, Plausibility, and Fruitfulness dynamically interact and cumulatively synthesize each other as students construct their personal science. As a result, the systematic examination of the students' web of conceptual systems entails an inquiry into the following subsystems of the student's understanding: (1) language, (2) worldview, conceptual ecology and justifications, and (3) organizing concept, thinking patterns, and content knowledge

Intelligibility (I) - Science Vocabulary

Lemke (1993, p. 91) suggested that accurately understood science terms should become part of the vocabulary of the scientifically literate student.
He stated that the student should not parrot science words but should be able to construct the essential meanings in their own words, and in slightly different words as the situation may require ... But they must express the same essential meanings if they are to be scientifically acceptable and, in most cases, practically useful.

Lee, Fradd, and Sutman's (1995) study of culturally and linguistically diverse students asserted that science knowledge refers to the demonstration of accepted knowledge and the correct use of specific vocabulary as defined by the scientific community. However, the authors of *Benchmarks for Scientific Literacy* (1993) caution science educators that the presence or absence of vocabulary does not necessarily reflect a student's level of understanding of the concept (AAAS, 1993, p. 312). Novak (1998) points out that it takes years for a technical vocabulary to develop. Nevertheless, the use of scientific vocabulary does facilitate communication and the appropriate use of key science terms is considered an indicator of understanding. Therefore, the researcher will examine the student's vocabulary in the written responses and transcripts of interviews. Correct scientific vocabulary, operational definitions, or the meaning stated in the student's own words will be accepted as valid by the researcher.

**Plausibility (IP) - Worldview, Conceptual Ecology and Warrants**

A person's worldview or *Weltanschauung* provides the cognitive lens through which he or she views and interprets phenomena in the world. Moreover, it forms the individual's grounding theory which determines his or her epistemological position (e.g., what counts as knowledge, what reasons are...
used as warrants to justify his or her knowledge claims, and how he or she frames the nature of observations made). A person’s worldview is the cognitive lens that is described by the simple heuristic as the difference between seeing and seeing as (Garrison, 1986) or the difference between simple description of the phenomenon and theory-based observations.

Some customary worldviews that people use to try to understand objects and events in the world fall along a continuum of science to pseudoscience. Popper (1959) describes this continuum as empirical science to metaphysics or scientific objectivity to a subjective feeling of conviction. This continuum is useful within the context of this study. The researcher will investigate the plausibility (IP) of the student’s personal theory by examining the student’s language, worldview, and warrants.

**Science worldview**

Lipps (1998) describes science as a disciplined way of observing events or things and drawing conclusions by gathering, evaluating, and using evidence. Science is a process of understanding phenomena that uses a clear and rational way to build knowledge of the real world by drawing conclusions from strong evidence. Lipps (1998, p.3) explains that science is never really finished or complete, but "requires constant testing of those beliefs and ideas with all the data. Science is a way of viewing the world that uses repeatable evidence and hypothesis testing."

Wicander and Monroe (1993, p. 4) define a theory as "a coherent explanation for one or several related natural phenomena that is supported by a large body of objective evidence." These theories continue to be tested, refined, adapted, or discarded as new data emerges. This process
separates science from other forms of human inquiry and ways of viewing the world. Therefore, science proceeds without any appeal to beliefs or supernatural explanations, not because such beliefs or explanations are necessarily untrue, but because there is no way to investigate them.

Pseudoscience worldview

Lipps (1998, p.3) explains, "Pseudoscience uses particular facts, beliefs, and unconfirmed opinions to foster a false understanding of events and things [in the natural world]." Pseudoscience or selective reasoning is complete upon presentation and requires only acceptance. UFO's, astrology, Bermuda Triangle, crystal power, channeling, and religious interpretation of natural science phenomena are some examples of pseudoscience. The misconceptions engendered by pseudoscience are misinterpretations of science concepts based on superstition or metaphysics and the religious misconceptions of fundamentalist religions.

Religion and superstition are ways of viewing the natural world and fall under the purview of pseudoscience. Beliefs (religion and superstition) are common ways of viewing the world that rely on certain people to inform others about the world. These teachings are beyond question, unchallengeable, and they may be mixed with other messages and goals as well (Lipps, 1998, p.3).

Religion uses the method of dogmatic authority to explain the physical world. Faith usually refers to personal beliefs that are accepted without empirical evidence. The National Science Education Standards (NRC, 1996) discuss the nature of scientific knowledge and states...
Explanations on how the natural world changes based on myths, personal beliefs, religious values, mystical inspiration, superstitions, or authority may be personally useful and socially relevant, but they are not scientific (p. 201).

Demarcation between science and religion

Ernst Mayr (1998), in considering the demarcation between science and theology, says that many people search for truth: theologians, philosophers, poets, politicians and scientists. In the search for truth, religion (theology) addresses concerns of the physical world and the metaphysical world (supernatural world of souls, spirits, angels, or gods). Science, in contrast, seeks to understand and explain natural phenomena only in the physical world by using empirical evidence. Religion, however, uses supernatural beings and forces to explain natural phenomena and divine revelation as a legitimate source of truth. Mayr (NAS, 1998, p. 42) writes, "These supernatural constructions are beyond the scope of science."

Popper (1959) established the criteria which distinguishes the empirical sciences from metaphysical systems and articulated why the supernatural is beyond the scope of science. His stated goal was to define the concepts of empirical science and metaphysics so that any set of statements could be classified as scientific or metaphysical. He says, [given that] "...there are an infinite number of logically possible worlds", empirical science "...is a system intended to represent only one world: the 'real world or the 'world of our experience.'" It "...must satisfy the criterion of demarcation" (1959, p. 39). Popper continues, "...scientific theories are never fully justifiable or verifiable, but they are testable.
The only viable criterion of demarcation is falsifiability; therefore, it must be possible for an empirical scientific theory to be refuted by experience" (1959, p. 44). In Popper’s definition of science, the distinguishing characteristics of empirical statements are they can be revised, criticized, superseded by better ones, critically compared with conflicting systems of theories by critical discussion within the scientific community (1959, p.32, 44).

In contrast, metaphysics is "...a subjective experience or feeling of conviction that can never justify a scientific statement..." (Popper, 1959, pp. 44).

Purely existential statements ('there-is' statements) or metaphysical statements are not falsifiable because no statement of an observed event can contradict them, and they are not limited to time and space (Popper, 1959, pp. 68-70).

Popper demands objectivity for basic statements as well as other scientific statements.

We cannot

1. Reduce the truth of scientific statements to our experiences.

2. Grant any favored status to statements which represent experiences.

3. These [kinds of] statements can occur in science only as psychological statements or hypotheses whose standards of inter-subjective testing are certainly not very high (Popper, 1959, p. 46-47).

In establishing the criterion for demarcation between science and metaphysical ideas, Popper neither seeks to destroy metaphysics nor present science as an ultimate truth (Popper, 1959, p. 37).
In this study, Popper's work will be used as the criterion for the demarcation between science and non-science concepts in the worldviews of MS Scientists and MS Pseudoscientists (the fundamentalist religious perspective).

Fruitfulness (IPP) - Organizing Concept, Thinking Patterns and Content Knowledge

This study examines the student's web of conceptual systems and personal theory about the natural history of the earth and life on earth. The systematic examination of the student's thinking patterns (the fruitfulness of his or her personal theory) entails investigating the individual's 1) schema, the organized set of concepts, strategies and rules used to evaluate new facts and procedures of justifying this knowledge, 2) understanding of geologic time, and 3) thinking patterns, general reasoning ability and knowledge framework of geologic time.

The student's schema in this study is encapsulated in the cognitive construct, e.g., the organizing concept. The schema is the individual's underlying organizational pattern or conceptual framework. This construct emerged from analyzing the open-ended responses on the Geologic Timeline Survey (GTS) and Concept Evaluation Statements (CES). The organizing concept (OC) is a dominant theme or idea that a student uses to organize or guide his or her thinking about deep time (geologic time) and is synonymous with the student's schema. The predominant OCs in the study were Dinosaurs, God Created, and Time.
Piaget's Study of Time

Piaget (1927, p. 2-5) defined the role of time in human experience as "temporal ideas linked to (1) memories, (2) complex causal processes, and (3) clearly defined motions." The interaction of these components results in the child's construction of the fundamental time concepts of "temporal order, simultaneity, equality and colligation of durations." (1927, p. viii). In other words, Piaget posited the individual must independently and progressively construct the concepts of succession or seriation, simultaneity, and duration by using memory, causality, and the motion of objects. The end result is the child's construction of the concept of time. Piaget asserted the concept of duration is the highest level of understanding of time because it is characterized as a system of time (a colligation) which requires the child to understand and integrate into a meaningful whole the relationship of succession, simultaneity, and intervals of time. At this point, the concept of time has been constructed and time can be conceived of as an independent system.

Piaget (1927, pp. 2-3) designed a simple experiment, the flow of a liquid from one container to another, to study the child's concept of time. From that experiment, he identified the time operations.

- Seriation, the fitting of various events into the series, A + B + C, by means of 'before' and 'after' relationships.
- Seriation is impossible if events are simultaneous.
- Duration, the fitting together of respective intervals AB, AC, etc.
In his study, Piaget (1927, p. 6) also described two forms of time: (1) empirical time (intuitive time), the understanding of seriation and duration by direct observation, and (2) rational time (operational time), the understanding the relations of succession and duration based on the patterns of logic, e.g., the causal processes of "establishing a chain between causes and effects and explaining the latter in terms of the former." Rational or operational time can be qualitative or quantitative (Piaget, 1927, pp. 294-297). Piaget found that children can generally succeed in understanding qualitative time before quantitative time.

Rational time is reversible in that it can be retraced in either direction (in the individual's thinking) and empirical time is irreversible as it is the simple and irreversible course of events in lived experience.

Piaget posited that since the logical operations the child uses to construct or reconstruct a time sequence are the same operations used in reasoning: chronology (quantitative seriation), causation (qualitative seriation which is before and after relationships), and deduction (reasoning from causes to effects or from effects to causes to create a seriation), the child's thinking of time in a linear series and reasoning abilities are one and the same. (Piaget, 1927, pp. 12-13).

**Geologic Time**

Many science education researchers and educators assert that the vastness of geologic time seems incomprehensible to students (Renner et al. 1981; Keown, 1982, 1988; Ritger and
Cummins, 1991; Trowbridge, in Good et al. 1992; Burgess, in Good et al. 1992). Gould (1987, p. 2) warns us, "Deep time is so difficult to comprehend, so outside our ordinary experience, that it remains a major stumbling block to our understanding." Dawkins (1996, p. 160) describes the difficulty humans experience in comprehending deep time, "What humans can imagine as plausible is a narrow band in the middle of a much broader spectrum of what is actually possible... We know that scales of size and time extend in both directions far outside the realm of what we can visualize...", but "our brains are built to cope with narrow bands of sizes and times." Dawkins offers two examples of the middle range of sizes and times the human mind can grasp, the human body size and the human life time, respectively. Renner, Brumby, and Shepherd (1981) found that the high school students in their study could not differentiate between a 2 million year and a 200 million year time span. Trowbridge (in Good et al. 1992) stated that although the concept of millions and billions of years is necessary to appreciate the rates of evolution, the problem is embedded in the student's understanding of magnitude of time scales. Students have little experience with time scales on the magnitude of deep time. These researchers evaluate students' understandings of the concept of geologic time in terms of Piaget's (1927) quantitative time.

Ault (1980), however, found that upper elementary students in 6th grade can conceptualize time: succession, before and after, deduce sequence and duration in
understanding geologic time in the Piagetian qualitative sense. Ault found that 6th grade students do understand geologic time in a similar way to how geologists conceptualize time. They could solve problems of temporal order and duration in terms of everyday-lived experience or Piaget's intuitive time, that is, identify the relative ages of layers of trash in a clear plastic tube.

This study found that middle school students could conceptualize geologic time in an abstract linear timeline or Piaget's rational time. They could apply the concepts of succession, before and after relationships, durations, causality, and the reversibility of time, e.g., retracing the ordered events in geologic time in either direction.

Thinking Patterns

Piaget (1927) found that the child's reconstruction of a linear time sequence is functionally related to his or her general reasoning ability and asserted that the student's use of chronological, causal, and deductive thinking in making perceptive judgments about time are the same methods the student uses in general reasoning. This researcher used Lawson's General Reasoning Abilities (Lawson, 1995), in addition to students' geologic timeline constructions and warrants about time, to further investigate students' thinking patterns about deep time.

Lawson's highest level of thinking is the hypothetico-deductive level and is described as "...the internal ability to ask oneself questions, generate possible answers, deduce predictions based on those answers, and then sort through the available evidence to verify or reject those answers" (1995, p. 122).
The next level is Lawson's empirical-inductive thinking pattern or child-like thinking which uses simple description. These thinkers use unsystematic thinking, do not consider alternative hypotheses or concepts, make observations and draw inferences, but do not "reason with the possible", and do not check their conclusions against given data, and are not aware of their own thinking patterns (Lawson, 1995, p. 61). Lawson (in Good et al. 1992, p. 139) stated that poor reasoners may tend to hold special creation misconceptions because without hypothetico-deductive reasoning skills, "they believe what they are told or what their intuition suggests" (p. 139).

Content Knowledge

In this study, the content knowledge of historical geology and biological evolution concepts becomes the bedrock of the student's web of conceptual systems. The student's concept knowledge of a domain reflects, connects, and determines the components of student's personal science theory (1) intelligibility: the language used to describe the science phenomenon, (2) plausibility: the warrants used to support the student's personal theory, and (3) fruitfulness: the powerfulness of the personal theory to interpret the science phenomenon and direct future learning.

Summary

In summary, this researcher argues, as did Strike and Posner (1983), that the elements of the student's web of conceptual systems are so enmeshed that they cannot be separated. The students' personal theories function as a paradigm which includes a schema with an organizing concept (a central theme), domain-specific content knowledge, an
idiosyncratic worldview, the student’s thinking patterns, and specific language. These concepts interact and depend on each other for their meaning in a semantic and syntactical relationship (language). Moreover, the cognitive constructs of schema and language are embedded in a web of deeper conceptual systems, e.g., the student’s conceptual ecology, worldview, content knowledge, and thinking patterns. Thus, this study examines student understanding as a system.

Watts (1994, pp. 54-55) describes the difficulties in examining this system, "...how best to map this [conceptual] space and chart the many theories, conceptions, and associations which are used within it... the possibilities are that such a mapping would be much more complex than... simply eliciting pupils' conceptions and theories around a single concept like 'force', 'matter' or 'living.'" Therefore, this researcher argues that the components of the student's personal science theory must be examined in a holistic manner, as a web of interacting systems which depend on each other for their meaning, rather than examining each component in isolation. A visual explanation of the interacting systems of a student's web of conceptual systems is shown in Figure 2. This original graphic is the author's concept of the student's web of conceptual systems based on Beeth's IPF, intelligibility, plausibility, and fruitfulness.
Figure 2. Student’s web of conceptual systems.

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A pragmatist research paradigm is an inquiry which applies quantitative and qualitative research methods at all stages of the research. Although the social and behavioral science research paradigms of postpositivism and constructivism traditionally hold dichotomous philosophies, Howe (1988) suggested that quantitative and qualitative methods are compatible within the research paradigm of pragmatism. The tenets of pragmatism support the philosophy of this study (Tashakkori & Teddlie, 1998, p. 23).

Methods: Quantitative and Qualitative
Logic: Deductive and Inductive
Epistemology: Accepts both objective and subjective points of view.
Axiology: Values play a large role in interpreting results.
Ontology: Accepts an external reality.
Causal linkages: There may be causal relationships, but one will have difficulty pinning them down.

Mixed-model Study

The philosophy of a pragmatist research paradigm corresponds to the tenets and methods of a mixed-model study design. A mixed-model design (Tashakkorri and Teddlie, 1998) applies postpositivist and constructivist methods at
all stages of the research design and uses holistic and analytic procedures. This study uses a "mixed form" (Patton, 1990; Tashakkorri & Teddlie) in all stages of the research: (a) design (naturalistic inquiry and experimental), (b) measurement (qualitative data and quantitative data), (c) analysis (content comparative and statistical).

**Action research**

Action research, according to McGee-Brown (1994, p. 2), is a systematic interpretive inquiry within the teacher’s own classroom and school

... which is naturalistic in that data are collected in the natural context of learning ... and interpretive in that the teacher is interpreting participants’ interpretations of their experiences.

The goal of this teacher-directed research study was to examine the effectiveness of using geologic time concepts to increase middle school students’ understanding of evolution concepts. The broad guiding questions were How does a geologic time unit develop students' understanding of the natural history of the earth and life on earth? and How do students move from prescientific understanding to scientific understanding? These broad questions addressed the specific research questions: RQ1: What are middle school students’ conceptual understandings of the science phenomenon of deep time, geologic time?, RQ 2: What conceptual change occurs during the school year in students’ understanding of the natural history of the earth and life on earth?, and RQ 3: How do students’ conceptual ecologies/worldviews influence their understanding of the history of the earth and life on earth?
Researcher

The researcher's role in this study was participant-observer as she assumed the dual roles of researcher and the prescribed role of teacher. Participant-observer roles are generally placed on a continuum with total participant at one end and total observer at the other end. McGee-Brown (1994) enumerates possible roles in action research.

- Teacher as observer/documenter.
- Teacher as facilitator.
- Interviewer/observer and teacher.

The teacher/researcher filled different roles on the participant-observer continuum at different times and contexts during the study. When teaching, the researcher occupied the participant role as she planned the curriculum and conducted the lessons. She filled the observer role when she acted as researcher by conducting observations, documenting, and analyzing students' understandings and behaviors. In writing this study, the researcher indicates the role she assumed on the participant-observer continuum by the labels the teacher/researcher, teacher, or researcher.

It is a challenge to observe one's self in most situations. Robert Burns aptly framed the problem when he wrote, "Would, some god, the gift would give us to see ourselves as others see us." Nonetheless, Stenhouse in Burnaford, Fischer, & Hobson (1996, p. 57) challenged the education research community to do just that when he wrote, "It is not enough that teachers' work should be studied; they need to study it themselves."

An on-going, problematic goal of the researcher throughout the study was to observe herself in the
The problem of observing one's self arises. How does an individual effectively decenter her perception from the first person position to the third person to simultaneously teach and observe herself? This researcher employed these methods.

- Paper and pencil planning of broad objectives and lessons for the geologic time unit.
- Careful recording of classroom events, observations, and conversations.
- A collection of student artifacts that documented classroom events.
- Electronic documentation (tape or video recordings) whenever possible and permitted.
- A mindful, deliberate sense of self-awareness.

Sampling

The teacher/researcher is currently employed at the middle school where the study was conducted and has been employed there for nineteen years. The study population was the teacher’s sixth grade Science classes, a nonrandom, convenience sample of fifty nine students. The large group sample included all the students in the teacher’s science classes. The multiple case studies were a purposeful sample of information-rich representatives selected from the categories which emerged in the study.

Setting and Students

The study was conducted at a rural middle school in the Deep South in a community with a strong religious base of both Catholic and Protestant religious affiliations. The school is in a state of flux as the community rapidly
changes from a rural community to a suburban community of one of the fastest growing cities in the state. As the community changes, the nature of the student body changes becoming more urban and sophisticated. This uncontrolled growth contributes to many school problems such as overcrowded facilities and strained financial and human resources. A more diverse, cosmopolitan student population also brings urban problems such as drugs, student apathy, and student suicide. The demands for space in the physical plant increases stress and tension in both the student body and staff.

Design of Study

The teacher/researcher conducted action research in her sixth grade Science classes by using a mixed-model design which employed an exploratory parallel, quantitative (QUAN) and qualitative (QUAL) design. It is a quasi-experimental, repeated-measures design with multi-case studies. First, the researcher took a panoramic view of the large group's understanding of geologic time. Then she zoomed in for a closer examination of the individuals from the large group. A timeline of the study is shown in Appendix K.

Tashakkori and Teddlie (1998, p. 19) define a mixed model study as a design as a "pragmatist paradigm" which "combines the qualitative and quantitative approaches within different phases of the research process."

Mixed-model Research Paradigm: Quantitative (QUAN) and Qualitative (QUAL)

Quantitative research paradigm

Large-sample-size research, a nomothetic approach evaluated by statistical techniques, was thought to produce
more powerful findings, that is, better able to detect an experimental effect and to produce more generalizable findings. However, Kazdin (1982) suggests that although information from group research is important, it excludes vital information about the uniqueness of the individual. Allport (1961) recommends using an intensive study of the individual, an ideographic approach, to enhance the study of groups. This quasi-experimental, repeated-measures study identifies and measures the understanding of the large group, and then, four case studies examine the conceptual systems of individuals from the group.

**Qualitative research paradigm**

All forms of qualitative research share some key characteristics, such as (1) an emic perspective, e.g., understanding the phenomenon from the participants' perspective; (2) a phenomenological focus, e.g., a subjective interpretation of the experience; and (3) the application of both inductive and deductive logic in the research process.

Qualitative case studies are frequently used in education research. Merriam (1998, p. 29) characterizes qualitative case studies as particularistic, descriptive, and heuristic. Stake (1981) points out that case study knowledge differs from other research design knowledge in that it is "more concrete and contextual ... and more developed by reader interpretation .... The generalization to a population is determined by the reader rather than, as in quantitative research, to a reference population." (Stake, 1981, pp. 35-36).
As in all research, the choice of a case study design depends upon what the researcher wants to know. Case study design in applied fields of study such as education allows the investigation of phenomenon in a naturalistic, contextual setting which has multiple variables. Therefore, the case study design is particularly well suited to investigate a classroom situation.

Limitations of case study research

The very nature of case study research engenders limitations. The study design is emergent and the methods are open and flexible. Case study research does not claim any particular methods of data collection or data analysis which abandons the researcher to her instincts and experience in conducting this type of research. The human researcher must use her intuition and judgment which is influenced by the researcher's bias, subjectivity, and experience. For these reasons, many critics claim that qualitative case study research is not as rigorous as traditional research.

Researcher bias

The researcher is both the greatest strength and greatest weakness of case study research. The quality of the work depends on the researcher’s abilities in conducting this type of research, her sensitivity, and her integrity. The subjectivity of the researcher generates issues of reliability, validity, and generalizability. The researcher must employ strategies to offset the effects of researcher subjectivity. These will be discussed later.

Reflective journal

A reflective journal is used as a practical tool to examine researcher bias and subjectivity. The journal
includes subjectivity audits which record situations during the research that arouse strong positive or negative feelings. This identifies areas in which the researcher’s own beliefs and background may influence her perceptions and actions in the research setting.

**Trustworthiness**

Trustworthiness or credibility in qualitative research, called validity in quantitative research, is the degree the researcher can persuade the audience that the study’s findings are worth paying attention to or the extent to which the reconstructions of the researcher are believable. Credibility may be a weakness in a case study design because the focus is on the individual, not a group. Some qualitative researchers conclude that traditional notions of validity and reliability do not apply to case study data. Other researchers accept the concept of validity. This researcher employs techniques to strengthen both validity and reliability in study design and the data analysis. First, the researcher looks at the big picture by developing modal narrative profiles of the groups. Then she focuses on individual representatives of the groups in multi-case studies. This mixed-model study design applies multiple methods, both quantitative and qualitative, to triangulate the data and strengthen the validity of the case study findings.

The researcher thinks this study meets the criteria of validity in qualitative research by using prolonged engagement (over two years of interaction with the case study students), rich, intimate description; triangulation of data sources, member checking, peer debriefing, and a reflexive journal (Lincoln & Guba, 1985).
Generalizability

Generalizability is the extent that a study's findings can be applied to individuals or situations other than those in which the results were obtained. Generalizability is theoretically achievable in quantitative research, but it is problematic in qualitative studies. Grounded theory which depends on the interaction of the data and the creative processes of the researcher is not replicable. Other researchers argue that case study research can be generalized by designing a study that will increase the probability that the findings will apply to other cases also representing the phenomenon. A third view suggests it is the responsibility of each reader or user of the case study research to determine the applicability of the findings to their own situations (Wilson, 1979).

The researcher uses the following strategies to strengthen the generalizability of the qualitative research findings: (1) thick description of the participants and contexts of the study, (2) establish the representativeness of case studies selected, and (3) multiple-case designs to conduct cross-case analysis. The researcher argues that the findings of the large group are generalizable to other sixth grade settings because of the size of the sample. However, the generalizability of the case studies to individual settings is left to the interpretation of the reader.

Data Collection and Analysis

Quantitative phase: Sources of Data and Analysis (Large Group)

The quantitative phase of the study used a repeated-measures design using the following instruments: (1) content
knowledge tests, (2) Geologic Timeline Survey, and (3) Concept Evaluation Statement (see Appendixes B and C).

The quantitative phase was conducted in a whole-class setting and examined the knowledge and conceptual change of the intact groups. This phase of the study employed a quasi-experimental design in which different variables, e.g., content knowledge and conceptual change, were measured before and after the treatment. The treatment was the implementation of the Geologic Time Unit. The results of the pre- and post-tests of content knowledge were analyzed using $t$-tests for dependent means, and the test-retest data from the Geologic Timeline Survey were summarized with descriptive statistics and contingency tables. The results from the open-ended responses on the Geologic Timeline Survey and Concept Evaluation Statement were also interpreted qualitatively and will be discussed later.

QUAN: Content Knowledge Assessments

This study tested the nondirectional hypotheses using a $t$-test for dependent means.

Hypothesis 1: Students' scores on content knowledge tests in Earth Science will not change after the geologic time teaching unit.

Hypothesis 2: Students' scores on content knowledge tests on biological evolution will not change after the geologic time teaching unit.

Sample Size: $N = 59$

$p < .10$

$t$ with $df = 58$ needed for 10% level, two-tailed $= \pm 1.671$.

In this exploratory study, the significance level $p < .10$ was used to test the hypotheses. This risked a Type I
error that the researcher will reject the null hypothesis when, in fact, it is correct. However, it might allow the researcher to find a potentially important difference, relationship, or effect that would not appear if a lower p value were set.

Two content knowledge tests were used to measure students' formal knowledge in the science domains, Earth Science (e.g., geologic time) and Life Science (e.g., biological evolution). The researcher and a colleague, an the eighth grade science teacher, selected relevant items from The Middle School Earth Science Survey developed by William C. Phillips (1992) at the University of Maryland. This test evaluates students' understanding of twenty-five fundamental Earth Science ideas and the student misconceptions associated with those ideas.

The Middle School Evolution Test, designed by Kathleen Fisher at San Diego State University, was used to measure students' formal knowledge of evolution concepts (K. Fisher, personal communication, April, 1998). Fisher's test is based on Bishop and Anderson's (1990) college-level test of concepts of natural selection. Psychometric information about these tests, e.g., test validity, test reliability, and item statistics, were not available.

Only one of the four traditional measures of validity was used in this study. Face validity, a casual, subjective inspection of the test items, was used to judge whether the test items covered the content that the test purported to measure. The teacher/researcher, other middle school teachers, and science experts in the field reviewed the tests and conferred about the face validity of the items. The reviewers found the face validity of the Middle School
Earth Science Survey adequate, but questioned the suitability of some of the high-level questions on the Middle School Evolution Test for middle school students, particularly sixth grade students. The researcher decided to continue with the plan to use the tests, but to interpret the results of the tests cautiously in light of the reviewers' recommendations.

QUAN: Geologic Timeline Survey Assessment

The Geologic Timeline Survey (GTS) also used a test-retest design. The researcher designed the two-tiered primary data collection instrument which included a timeline of deep time and a related questionnaire (see Appendixes A and B).

The test of the instruments in the pilot study determined if they effectively measured students' understanding of index time-events in geologic time. In the Geologic Timeline Survey, the geologic timeline is not to scale due to the simple practicality of fitting it on one sheet of paper. Most geologic timelines in textbooks and reference books are not to scale for the same reason (NAS, 1998, pp. 36-37; Morrison, Moore, Armour, Hammond, Haysom, Nicoll, & Smith, 1997, p. S184; Plummer & McGreary, 1996, p.4 5). In the first tier, the students were asked to place the following seven events on a logarithmic-like geologic timeline: a) When did the first plants appear on land?, b) When did the universe form?, c) When did dinosaurs first appear on earth?, d) When did they disappear?, e) When did the earth form?, f) When did prehistoric humans first appear?, and g) When did the first vertebrate animals appear on land? (see Appendix A). The researcher presented
the events out of chronological order and guided the class through the questions by using a transparency, revealing each question separately, and stating the question aloud. First, the students were asked to reconstruct key events in the natural history of the earth and the development life on earth on the geologic timeline. Then, they were asked to justify those answers.

In the second tier of the questionnaire (e.g., an open-ended response), the students were asked to write their reasons or evidence for placing the event at that point (or time) on the timeline. This task was completed individually by each student. However, the researcher carefully monitored the students during all the written responses because she noted that some students gave incomplete responses in the pilot study.

Before the pilot study, the researcher established a codebook with the currently accepted science knowledge about each of the index time-events on the Geologic Timeline Survey. Then, the researcher and the eighth grade teacher who participated in the pilot study selected the following three index time-events from the Geologic Timeline Survey to analyze students' understanding of the natural history of earth and life on the earth: a) When did the earth form?, b) When did dinosaurs become extinct?, and c) When did the first prehistoric humans appear? The collaborators agreed that these events were significant in geologic time and stressed in the middle school science curriculum. Jeffery and Roach's (1994) findings supported the researcher's choice of index time-events. Their study analyzed elementary and middle school science textbooks for evolution protoconcepts, that is, topics that prepare students to study
evolution in later years. Earth history, dinosaurs, extinction, and the concept of time were included in the list of evolution protoconcepts which were addressed in the elementary grades 1-3 and middle school grades 4-6 in the Jeffery and Roach study. Human origins, however, were not mentioned as a precursor concept. The researcher and the pilot study science teacher agreed that the appearance of humans is an index time-event in the history of the earth and life on earth. These three topics became the framework of both the quantitative and qualitative data analysis.

**QUAN: Concept Evaluation Statement**

A Concept Evaluation Statement (CES), which entailed a drawing and a justificatory paragraph explaining the drawing (Renner et al. 1981), was administered to assess students' understanding of origins of life on earth and to triangulate the findings from the Geologic Timeline Survey. The following CES was used: **The word protozoan is Greek for first animal. What was the first animal to appear on earth and what did it look like?**

Other CES were eliminated from the study because the pilot study students described the CES as "hard" during a focus group discussion of the study's goals and instruments.

The researcher also observed that during the pilot study testing the students' body language and clarification questions indicated the CES challenged and taxed their thinking abilities more than the other measures. The CES required the students to think deeply about the topic, to integrate what they knew about the topic, to represent their thinking in a drawing, and to explain their thinking in a written paragraph. This proved to be difficult for the
students, but very rich in information about the students’ understanding of the concept and the students’ conceptual ecologies. It is a lucid, self-evident measurement.

**Qualitative phase: Sources of Data and Analysis**

**QUAL: Content Analysis of Open-ended Responses GTS and CES (Group)**

Student open-ended responses on the GTS and CES which reveal students’ web of conceptual systems, e.g., personal science theories, conceptual frameworks, and conceptual ecologies, were examined by using content analysis. Then, researcher investigated the components of the specific subsystems of student understanding of deep time: content knowledge, science vocabulary, worldview, and thinking patterns. In the analysis of the large group qualitative data, the researcher identified the following categories of student thinking about deep time which appear in the sixth grade: MS Scientist (correct science), MS Protoscientist (approaching correct science), MS Prescientist (everyday-science explanations), and MS Pseudoscientist (metaphysical, e.g., fundamental religious explanations).

**QUAL: Multi-case Studies (Individuals)**

The second phase of the qualitative analysis applied a multiple-case-study design. The purpose of this case study design was to use the individual as the unit of study, to develop a holistic, rich description of representatives from each category. The qualitative phase focused on cross-case studies of representatives from the four categories of student knowledge which emerged in the study.

The case study phase of the research used both an IPF analysis, e.g., intelligibility, plausibility, and
fruitfulness, (Beeth, 1998) and Burnaford’s model for action research to evaluate conceptual change.

- Connections across content areas.
- Awareness of the affective dimensions of teaching and learning.
- Active involvement of students in the research process with support, feedback, and decision making which supports an emic perspective (Burnaford et al. 1996).

Burnaford’s pattern of action research is well suited to measure conceptual change because it is less restrictive and more open-ended than other definitions of action research.

Data Sources

The student artifacts from the Geologic Time Unit which the researcher examined are student journals, drawings, a word association assessment, and transcripts of interviews based on teacher/researcher designed interview-problems.

Student journals

The journal prompts which were employed to examine the development and change in student thinking were

- What is an animal?
- What is a billion years like? What is a million years like?
- What happened to different species of animals over billions or millions of years of earth time?
- What does the geologic timeline tell you about the development of life on earth?
- Explain how animals changed over time?
- Based on “A Walk Through Geologic Time”, explain how the earth changed over time and life developed.

Word association

White and Gunstone (1992, p. 142) assert that “Word association is direct probe of the associations that a
person perceives about a concept. Simple word association assessments were administered before and after the treatment to measure change in vocabulary and the individual’s understanding. The number and types of responses provide a subjective interpretation of the student’s understanding of the topic, according to White and Gunstone. The teacher/researcher presented the stimulus word: geologic time, and the students wrote as many single word responses to the stimulus word as possible.

Interview-problem Assessment

White and Gunstone (1992, p. 65) describe an interview-problem assessment as “interviews about instances and events.” Piaget perfected this technique in his many studies of children. White and Gunstone (1992, p. 65) elaborate on this method.

An interview about an instance is a deep probe of student’s understanding about a single concept that checks whether the student can not only recognize whether the concept is present in specific instances but also whether the student can explain his or her decision. The explanation reveals the quality of the student’s understanding.

The teacher/researcher designed two interview-problem assessments which explored the case study students’ qualitative understanding of deep time. In the Prehistoric Plant and Animal Card Problem, the student was asked to arrange a series of pictures of unfamiliar prehistoric plants and animals in the sequence in which he or she thought they appeared on the earth. Then the student was asked to explain why he or she put them in that order. This is an abstract succession and relational time problem.
with an added element of uncertainty or disequilibrium for the student. In this problem, the plants and animals are exotic, and the student may doubt that these organisms actually existed. The second problem is a linear time sequencing problem that measures the time concepts of succession, relational time, and relative duration. The Fossil-Timeline Problem asked the student to place a set of fossils on a geologic timeline at the point (in time) where they thought the animal appeared in the natural history of earth and defend their responses. This problem was a more concrete problem because the student could see and manipulate the fossil evidence and, thereby, infer that these animals did exist. The Prehistoric Plant and Animal Card Problem was presented near the beginning of the Geologic Time Unit, whereas the Fossil-Timeline Problem was administered at the end.

**Scale and Magnitude of Geologic Time**

The teacher/researcher developed the students' scale-based understanding deep time with a series of timeline-based activities using different scales. These activities were presented in this order. (1) Timeline A: a team of two students constructed a timeline four and one half meters long and divided it into 50 millimeter intervals. The scale was one millimeter equaled one million years. This model developed the concept of millions and billions of years. The students were asked to write the seven index time-events on the timeline. (2) Later in the study, each case-study participant placed a set of fossils on Timeline A in the Fossil Timeline Problem. (3) Timeline B: a teacher-made timeline placed along the perimeter of the classroom walls.
The scale was one meter equaled five billion years. The team timeline was constructed at the beginning of the Geologic Time Unit, the individual timeline was used in the middle, and the teacher timeline was presented as the culminating activity in the unit.

Validity and Generalization

To increase the rigor of this study, the researcher used a multi-case design. Miles and Huberman (1994, p. 29) state cross-case studies, "strengthen the precision, the validity and the stability of the findings." The inclusion of multiple cases is a common strategy for enhancing external validity or generalizability of the findings. Merriam (1998, p. 40) explains that the greater the variation across the cases, the more compelling an interpretation is likely to be. To increase the variation of this study, the researcher analyzed a representative from each of the four groups which emerged: MS Scientists, MS Protoscientists, MS Prescientist, and MS Pseudoscientists. However, in order to maximize the findings of the study, the researcher minimized the differences between the final case study individuals by keeping the following student variables very similar.

The researcher chose these case studies to control for important variables and reduce the impact of extraneous variables (e.g., socioeconomic factors, school achievement and attendance, and attitude toward school). This increases the strength of the findings, that is, it strengthens the probability that the results represent students' thinking levels or conceptual frameworks and not the effects of other variables. However, it also possibly introduces other factors such as the experimenter bias effect (Rosenthal,
1976) or the Hawthorne effect, e.g., "the tendency for subjects of research to change their behavior simply because they are being studied" (Vogt, 1993, p. 104).

The researcher was acutely aware of researcher bias throughout the study. She systematically balanced that effect by building rapport with the case study students while simultaneously maintaining a professional distance. Much of case study data was gathered in the whole class setting and from whole class assignments (e.g., journal entries, tests, drawings, word associations). The demands of teaching 6 classes a day insured a methodical, effective use of time during the interviews about instances and post-study interviews with the case study students. The researcher's subjective journal entries reflect these problems.

April 14: It is very difficult to play the dual roles of researcher and teacher. The role of teacher and obligations (grading tests, student interim reports, report cards, ethics, commitment to the requirement of the state and local curriculum) always seem to win.

April 20: It is difficult to select the group of students for case studies....In choosing the students to interview and focus on their concept development in their journals, I will use the CES drawings: What was the first animal? to classify them into groups....I will choose candidates from all the science classes.

Although the researcher designed the study to minimize competing explanations for the results in the case studies by using the triangulation of data sources, the Hawthorne effect seems inherent in the very nature of case study research. For those reasons, the researcher carefully described her methods and included the study instruments so...
the study can be replicated. She also provided a thick description of the case studies. The reader can determine the applicability of the findings to his or her practice. **Triangulation**

The researcher also used triangulation of multiple data collection methods, data sources, data analysis, and theories to increase the validity and reliability. Triangulation can reduce biases that could result from the use of only one data collection method, one data source, one form of data analysis, or one theory. The design of the analysis of the multi-case studies is thoroughly discussed in Chapter 6.
CHAPTER 4
LEARNING ENVIRONMENT

The School

Physical Appearance

Soon after one exits the interstate and drives south on a two-lane state road toward the Mississippi River, one meets the usual wall of traffic and inches past a new Texaco service station and a Burger King, typical structures at an interstate exit in the South. The mile to the school will take five to ten minutes to negotiate at six fifty-five in the morning. Finally, one sees the sprawling gray cement buildings, River Town Middle School, and abruptly turns left.

River Town Middle School is a Thirties design school that resembles a fortress; a visitor has the sense that it has survived many natural disasters. Two long, gray L-shaped cement block buildings angle off in opposite directions from a central point, the gym. A new flat-topped administration building is situated in front of the gym and between the two gray cement buildings. A long, flat covered walkway runs parallel to the front of the school. One is aware of all the flatness and grayness.

School Demographics

The 1998-99 middle school (5-8) enrollment was 657 students; 507 were regular education (77%) and 150 were special education (23%). At the time of the study, 41 classes in the school (25%) had a class size of 1-20 students, 78 classes (48%) had a class size of 21-26 students, and 44 classes (27%) had 27 or more students. This count does not include specialty classes such as band,
art, or physical education. The teacher/researcher’s class sizes varied from 21-26 students.

**Academic Performance Scores**

The principal categorized the school as a high average school with a 22% minority enrollment. The Iowa Test of Basic Skills (ITBS) provides a score of the Core subjects: Math, Reading, and Language. The grade level composite scores in core subjects for grades five to seven on the 1998-99 Iowa Test were fifth grade, 54%; sixth grade, 55%; and seventh grade, 55%. The eighth grade students’ learning in English Language Arts and Mathematics was measured with the LEAP 21 Tests. The students’ performance on the 1998-99 LEAP 21 Tests were reported in five performance levels: Advanced, Proficient, Basic, Approaching Basic, and Unsatisfactory. The school received performance scores above state and district levels both in Mathematics and English Language Arts in these tests. In mathematics, 69% of the students had Basic to Advanced performance level and 31% had an Approaching Basic to Unsatisfactory performance level. English Language Arts student scores reported 65.1% of the students performed on the Basic to Advanced level and 34.1% scored on the Approaching Basic to Unsatisfactory level. The school’s attendance rate was 95.7 percent.

Each school’s performance score (SPS), the School Report Card, was an assessment from a composite of four indicators (1) LEAP Test Scores, (2) Iowa Test Scores, (3) Student Attendance, (4) Student Dropout rates. The school in this study had the highest SPS middle school score in the district, 94.9 percent, and was categorized as Academically Above Average. The SPS Range for the Academically Above Average category is 69.4 - 99.9 percent.
School Climate

Moos (Frazer, 1991, p. 29) writes, "Individuals are profoundly affected by the social matrix in which they are embedded." This study recognizes that the complex interplay of real-life processes which influence students and teachers are a significant variable in teaching and learning. Describing the school climate is an attempt to introduce the psychosocial aspects of learning and situate the study within the context of school and classroom setting.

Generations of family members have attended River Town School; many members of the faculty attended the school as well. Parents are all around the school during the day, working in the office or helping the teachers. The school program receives unusual parental support. "Teacher talk" frequently reflects the stable population of both student body and the faculty, e.g., "I taught little Johnny's parents. Now, I'm teaching little Johnny. The apple doesn't..." or "Don't you remember teaching Dawn, Mary's sister? Dawn is in jail now."

Sports is a dominant theme. Sports trophies, from long past games, line the 7th and 8th grade hallways and the gym. Sports banners hang like tapestries from the gym walls. A mother proudly brings her beautiful three-year-old daughter to visit the school dressed in her (the mother's) River Town School cheerleader uniform. The community cherishes its River Town School experiences and clearly still loves the school which their children now attend.

The Teacher and Her Teaching Practices

At the time of the study, the teacher was in her nineteenth year of teaching and just returned to her sixth
grade classroom after a two-year leave of absence. The teacher had just returned from fulfilling a year's residency at Louisiana State University and also working for two years in the Physics Department as a Teacher Assistant in a Physical Science class. Upon returning to her sixth grade classroom, the teacher felt empowered in her science content knowledge. However, she felt like a first-year teacher in the area of classroom discipline.

The Classroom Setting and Climate

The teacher's classroom is in the new wing of the school, the Administration Building. The modern classroom is a modestly-equipped science room with a sink, running water, and many electrical outlets. Built-in oak cabinets and counters line two walls of the room; science equipment, e.g., triple-beam balances, graduated cylinders, spring scales, and overflow cans are neatly arranged on the counter tops. Student projects are stacked in a large white three-tier portable shelving rack at the back of the room. Two computers stare out from the back of the room. All around the room large plexiglass framed science posters on astronomy, astronauts, rockets and space stand on the counter tops like sentinels of science. Students' ideas and thinking dominate the room. Large newsprint KWL Charts and data tables hang from the bulletin boards. Students' work, designs and models of towers, boats, rockets, and robots are displayed around the room.

Seating Arrangement

Students sit in pairs at black-topped lab tables or in groups of four. The seating arrangement and partners or teams change each 9-weeks. Sometimes the tables are
arranged end-to-end in 4 x 4 rows, and at other times, the tables are randomly arranged in 2 tops, e.g., two tables pushed together, table top-to-table top, to form a square. These arrangements allow the students to work as individuals, pairs, or groups-of-fours at different times throughout the 9-weeks. This seating arrangement also lends itself to much classroom side-talk (Lemke, 1990, pp. 71-82) and potential discipline problems. The room is crowded.

Classroom Management

To manage keeping students focused on the problem at hand, the teacher, in addition to general classroom rules, has specific, well-articulated rules and procedures for working in teams.

• Keep the room safe at all times.
• Books and belongings are in the desk or under the desk.
• Use all materials safely and carefully.
• Stay on task.
• Talk with soft voices and no talking outside of teams.
• Do your fair share of the work.
• Rotate jobs within the teams at each new class activity.
• Record all work in your journal.

The jobs within the teams have classroom management rules and procedures embedded in them as well. The Principal Investigator is the leader of the team and in charge of keeping everyone on task, making sure they do their job, their fair share of the work, and resolving conflicts within the team. The Recording Secretary writes all team reports or data charts which must be turned in and orally presents the team's work to the class. Two other jobs are in the teams, and these are the only people who can move about the room. The Materials Director gets materials, cleans them, and puts them away; and the Maintenance Supervisor, handles any spills, cleans the
tables, and area around the tables at the end of the activity. These jobs are rotated at each new activity. In addition, the students receive an individual grade from effectively following the rules and procedures for working in teams. The teacher is confident that these routines will provide a climate of learning for the class.

However, there is an undercurrent of resistance to learning by a small hard-core group of students in each class who persistently disrupt the learning of the group. The teacher has received several death threats by mid-year and is often concerned with protecting her students and herself from threats of violence.

Subjects and Scheduling

The classes are on a block schedule, approximately a two hour period each day. Therefore, science activities can last from one to three days. Time is available for thinking, working, developing ideas and presentations, and defending and challenging ideas. Science and Math are taught as integrated subjects as much as possible.

Science Curriculum

The teacher develops the sixth grade science curriculum and coordinates it with the National Science Standards, the State Standards, and the parish science curricula. These "big ideas" were presented to the class throughout the school year in this order: Measurement and tools for measuring; Matter; Mass, Volume, Weight, and Density; Solar System, Forces and Motion; Types of Rock and the Rock Cycle; Physical and Chemical Changes; Mixtures, Solutions, Acids and Bases; Cells: Plant and Animal; Animals, and Geologic Time (see Appendix L).
KWL Charts' were first made by the individual, and then individual ideas were combined to form a class KWL for selective units, e.g., What is Matter?; What is Sinking and Floating?; What is a Chemical?; and What is an Animal? The teacher used these charts as an informal assessment of prior knowledge (Ausubel, 1963) at the beginning of a unit and as posttest assessment of student learning at the end. The "What do I want to know" section was used to direct teaching to students' interests in that particular concept. Much of the classroom dynamics and discussion revolves around the development, revision, and presentation of individual and class KWL charts.

Science Textbook

The journal, used as the text for the class, recorded the process of each student's concept development with problem-solving procedures (e.g., a modified scientific method), data charts, student's drawings, science vocabulary, teacher presentation notes, and teacher-directed concept summary paragraphs.

There is a classroom set of the science textbook Science Plus Technology and Society, Level Green (1997) by Holt, Rinehart and Winston, Inc., and the students could check out a copy of the text to use at home when they needed it. However, the teacher used the textbook in class only to supplement her instructional methods with selected readings and vocabulary development.

KWL charts are as used advanced organizers and informal assessments. In KWL Charts students put the title of the subject and divide the paper into three columns with the headings K: What I know; W: What I want to know; and L: What I learned. This is method is a modification of the reading strategy known as the K-W-L strategy. (Ogle, 1992 in Vacca & Vacca, 1996, pp. 211-217.)
Teaching Methods

Modified Scientific Method

The students were systematically introduced to a modified scientific method which they used as a model for problem-solving in class activities. The students were individually responsible for recording all work in their journals in this form: 1) investigative question, 2) prediction, 3) materials, 4) data chart, 5) paragraph explaining step-by-step how you did this experiment or activity, and 6) reasons and evidence (e.g., What did you learn from this activity? How can you prove it?). These steps were progressively introduced throughout the school year and provided both direction and form to classroom activities. The steps guided the group through the class assignment and also provided the form to record and report the results of the assignment. These steps were neither presented nor used in a lockstep fashion, but were often presented and applied in different combinations.

Think, Plan, Square (Working in Groups)

When a problem was originally proposed to the class, each individual first developed a written plan in his or her journal to solve the problem. Then the individual presented his or her ideas to the team. From the individuals’ ideas, the team developed a group plan and did the activity. Most of the time students worked in pairs, rather than groups-of-four. The teacher called this method the Think, Plan, Square Problem-solving Model. The math analogy of squaring a number is used to explain the teaming rationale in terms a sixth grade student can understand and appreciate. An individual’s thinking can be increased in magnitude when
shared with a team just as a number is increased when it is squared (e.g., $2^2$ or $4^2$).

**Development of Scientific Method**

Typically, each activity was introduced with the presentation of a problem. At the beginning of the school year (August-September), the teacher would say and write on the board, "Your problem for today is ‘How can you build the tallest free-standing paper tower from one sheet of paper?’ or ‘How can you test the accuracy of your graduated cylinder?’" The students enter the assignment in their journals in this form: 1) Your problem is..., 2) Write a plan to solve the problem, and 3) Record your data. Frequently, the teacher would put a data chart on the overhead with only the column headings of the data that needed to be obtained, e.g., Object, Mass, Volume, Weight, and say, "Your problem today is to write a plan to find this information and then do it." By October, the students were presented with more complex problems, e.g., "Why do some things sink and others float?" or "Does the mass of a candle change when it burns?" Steps 1-5 were added to the inquiry method. After mid-year, the students were expected to complete Step 6 in the modified scientific method, e.g., a conclusion and a defense.

**Summary**

The teacher's instructional method is a synthesis of a modified scientific method, scientific "habits of mind", systematic skepticism, and the Learning Cycle (Karplus and Their, 1967; Lawson, 1988). Science for All Americans (1989) presented the scientific habits of mind to the science teaching community. One of those habits of mind is
systematic skepticism*, and the Learning Cycle* (Lawson, 1988; Karplus and Thier, 1967). First, Lawson's model of the Learning Cycle will be discussed. Then, the teacher's variation of the learning cycle used in her practice will be explained. Lawson has worked extensively with the three-phase learning cycle and calls the phases Exploration, Term Introduction, and Concept Application. In the Exploration phase, the students explore the problem; the students learn through their own action and reactions with the new situation or phenomenon with minimal guidance. They begin to make observations, generate hypotheses, identify patterns, ask questions, propose explanations or alternative explanations. The term introduction phase is when science terms are introduced by the teacher, the textbook, or any other medium. During the concept application phase, the newly formed concept is applied to many different examples of the concept. This phase allows the student to abstract the concept and generalize it to other situations (Lawson, 1995, pp. 136-137).

This teacher applies a variation of the learning cycle in which the original three phases are called Exploration, Explanation, and Elaboration. The Exploration phase is essentially the same as Lawson's phase. The Explanation phase is

* Systematic skepticism is institutionalized skepticism. A central tenet of science practitioners is that "one's evidence, logic, and claims will be questioned and one's work should be replicated. In science classrooms, it should be normal practice for teachers to raise such questions as: How do we know? What is the evidence? What is the argument that interprets the evidence? Are there alternative explanations or other ways of solving the problem that could be better?" (Rutherford & Ahlgren, 1989, p. 191).

*Karplus and Thier called the three phases of the learning cycle, exploration, invention, and discovery. Lawson renamed the three phases exploration, term introduction, and concept application. (Lawson, 1995, p.136)
phase (Lawson's term introduction phase) is a formal teaching phase where science terms and science concepts are introduced by the teacher, the textbook, internet, or video. In the Elaboration phase (Lawson's concept application phase), the student's well-formed concept is presented, justified, defended, challenged, and possibly revised or disregarded. The students are expected to present not only the concept, but also reasons and evidence to support that concept. Popper's (1959) critical discussion occurs at this phase of the learning cycle.

At this time, student ideas and evidence are questioned, defended, and revised if necessary. Many critical discussions were continued after class in the hallways or on the way to lunch. Within this process, the newly formed concept was applied to another applications and contexts.

The Teacher's Philosophy

The teacher's philosophy is pragmatism, a combination of weak constructivism and traditional transmitter-of-knowledge methods. The teacher moves between the roles of a

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"This phase is like the critical discussion in Popper's theory of knowledge growth. "Objective knowledge consists of guesses, hypotheses, or theories ... It also consists of unsolved problems and of arguments for and against the various competing theories." (Popper, 1994,p.10). Popper argues that knowledge grows as a "result of competing theories [in a Darwinian sense] offered tentatively to some objectively known problem" and ". . . is accepted into the objective domain, or the public domain, only after prolonged critical discussion based on tests" (Popper, 1994, p.13). Then Popper offers his tetradic schema of knowledge growth with the method of trial and of error elimination, $P_1 \rightarrow TT \rightarrow EE \rightarrow P_2$. $P_1 =$ Starting Problem, $TT =$ Tentative theory (hypothesis), $EE =$ Process of Error Elimination (by way of critical tests or of critical discussion), $P_2 =$ Problems with which we end. This schema reflects knowledge growth and the growth of knowledge achieved is estimated by the distance between $P_2$ and $P_1$. (Popper, 1994,p.11).
facilitator of knowledge (constructivist model) and giver of knowledge (traditional model). Researchers have noted the impossibility of students discovering all the concepts they need to know in science (Driver, 1983; Matthews, 1994).

The teacher is a cautious constructivist in that she maintains that children’s learning is a process of personal, individual, and intellectual construction of knowledge arising from the activity in the world as Piaget’s work suggested (Matthews, 1994). Many researchers (Nola, 1997, pp. 55-83; Matthews, 1994, p. 146) warn against the following propositions of constructivist learning:

- A child in isolation can discover and vindicate scientific truths.
- The language and concepts required for hypothesis development can be acquired independently of teachers or, more generally, independently of social interaction and participation in language communities.
- The testing of a hypothesis, and the interpretation of the test, is straightforward, and indeed simple enough even for elementary school children.
- Scientific concepts are formed by abstract from particulars.
- The scientific method is inductive.

Matthews explains that these propositions are the central causes of the failure of inquiry or discovery learning in the 60’s and are the core philosophical problems of constructivist learning.

Summary

The teacher’s classroom instruction includes a variety of methodologies: critical discussions, investigative activities, lectures, and debates. The classroom climate encourages risk-taking, deliberating on concepts and theories, admitting error, and creating dissonance with
current understanding of science concepts. Questioning is encouraged in student-student dialogues and teacher-student interactions. Questioning, a rational defense one's conclusions, and skepticism are expected and valued. This is Popper's critical discussion, e.g., the critical tests used to determine the falsifiability of any theory. There is a thoughtful exploration of objects, events, ideas, and theories which result in a systematic development of students' understanding and scientific habits of mind.

The teacher, if questioned, will describe herself as a master teacher as a matter of in fact the previous description of her philosophy and methods does reflect Frazer's descriptors of an exemplary teacher. Frazer writes, exemplary teachers (1994, pp. 517-519)

- Use management strategies that facilitated sustained student engagement.
- Use strategies designed to increase student understanding of science.
- Utilize strategies that encouraged students to participate actively in learning activities.
- Maintain favorable classroom learning environments.

Within the context of this learning environment, described by the school and classroom climate and the teacher's philosophy, geologic time was systematically taught by the teacher, and the students' understanding of geologic time was investigated by the researcher.

In an attempt "to see one's self" and to allow the reader "to see" the teacher within the setting of the teaching unit, the goal of Chapters 5 and 6 is to project an image on the wall of the teacher and her methods in the Geologic Time Unit.
Teaching Geologic Time

The teacher’s professional goals for the Geologic Time Uniy were recorded on August 25, 1998 when she submitted her Professional Growth Plan. Her overall goal was to develop the sixth grade science curriculum within the framework of geologic time (see Appendix L).

Precursor Concepts

The teacher’s intent was clear from the beginning of school. Many activities throughout the year were aimed at developing general precursor skills and concepts which the students needed to explore and understand the specific concepts in the Geologic Time Teaching Segment, e.g., critical thinking skills, scientific tools and methods, scientific habits of mind, and the basic science behind the theories of the earth and the development of life on earth (see Appendix M).

In the summer of 1997, the researcher correlated the evolution concepts in the middle school science curriculum to the questions on the Geologic Time Survey. These were the geologic time concepts covered in a survey manner in the sixth grade science textbook: scientific classification, evolution and genetics, cells, earth and earth history, types of rocks and the rock cycle, plate tectonics, geologic time, erosion, physical and chemical weathering, and glaciation.

The teacher identified precursor concepts which she included in the teaching segment from January through May: Solar System Unit, Earth History (Rocks and the Rock Cycle), Chemistry (Elements, Solutions, Mixtures, Acid and Bases), Biology (Classifying Animals, Characteristics of Plants and
Animals, Cells), and Geologic Time. The key was to present these ideas as a unified whole.

The teacher is highly trained in the science education domains of Space Science, Physical Science, Chemistry, and Marine Science. She is certified to teach Aerospace Education and has completed the pilot's ground school, spent five intense summers being retrained in Physical Science, Chemistry, and Astronomy in the Louisiana Systemic Initiative Programs at Louisiana State University, and spent three demanding summers at the Gulf Coast Research Lab in Ocean Springs, Mississippi studying Marine Science. Therefore, the teacher develops her own science curriculum and materials from her training and uses the textbook as supplementary reading. The teaching units on these topics are show-piece units in their own right, however, they will not be discussed in this paper. The only parts of these units which will be discussed are the precursor concepts related to the understanding of geologic time.

Precursor Teaching Episodes

Solar System

The Solar System Unit contributed three precursor ideas, e.g., the Big Bang, the mechanisms of time, and an introduction to magnitude of distances in the solar system.

The Louisiana Systemic Initiative Program (LaSIP) is a statewide program to retrain inservice teachers in the current reform teaching methods in Science and Math. These methods are elaborated in American reform program, Project 2061, and grounded in the following literature, *Science for All Americans* (Rutherford & Ahlgren, 1990), *Benchmarks for Scientific Literacy* (AAAS, 1993), and *National Science Education Standards* (NRC, 1996). Project 2061's primary goal for science education is to produce a scientifically literate adult population in this country.
The Big Bang, although not part of geologic time, is a key idea in the scheme of time - the beginning event. In developing a student's understanding of geologic time, the teacher thinks of geologic time as a system in which the event of the beginning of the universe is an important point of reference in the entire scheme of time. The Big Bang Theory introduces the students to the science/religion argument.

Although students are exposed to the mechanisms of time, (e.g., day and night and the earth's year) do they understand how to mark and measure time? In a conversation with Dr. Denise DeNyne's on time and children's understanding of time, she cautioned the researcher, "Check the assumptions we make about children's understanding of time. Do they know the mechanisms of time? The rotation of the earth? The revolution of the earth? Do they know duration and right and left in understanding the timeline?" (personal communication, October, 1998). Thus, the teacher presented a demonstration and review of the motions of the earth-sun system in the earth's day/night and year.

In January, the teacher used the solar system to develop the concept of the numbers - a million and a billion and a sense of the immense scale of the solar system. The Solar System Scale Model by the Harvard-Smithsonian Center for Astrophysics demonstrated the distances of the planets from the sun. A scale factor of 1 centimeter equals 1,000,000 kilometers was used and paper cut-outs of the planets were placed on a string 59.3 meters long.

Dr. James Wandersee directed the teacher to explain how she developed the students' concept of scale as defined in
the National Science Standards (personal communication, March, 2000). SFAA (1989, pp. 167-169) informs the education community that the "ranges of magnitudes in our universe - sizes, durations, speeds, and so on - are immense. Many of the discoveries of physical science are virtually incomprehensible to us because they involve phenomenal scales far removed from human experience." SFAA continues "...these extremes exceed our powers of intuitive comprehension. Our limited perceptions and information-processing capacities simply cannot handle the whole range. Nevertheless, we can represent such magnitudes in abstract mathematical terms (for example, billions of billions) and seek relationships among them that make sense." The teacher began a systematic development of the concepts of million and billion and scale with experiential activities.

The Earth and Rocks

In February, the teacher began the unit on types of rocks, the rock cycle, and plate tectonics. The history of the earth assists the student in understanding the significance of the fossil record.

Chemistry

In March, the students studied chemistry, e.g., elements, atomic structure, solutions, acids and bases, and parts per million. Basic chemistry ideas are related to the ideas of elements, an old earth, and the primordial soup. Parts per million provided another a physical model of the number, one million. First, the students did a serial dilution of parts per million and parts per billion. Then they made a physical model of one dot in a million dots.
What is an Animal? and Plant and Animal Cells

In April, the teacher began developing the concepts of What is an animal? and Plant and animal cells. The Geologic Time Unit officially began on April 7 and ended on May 14.

**Geologic Time Unit**

This description of the Geologic Time Unit is an attempt of the teacher/researcher to project an image on the wall of the events in the Geologic Time Unit so the reader and the researcher can see the teaching episodes. This description is a composite of the teacher's lesson plans, student journals, and the researcher's reflective journal.

**Geologic Time Unit**

4/8 THU Activity: Animal/not animal\(^2\): Hands-on/minds-on activity to classify 75 pictures of living and non-living things as an animal or not an animal.

4/9 FRI Prepare Group Charts. Present charts to class.

**Student Journal (Pretest) What is an animal?**

4/12 MON Video Animals

Identify characteristics of animals.

**Student Journal- (Posttest) Based on last week's activity: What is an animal?**

4/14 WED Discuss the characteristics of plants and animals. Students read from journals.

Discuss and refine their ideas. Read text pp. S36-S42. Cell theory, plant & animal cells.

**Reflective Journal:** It is very difficult to play the dual roles of researcher and teacher. The role of teacher (obligations, grading tests, etc.)

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\(^2\)I used the simple classification animal or not animal because I believe that keeps the concept pure. There were pictures living and nonliving things in the cards, e.g., plants, animals, and objects.
student interim reports, report cards, ethics, commitment to the requirements of state and local curriculum) always seems to win.

4/15 THU Lecture

Reflective Journal: Today taught in lecture format. (After students explored classifying more than 100 pictures as an animal or not an animal and developing their characteristics of animals.)

Today’s lecture:

Animal characteristics: (1) Animal cell has nucleus, organelles; (2) Multicellular, (3) Locomotion, (4) Does not produce its own food; must ingest and digest food.

Plant cell: (1) Plant cell has nucleus, organelles, cell wall, (2) Stationary (no locomotion), (3) Produces its own food.

Then had students draw the plant and animal cells and copy cell theory.

(1) The cell is the basic unit of life.
(2) All living things are made of cells.
(3) Only a cell can produce another cell.

Draw plant and animal cells (pp. S40-S41).

4/16 FRI Student Journal: Analogy - A million years is like.... A billion years is like.... Student’s write an analogy.

4/16 FRI Video: Mary Anning, Fossil Hunter. A vignette on the life of fossil hunter, Mary Anning, (e.g., fossils, ammonites, and the ichthyosaur).

Student Journal: What did you learn from the Mary Anning video?
Activity: Geologic Timeline. Pairs of students make geologic timeline on four and one half meters of adding machine tape. Scale: 1 millimeter = 1 million years.

Reflective Journal: It is difficult to select the group of students for case studies. I'm surprised and pleased that so many individuals want to participate. In choosing the students to interview and focus on their concept development in their journals, I will use the CES drawings (What was the first animal?) to classify them into groups: Scientist, Creationist, Misconceptions. I will choose candidates from all the science classes.

Video - Eyewitness Prehistoric Life
Student Journal: What happened to different species of animals over billions or millions of years of earth time? Give evidence and examples.

Teams - Work on Geologic Timeline.
Reflective Journal: It is extremely difficult to play the dual roles of teacher and researcher. In the teacher role, I think in terms of meeting prescribed curriculum and standards. And design original lessons to meet those objectives. As a researcher, I design or search for probes that will reveal students deep knowledge or understanding of a concept. They are fundamentally different roles, but I don't understand the difference yet.

Teams work on Geologic Timeline.
5/3 MON Activity: *Species cards.* Classify or group the animals according to the changes in their characteristics. What happened to the two groups of animals over time? Give examples and evidence. The activity shows speciation. The grouping of the animals reveals changes in body characteristics, e.g., spots, toes, and nose over time.

5/4 TUE Pretest - Word Association: List all the words you know related to geologic time. Read aloud science text pp. 30-35, (e.g., theory of evolution, speciation, adaptation and evolution.) Discuss how changes in species occurs over time.


Student journal: Describe what you learned for the "Walk Through Geologic Time."

Reflective Journal: I took the students on an imaginative walk through geologic time today modeled on Calvin's work (Calvin, 1986). I used the geologic timeline along the walls of the classroom (not to scale). I told the class a Wizard would visit them today and I expected them to be on their best behavior and *Take notes.* I stepped out of the room; the students looked at each other wondering. They have learned from experience in this classroom to expect the unexpected. The Wizard, dressed as Disney's
Sorcerer's Apprentice in long red robes and a pointed red sorcerer's hat with Mickey Mouse ears, returned in my place. She looks a lot like me. The Wizard introduces herself as the Geologic Time Wizard and with a flash of her wand takes them for a Walk through Geologic Time: Big Bang (4.6 bya), Primordial soup (4 bya), Bacteria form and Rusting of planet (2,500 mya), Oxygen atmosphere (1,800 mya), Simple cell¹ (1,700 mya), Super cell (1000 mya), Jellyfish (980 mya), Invertebrates and Jawless fish (500 mya), Land plants and Spiders (400 mya), Amphibians (390 mya), Reptiles (340 mya), Permian extinction (225 mya), Dinosaurs (200 mya), Cretaceous extinction (65 mya), Mammals (65 mya), Monkeys (50 mya), Homo sapiens (100 tya). The students giggle and look, listen, and learn. As the Wizard, I kid the group; they wink and play the game. We all had fun today.

I note that very controversial ideas were presented without challenge, and I wonder is it because of the Wizard or because of all the precursor concepts teaching and geologic time concepts. However, I am certain the Wizard helped the medicine go down. I know I could have tested the effectiveness of the Wizard by not doing the presentation with one group and compare the groups. However, as usual the teacher won over the researcher. As a teacher, I could not exclude a class from that learning experience.

¹Simple cell is a cell without a nucleus, a dumb cell. Super cell is a cell with a nucleus, a smart cell.
5/14 FRI  Posttest-Word List: List all the words you know about or related to Geologic Time.

5/20 THU  Posttest Geologic Timeline Survey

5/24 MON  Posttest "First Animal" Drawing

5/25 TUE  Posttest Earth Science

5/26 WED  Posttest Evolution

There were no formal paper-and-pencil tests on the Geologic Time Unit for two reasons (1) the unit had a conceptual teaching focus not a content knowledge building and (2) the teacher wanted to limit the stress of testing on the group because so much formal research testing was done.

However, grades were taken on the following activities:

• Activity: Animal Classification.
• Journal Entry Posttest: What are the characteristics of an animal?
• Journal Entry: Mary Anning Video: What did you learn?
• Activity: Speciation - Classify the animals according the their characteristics.

A list of the activities and methods used in the Geologic Time Unit are cataloged in Table 1. This data was taken from the teacher’s lesson plans.

Table 1

<table>
<thead>
<tr>
<th>Instructional Method</th>
<th>Number of Uses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Audio-visual Presentations</td>
<td>3</td>
</tr>
<tr>
<td>Hands-on/Minds-on Activities</td>
<td>3</td>
</tr>
<tr>
<td>Journal Entries</td>
<td>9</td>
</tr>
<tr>
<td>Discussions (within-groups)</td>
<td>9</td>
</tr>
<tr>
<td>Class discussions</td>
<td>6</td>
</tr>
<tr>
<td>Lectures</td>
<td>2</td>
</tr>
<tr>
<td>Drawings</td>
<td>2</td>
</tr>
<tr>
<td>Readings</td>
<td>2</td>
</tr>
</tbody>
</table>
At the end of the Geologic Time Unit, the four final case study participants were selected from the original group of ten students. There was a representative from each of the four categories which emerged from the content analysis of the data, e.g. MS Pseudoscientists (fundamental creationist thinking), MS Prescientists (everyday knowledge misconceptions), MS Protoscientists (beginning science thinking), and MS Scientists (scientific thinking). The case study participants' thinking about geologic time will be explored in depth in Chapter 6.
CHAPTER 5
ANALYSIS OF GROUP DATA

Pseudoscience

The Demarcation between Religion and Science

One way of explaining the physical world and changes over geologic time is with pseudoscience or metaphysical explanations. Pseudoscience explains the natural world with myths, personal beliefs, religious values, mystical inspiration, superstitions, and/or authority. These metaphysical explanations are beyond questioning and therefore unchallengeable (Mayr, 1998; Lipps, 1998; Popper, 1959). UFO's, astrology, the Bermuda Triangle, crystal power, channeling, and religious explanations of natural phenomena are some examples of pseudoscience. In this study, the pseudoscientist category is composed of the students with religious misconceptions about the natural history of the earth and the development of life on earth.

Religion uses the method of dogmatic authority to explain the physical world, and these explanations must be accepted by faith. Faith usually refers to beliefs that are accepted without empirical evidence or questioning. Pseudoscience or selective reasoning is complete upon presentation and requires only acceptance, not critical examination. Lipps (1998, p. 3) explains, "Pseudoscience uses particular facts, beliefs, and unconfirmed opinions to foster a false understanding of events and things."

Religious beliefs about the natural history of the earth and life on earth fall along a continuum from fundamentalist Jewish, Moslem, and Christian views to the theistic evolution interpretations of liberal Christians.
and Jews. Berra (1990) points out that many Jews, Catholics, and most mainstream Protestant denominations (Episcopalian, Presbyterians, and Methodists) have reconciled the theory of evolutionary and their religious beliefs. Theistic evolutionists, like the Deists of the 1700 and 1800’s, see evolution as God’s plan, not as a denial of their belief in God. These religious denominations interpret the Old Testament, particularly the book of Genesis, as metaphor, myth, or allegory.

On the other hand, the fundamentalist religions, sometimes called the religious right or moral majority, perceive the science concept of biological evolution within the framework of geologic time as irreconcilable with the tenets of their religious beliefs. They reject theistic evolution and insist on a literal interpretation of the Bible. These religious groups view the Bible, as the inerrant, inspired word of God and as historically and scientifically true. Therefore, they view the account of origins in the book of Genesis as “a factual presentation of simple historical truths” and other biblical stories as scientific accounts, e.g., “God’s direct creation of the earth and all things in six days, Noah’s flood, Adam and Eve…” (Berra, 1990, p. 124-125).

For the purpose of this study, a creationist worldview is broadly defined as an unquestioning, dogmatic belief in the tenets of Christian dogma in Darwin’s age, 1859. (1) A belief in a constant world. (2) A belief in a created world [a six-day creation.] (3) A belief in a world designed by a wise and benign Creator. (4) A belief in the unique position of man in the creation (Mayr, 1991) and a belief in a literal interpretation of the Genesis creation account and
other biblical stories. This doctrine is supported by more specific pseudoscientific ideas and teachings (Berra, 1990, pp. 126-132).

- The earth was created about 10,000 years ago.
- All fossils were deposited at the time of the Noachian flood.
- Fossils seem appear out of nowhere at the base of the Cambrian, therefore, they had to have been created.
- The chances of the proper molecules randomly assembling into a living cell are impossibly small.
- Dinosaur and human footprints have been found together in Cretaceous limestone at Glen Rose, Texas. Therefore, dinosaurs could not have preceded humans by millions of years.
- The separate ancestry of humans and apes.

Ernst Mayr, in considering the demarcation between science and theology, wrote that many people search for truth: theologians, philosophers, poets, politicians, and scientists. In the search for truth, religion (theology) addresses concerns of the physical world and the metaphysical world, e.g., the supernatural world of souls, spirits, angels, or gods. Science, in contrast, seeks to understand and explain natural phenomena in only the physical world with empirical evidence. Religion uses supernatural beings and forces to explain natural phenomena and divine revelation as a legitimate source of truth about the physical world. Mayr (NAS, 1998, p. 42) says, “These supernatural constructions are beyond the scope of science.” Therefore, the problem as defined by the scientific community and the science education community is not with religion itself or even religious explanations of the creation events. The problem emerges when religious
explanations of natural phenomena are presented and accepted as scientifically true (NAS, 1998, p. 42).

In contrast, the problem, as defined by the fundamentalist, creationist groups and fueled by their deep-seated misunderstanding and mistrust of postpositivist science, is the very nature of science itself, e.g., the scientific philosophy of questioning, skepticism, and empirical evidence. As a result, they perceive the scientific explanations of the natural history of the earth and the development of life on earth as a threat to their religious beliefs.

The American public at large is confused about the demarcation between science and religion. In a recent newspaper article, the Religion News Service reported that in a 1999 Gallop poll, 68% of the American public favored teaching creationism in schools along with evolution, 55% opposed the ideas of teaching creationism instead of evolution, 25% of American think teaching creationism should be required in public schools, and 56% say creationism should at least be offered to students as a subject of study (Saturday State-Times/Morning Advocate, 2000, p. 2F).

Dawkins (1997, p.1) explains, "There is a difference between a belief that one is prepared to defend by quoting evidence and logic and a belief that is supported by nothing more than tradition, authority, or revelation."

Most individuals in the science community understand this difference. Most people in the fundamentalist religious community do not and the American public does not. The nexus of the demarcation between science and pseudoscience is to understand this difference.
Middle School Pseudoscientists

Criteria for MS Pseudoscientists

Placement in the Pseudoscientist category from the topologies requires the explicit use of the words: God, Bible, or a direct reference to religious teaching (e.g., the Judeo-Christian creation story or another belief-system’s creation story) in the open-ended responses. Special creation could neither be implied nor inferred from the response. "God created" or an equivalent statement must be made. Some characteristics of this group are they (1) do not use the science vocabulary, (2) have incorrect science content knowledge, (3) use creation stories to understand geologic time, and/or (4) use the dualist concepts e.g., science and religion or everyday misconceptions (dinosaurs) and religion to explain events in the natural history of the earth.

Modal Profile of MS Pseudoscientist Group

Composite of the MS Pseudoscientist Group

At the end of the sixth grade, twelve percent of the students are in the MS Pseudoscientist Category, compared to thirty percent at the beginning of the study. The Pseudoscientist group is composed of seven students, 3 females and 4 males with average age of 12.6 years old

Organizing Concept

God Created (86%) was the major organizing concept for the MS Pseudoscientist group. These students used a fundamental creationist theory, e.g., "God Created" or other Bible stories "Adam and Eve" to develop their thinking about the index time-events in geologic time. The data from the
MS Pseudoscientist category fell along a continuum of strong creationist worldviews (29%) to weak creationists views and dualist views of science-based and creationist ideas (29%), creationist and secular misconceptions (dinosaur) (29%), or human and dinosaur focus (14%).

Table 2

<table>
<thead>
<tr>
<th>Organizing Concept</th>
<th>N</th>
<th>Percent Category</th>
<th>Percent Study</th>
</tr>
</thead>
<tbody>
<tr>
<td>God Created/Adam&amp;Eve</td>
<td>2</td>
<td>29</td>
<td>4</td>
</tr>
<tr>
<td>God/Dinos</td>
<td>2</td>
<td>29</td>
<td>4</td>
</tr>
<tr>
<td>God/Science</td>
<td>2</td>
<td>29</td>
<td>4</td>
</tr>
<tr>
<td>God/Humans/Dinos</td>
<td>1</td>
<td>14</td>
<td>2</td>
</tr>
</tbody>
</table>

Concept of geologic time

Sixth Grade MS Pseudoscientists did not effectively use time as an organizing concept even after the implementation of a systematic plan to develop the concept of geologic time. The teacher used several hands-on, minds-on geologic timeline activities to develop the concept of geologic time and scale, as well as multimedia presentations (e.g., textbooks, videos, vignettes, skits) to present the concept of geologic time in the various learning styles. In the pretest, all events on the geologic timeline were placed at 0-time when “God created.” After the Geologic Time Unit, the key time-events, although not correctly placed, were spread out along the geologic timeline instead of clumped together at 0-time. This indicates a positive change to more scientific thinking in the group’s understanding of geologic time. However, only one of the seven MS Pseudoscientists knew the scientifically accepted time of "Number of students in Pseudoscientist group.
"Total number of students who took Geologic Timeline Survey.
two of the three index time-events, the formation of the earth and prehistoric humans appeared. She was a case-study participant who received much more individual interaction with the researcher on the concept of geologic time than the regular class members. Two of the seven knew the accepted time when prehistoric humans appeared. None of the MS Pseudoscientists knew the correct time for dinosaur extinction. The data indicate the time-event this group most clearly understands is prehistoric humans appeared (29%). The researcher interprets this strong anthropocentric focus as a characteristic of Piagetian egocentric thought.

Of all the students in this study, this group has the weakest concept of geologic time. This indicates to the researcher that (1) an understanding of qualitative geologic time may be a logical precursor concept to the student's understanding of biological evolution and (2) the child's understanding of time may be directly related to his or her general thinking ability (Piaget, 1959).

Table 3 shows MS Pseudoscientists understanding of the index time-events on the Geologic Timeline at the end of the study. These students are most familiar with the time prehistoric humans appeared.

<table>
<thead>
<tr>
<th>Quest. Correct time</th>
<th>Accepted Range</th>
<th>N</th>
<th>Percent Category</th>
<th>Percent Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Earth Forms</td>
<td>4.6 bya&quot;</td>
<td>1</td>
<td>14</td>
<td>2</td>
</tr>
<tr>
<td>Dino Extinct</td>
<td>65 mya&quot;</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Humans Appear</td>
<td>2-4mya</td>
<td>2</td>
<td>29</td>
<td>4</td>
</tr>
</tbody>
</table>

"bya = billions of years ago.
"mya = millions of years ago.
Sixth Grade Pseudoscientists, as a group, thought about geologic time in this way. The typical MS Pseudoscientist is 12.6 years-old. As a group, the students are below-average and over-age (e.g., the average age of a sixth grader in the second semester is 11.5 years old), but they thoughtfully considered the problem of deep time. Although these students are firm in their position, they have difficulty defending their thinking with evidence or reasons. The warrant for their defense is an appeal to a higher authority, e.g., “God said” or the “Bible said.” They use a fundamental creationist theory, God created, as the primary organizing concept to construct their personal conceptual understanding of geologic time.

Thinking about the Three Index Time-events

They explain their thinking about the three key events: earth formed, dinosaurs extinction, and prehistoric humans appeared in this way.

**Earth formed (4.6 bya): MS Pseudoscientists**

Mike 12: “God made the earth when he made it.”

Melanie 13: (500 mya) “Before everyone was born except for Adam and Eve and God.”

Mary 12: (10 bya) “Personally, I think it was formed after the universe was formed which was millions of years ago.”

Will 13: (10 bya) “About 5 bya after the universe formed which was formed in 6 days after the universe formed.”

**Dino Extinction (65 mya): MS Pseudoscientists**

Mike: (55 mya) “About 5 billion years after they came.”

Melanie: (500 tya) “When people started killing them for fun.”
Humans Appear (1-2 mya): MS Pseudoscientists

Melanie: (25 mya) "When Adam and Eve made us, that was when God gave the strength."

Will: (2 mya) "It was about 250 mya after earth formed. It all had to be calm and have light."

Jake: (15 bya) "The big bang happened because God had to get rid of the animals and put oxygen on earth."

MS Pseudoscientists use stylistic, biblical language (e.g., "in the beginning", "the serpent", or "the forbidden tree") and traditional creation stories from the Judeo-Christian Bible as warrants to support their answers (e.g., "The snake was the first animal because that's what the devil was in Adam and Eve"). The epistemic operation they use is an appeal to authority, such as "God created", the Judeo-Christian Bible, or my religious training.

MS Pseudoscientists' use of a fundamental creationist theory as an organizing concept is further corroborated by a casual inspection of their responses to the other index time-events on the Geologic Timeline Survey. Although these students use the creationist concept God created to explain the formation of the earth, as a group they do not claim that God created the universe. They use either a more scientific explanation (e.g., the geologic timeline or the Big Bang) or a prescientific framework (misconceptions) to explain that event. However, they return to creationist theory in reference to formation of plants and animals. Their exact responses are as follows.

Universe Formed (13 bya): MS Pseudoscientists

Melanie: "At the beginning of time."

Mary: "All I know is that the universe formed before the plants formed."
Plants Appeared (420 mya): MS Pseudoscientists
Mike: "God put plants on the earth when he made it."
Mary: "I think when Adam and Eve was made on earth."
Will: "It formed about 23 mya because when dinosaurs was living, they needed plants to eat."

Vertebrate Animals (350 mya): MS Pseudoscientists
Melanie: "Whenever they were born and God made them."
Mary: "When the humans appeared."
Will: "About 23 bya because after dinosaurs disappeared more animals with backbones appeared."

CES: protozoan MS Pseudoscientist Group
A quantitative analysis of the data of MS Pseudoscientists' drawings shows the percentage of the students that appeared in each drawing category closely correlated with the results of the analyses of the open-ended responses on the geologic timeline. The two most prevalent drawing categories were pseudoscience (40%), e.g., a biblical animal or Adam & Eve, and prescience (40%), e.g., a dinosaur. These findings closely corroborate the results of the analyses of the students' open-ended responses on the Geologic Timeline Survey where MS Pseudoscientists used fundamental creationist theory ideas (29%) or dualist concepts (43%), e.g., dinosaurs combined with a creationist theory or anthropomorphic focus as organizing concepts. In addition to using stylistic language (e.g., the serpent, Satan, power) and traditional stories (e.g., Adam & Eve, 6-day creation, the fall of man in the garden) from the Bible as warrants for their personal theories, MS Pseudoscientists also use sacred pictures to explain their understanding of events in the history of the earth. This group used sacred
animals and religious justifications to illustrate and explain the protozoan, first animal (see Figure 3).

Mike 12: The protozoan

Mike's Justification: "I picked the snake. When God made the earth, he made animals. But, the first animal talked about is the Snake. The devil tried to get Adam and Eve to eat the apple."

Bryan 13: The protozoan

Bryan's Justification: "According to the Bible along with the first two people, Adam and Eve, come a serpent which is a snake. A snake is an animal, so that means the first animal is the snake."

Figure 3. MS Pseudoscientists' Concept Evaluation Statement - drawings and justifications of protozoan, first animal.

Characteristics of Poor Reasoners

Driver (1985, pp. 53-58) describes some of the characteristics of poor reasoners or child-like thinkers described by Piaget's work. She writes that some key characteristics of Piagetian concrete operational thought are egocentrism, reversibility of thought, the ability to classify objects into classes in many ways including hierarchically organized classes, and the use of simple inferential logic to solve some kinds of problems, that is, if A is > B and B is > C, which one is the smallest?

Egocentrism, Driver continues, is an overarching quality of child-like thought which is described as
(1) tending to see the world with themselves as an agent, 
(2) having difficulty imagining events from a perspective 
which differs from their own, (3) having difficulty viewing 
a situation from other than their own point-of-view, and 
(4) tending to explain events in terms of their [personal] 
action on a system, rather than in terms of the properties 
of the system itself. The limitation of child-like thinking 
is the student's inability to think hypothetically.

Lawson (in Good et al. 1992, p.139) found that poor 
reasoners rather than good reasoners are more likely to hold 
misconceptions such as Special Creation, e.g., the doctrine 
that the universe and all that is in it was created all at 
one time by God, essentially in its present form. He 
explains that good reasoners use hypothetico-deductive 
reasoning. They are able to (1) generate causal questions, 
(2) generate alternative hypotheses to possibly answer those 
questions, (3) imagine the correlational or experimental 
events to test the alternatives, (4) make predictions based 
on the assumption the hypothesis is correct, (5) collect and 
analyze empirical data to compare the predicted result with 
the actual result, and (6) draw a conclusion that supports 
or does not support the hypothesis which indicates their 
understanding of the correspondence between what was 
predicted to happen and what in fact did happen. Poor 
reasoners, Lawson continues, have not developed the 
"necessary hypothetico-deductive reasoning abilities to 
analyze alternative hypotheses, their predicted 
consequences, and the evidence... They are left with no 
alternative but to believe what they are told or what their 
initial intuitions suggest" (in Good et al. 1992, p.139).
The overshadowing question to this researcher is: Are MS Pseudoscientists limited by poor reasoning abilities or are MS Pseudoscientists' reasoning abilities limited by the nature of their religious training, that is, being taught to accept teachings without critical examination and skeptical questioning. Driver (1985, p. 5), quoting Popper, writes "...we are prisoners caught in the framework of our theories." Then, she makes this observation about school science "... children, too, can be imprisoned in this way by their preconceptions, observing the world through their own particular 'conceptual spectacles.'"

MS Pseudoscientists in this study illustrate some characteristics of poor reasoners in that they "believe what they are told", do not generate alternative hypotheses or questions, and demonstrate an egocentric point-of-view by focusing their understanding of deep time on the human in geologic time, an anthropocentric view. The student responses in the MS Pseudoscientist Group support Lawson's statement that "poor reasoners believe what they are told." Many students in this group use the following responses as warrants for their thinking.

"According to the Bible..."
"God made it."
"The answer is on the wall."

Middle School Prescientists

Criteria for MS Prescientist Category

MS Prescientists hold misconceptions, obviously false concepts or inaccurate science knowledge. These misconceptions are sometimes called children's science,
common-sense knowledge, or alternative frameworks in the conceptual change literature. Additionally, these students either do not use specific science vocabulary or use the scientific language, but do not appear to understand the meaning. The most common misconception of this group is to explain the events in geologic time from a dinosaur perspective and use a dinosaur theory to organize their thinking about geologic time.

Modal Profile of MS Prescientist Group

Composite of the MS Prescientist Group

Sixty eight percent of the students are in this category. The composition of the group is 41% are male and 59% are female with an average age of 11.9 years.

Table 4 presents the organizing concepts of the MS Prescientist Group. A dinosaur theory (49%), the predominant organizing concept of this group, forms a spurious framework that results in significant misconceptions for the individual as evidenced in the following discussion.

Table 4

Organizing Concepts of Sixth Grade Prescientists

<table>
<thead>
<tr>
<th>Organizing Concept</th>
<th>N</th>
<th>Percent Category</th>
<th>Percent Study</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dinosaur theory</td>
<td>19</td>
<td>49</td>
<td>33</td>
</tr>
<tr>
<td>Relational time</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Before/after</td>
<td>6</td>
<td>15</td>
<td>11</td>
</tr>
<tr>
<td>universe, earth,</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>animals.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anthropocentric</td>
<td>6</td>
<td>15</td>
<td>11</td>
</tr>
<tr>
<td>focus</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Before/after</td>
<td>6</td>
<td>15</td>
<td>11</td>
</tr>
<tr>
<td>humans.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reference science</td>
<td>6</td>
<td>15</td>
<td>11</td>
</tr>
<tr>
<td>event</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>2</td>
<td>5</td>
<td>4</td>
</tr>
</tbody>
</table>

N=39” N=57”

*Number of students in Prescientist Category.
*Total number of students in Geologic Timeline Survey.

91
Forty-nine percent of MS Prescientists used a dinosaur theory to organize their thinking about key time-events in geologic time and to justify their thinking about why the earth, plants, and animals formed in the natural history of the earth. These findings were triangulated by three different qualitative measures (1) open-ended responses to key time-event in geologic time, (2) Concept Evaluation Statement (CES), e.g., student-generated drawings of the first animal and written justifications of those drawings, and (3) word association responses to the prompt, geologic time.

Table 5

<table>
<thead>
<tr>
<th>MS Prescientists’ Correct Responses to Index Events on Geologic Timeline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quest.</td>
</tr>
<tr>
<td>--------</td>
</tr>
<tr>
<td>Earth Forms</td>
</tr>
<tr>
<td>Dino Extinct</td>
</tr>
<tr>
<td>HumansAppear</td>
</tr>
</tbody>
</table>

Almost twenty-five percent of the MS Prescientists gave the correct time on the Geologic Timeline for one index time-event, earth forms. However, most did not provide an acceptable justification of the time-event. This indicates to the researcher that the first structure and perhaps a crucial structure in the development of correct student thinking about the natural history of the earth is the correct chronological time of some key events. The student’s understanding of events in geologic time is then built around those structures. The Prescience group, following the pattern of seventy-five percent of the students in the study, is most familiar with the time the
earth formed and least aware of the time prehistoric humans appeared. This pattern is reversed for the Pseudoscience group who have an anthropocentric focus and are most aware of the time prehistoric humans appeared. This pattern may reflect the students' epistemological position, e.g., what knowledge the students' attend to and ignore related to their worldview.

Interestingly, although the Prescience group uses a dinosaur theory to organize their thinking about deep time, and they have been learning about dinosaurs since the second grade, they know neither the correct time of dinosaur extinction nor when dinosaurs existed. Thirty percent of this group are beginning to use relational time (X event occurred before Y event), but do not use a system of time in their thinking about the events in geologic time.

Geologic Time

When did time begin? When was 0-time? Different disciplines may place 0-time at different positions on the geologic timeline continuum, corresponding to the focus of their fields. Geologists may claim time began when the earth formed 4.6 bya or biologists may argue time began ~3.8 bya with the formation of life on the planet. Some creationists may assume time began on October 22, 4004 B.C. according to recorded history and the genealogies described in Judeo-Christian Bible. The purpose of this study is to examine the big picture of students' theories about origins of the earth and life on earth. Therefore, the researcher offers a cosmic view from the physics perspective and defines 0-time (time begins) with the Big Bang event, the birth of the universe at ~ 13 bya on all timelines used to
explore students' understanding in the study. However, the Big Bang event is used only as a point of reference not as geologic time. Specific to the goals of this study, the timeframe examined by the researcher is geologic time-events from the formation of the earth \( \sim 4.6 \text{ bya} \) to the first appearance of prehistoric humans, currently thought to be \( \sim 2 \text{ mya} \) (Wicander and Monroe, 1993).

MS Prescientists are most familiar with the time the earth formed in the history of the earth. Twenty-four percent gave the correct time on the geologic timeline (4-5 bya) and correct warrants for their answer. However, as Table 5 denotes MS Prescientists, as a group, exhibit an extremely deficient understanding of the time of index time-events on the geologic scale.

**MS Prescientist Group**

The MS Prescientist Group’s average age is 11.9 years old and consists of a mixed group of males and females who use a dinosaur theory to think about geologic time. The classroom teacher describes this group as a low-average group of students (based on their performance on tests and class participation) who become engaged in science topics they find appealing, but are not consistently interested in science. The Benchmarks suggest, "Students’ curiosity about fossils and dinosaurs can be harnessed to consider life forms that no longer exist" (AAAS, 1993, p. 122). Although this group has been learning about dinosaurs in the science curriculum since the second grade, they reveal serious misconceptions about them. They use dinosaurs and dinosaur trivia to organize their thinking about the key time-events discussed in this study.
Thinking about the Three Index Time-events

As a group, MS Prescientists think about the natural history of the earth in this way. The students’ theories will be presented in their own words, and the age of the student is given only once when that student first appears in the document. The purpose of this approach is used to add validity by balancing researcher bias and increasing reliability by allowing the reader to interpret this information. This set of responses is a composite of nine different students’ justifications of time-events on the Geologic Timeline.

Earth Formed (4.6 bya): MS Prescientists

Liz 12: "After the dinosaurs left the earth."

Drew 12: (10 bya) "The earth formed before plants and dinosaurs."

Miranda 13: (1 bya) "It formed a little after dinosaurs disappeared."

Lisa 12: (12 bya) "Because the plants, dinosaurs, and cavemen had to be on earth."

Dino Extinction (65 mya): MS Prescientists

Drew: (7 bya) "They were gone before humans came."

Donna 12: (25 mya) "They had to die right before vertebrate animals."

Miranda: (500 mya) "Because they roamed the earth for 65 years."

Joy 12: (5 bya) "Because they were not alive very long because the humans tried to kill them."

Humans Appear (1-2 mya): MS Prescientists

Jerry 12: (1 mya) "They were after the dinosaurs."

Ann 12: (55 mya) "Because right after the dinosaurs disappeared, humans appeared."
Marie 12: (65 mya) "They came to earth a while after the dinosaurs disappeared."

Joy: (9 bya) "Because they appeared just before the dinosaurs became extinct."

The MS Prescientist group's thinking illustrates features of Lawson's (1995) empirical-inductive or child-like thinking pattern. They use class inclusion (dinosaurs) which entails simple classifications and generalizations to construct their personal understandings of the natural history of the earth and life on earth. They complete their dinosaur theory by referring to dinosaurs as their warrants for other geologic time-events as well.

Thinking about the Remaining Index Time-events

Universe Formed (13 bya): MS Prescientists

Sue 12: "That is the first thing that had to happen. The earth couldn't form before the universe or anything else because the earth is the universe."

Lisa 12: "The universe formed before the dinosaurs and humans."

Marie: (15 bya) "A little after it happened, they had a big bang."

Plants Appeared (420 mya): MS Prescientists

Sue: "When the dinosaurs come they needed food because dinosaurs can't live without food."

Niki: "Before the dinosaurs because it had to have been here to support the life of the dinosaurs."

Lisa: "The plants had to form before or with dinosaurs because they had grass and plant eating dinosaurs."

Vertebrate Animals (350 mya): MS Prescientists

Liz: "Between the time dinosaurs appeared and disappeared."

Lisa: "When the dinosaurs appeared because the dinosaurs are vertebrate animals."
Meg: "I put it at 65 mya because a type of dinosaur had to have a backbone."

John: "Dinosaurs are vertebrate animals and that's when dinosaurs first appeared."

**Characteristics of Child-like Thinking: Empirical-inductive Thinking Pattern**

MS Prescientists' thinking illustrates Lawson's child-like thinking: simple description rather than adult-like thinking (e.g., reflective, self-regulatory reasoning). These students use simple description of the events in the history of earth and life on earth based on a specious organizing concept, dinosaur theory, and personally interesting science facts and individual intuitions about dinosaurs. As their thinking develops around a specious organizing concept, their misconceptions escalate systematically into unfruitful, implausible theories:

- The earth formed for dinosaurs to have a place.
- Dinosaurs were the first animal.
- Plants and animals were formed to provide food for dinosaurs. Humans appeared right after dinosaurs died as recorded by cave drawings or humans killed dinosaurs for food.

These personal theories are incorrect, yet the students neither question nor reflect on the believability or correctness of their ideas. In terms of Beeth's status construct theory of intelligibility, plausibility, and fruitfulness, this is what MS Prescientists believe to be true (plausibility) and the schema or theory (fruitfulness) they use to understand scientific phenomena of the natural history of the earth and life on earth (Hewson, 1981, 1982; Beeth, 1998).
In thinking about index events in geologic time, these students demonstrate some of the limitations of Lawson's empirical-inductive thinking pattern: (1) use unsystematic thinking, (2) fail to consider alternative hypotheses or concepts to explain the phenomenon, (3) make observations and draw inferences, but do not "reason with the possible" (Lawson, 1995, p. 61), and (4) do not check their conclusions against given data because they are not aware of their own thinking patterns. For example, several students state, "plants appeared to provide food for the dinosaurs." They do not consider alternative hypotheses, e.g., Were there first simpler forms of animals that ate plants before dinosaurs were on earth? or Did plants cause any changes in earth's early environment because they produced oxygen? Although the teacher presented these ideas, the students do not question their assertions and do not imagine other explanations. Many students associated the appearance of prehistoric humans with an event related to the dinosaurs' disappearance or extinction. Those that said humans and dinosaurs existed together or that humans "wiped out the dinosaurs" did not reflect on their thinking to consider the plausibility of those statements. They simply uncritically accept and report what they view on television or at the movies as science. Forty-six percent of the MS Prescientist group used a dinosaur theory as a specious organizing concept (see Table 4) in their thinking in the natural history of the earth.

**CES: protozoan MS Prescientist Group**

A Concept Evaluation Statement (CES) was used to triangulate the findings from the closed and open-ended
responses on the Geologic Timeline Survey. The students were asked to draw and to write a paragraph to provide reasons and evidence supporting their drawing of the first animal. The students were directed to respond to this CES: The word protozoan is a Greek for first animal. What was the first animal to appear on earth, and what did it look like?

The CES results show that as a group MS Prescientists thought dinosaurs were the protozoan, the first animal. Forty-one percent of the group drew a dinosaur as the protozoan. These findings closely corroborate the results of the open-ended responses on the Geologic Timeline Survey (46% used dinosaurs as OC). The researcher argues that these findings establish that MS Prescientists in this study used a secular OC, dinosaur theory, which lead to a system of misconceptions and a spurious theory of the origins of earth and life on earth.

Dave 12: The Dinosaur

Dave’s Justification: “I think a dinosaur was the first animal because I read about them and the book said they were born million years ago. And that they were the first animal.”

Liz 11: The Dinosaur

Liz’s Justification: “I think that a dinosaur was the first animal. I think that this animal is the first animal because people and movies always say that this animal was the only one known before humans....”

Figure 4. MS Prescientists’ Concept Evaluation Statement - drawings and justifications of protozoan, first animal.
The drawings and justifications the MS Prescientists employed to represent the concept of protozoan are shown in Figure 4. The dinosaur organizing concept perpetuated those misconceptions about the development of life on earth.

Middle School Protoscientists

Criteria for MS Protoscientist Category

The MS Protoscientist category does not consider student's placement of index time-events on the timeline as part of the criteria. Time is only considered if it appears as a warrant in the student's written responses. MS Protoscientists' thinking about the natural history of the earth and life on earth is approaching currently accepted scientific thinking. The students may use some specific scientific language and some correct science vocabulary (Lee, et al. 1995). These students used three main organizing concepts, e.g., evolutionary time, relational time, and dinosaur theory.

Modal Profile of MS Protoscientist Group

Composite of the MS Protoscientist Group

Seven percent of the students in this study are MS Protoscientists with an average age of 11.8 years old. None of the students were in this category at the beginning of the study. Three of the MS Protoscientist group are male and two are female. They are beginning to refine their thinking about the key index-events in geologic time and have moved away from a dinosaur theory (in pretesting) toward a more scientific understanding of geologic time. The MS Protoscientist group are all serious students and "good thinkers". This group's profile demonstrates how successful thinking develops. As shown in Table 6 and
Table 7, eighty percent of the students use *Geologic Time* as an organizing concept and sixty percent are most familiar with the time the earth formed.

Table 6

<table>
<thead>
<tr>
<th>Organizing Concept</th>
<th>N</th>
<th>Percent Category</th>
<th>Percent Study</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geologic time</td>
<td>4</td>
<td>80</td>
<td>7</td>
</tr>
<tr>
<td>Fossil evidence</td>
<td>1</td>
<td>20</td>
<td></td>
</tr>
</tbody>
</table>

Table 7

**MS Protoscientists' Correct Responses to Index Events on Geologic Timeline**

<table>
<thead>
<tr>
<th>Quest.</th>
<th>Correct time</th>
<th>Accepted Range</th>
<th>N</th>
<th>%</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Earth</td>
<td>4.6 bya</td>
<td>4-5 bya</td>
<td>3</td>
<td>60</td>
<td>5</td>
</tr>
<tr>
<td>Dino Ext</td>
<td>65 mya</td>
<td>70-60 mya</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Humans</td>
<td>2 mya</td>
<td>1 mya-2 mya</td>
<td>1</td>
<td>20</td>
<td>2</td>
</tr>
</tbody>
</table>

Thinking about Index Time-events

The students' open-ended responses from the Geologic Timeline Survey indicate that MS Protoscientists are beginning to think about the events in *deep time* in terms of *geologic time* itself.

**Earth Formed (4.6 bya): MS Protoscientists**

Beth 12: (10 bya) "The timeline around the class."

Eon 11: (3 bya) "The geologic time scale."

Matt 12: (4.5 bya) "From other timelines scientists have made."

*Number of students in Protoscience category.
*Number of students who took Geologic Timeline Survey.
**Dino Extinction (65 mya): MS Protoscientists**

Beth:  (5 mya) "The movie when they rate the age of the fossils."

Eon:  (10 mya) "They disappeared millions of years after they were formed."

Matt:  (50 tya) "When the date stopped from the fossils."

**Humans Appear (1-2 mya): MS Protoscientists**

Beth:  (1mya) "They have some fossils of human-looking bones."

Eon:  (50 tya) "Geologic time scale."

Matt:  (1 tya) "From fossils and history class."

**Universe Formed (13 bya): MS Protoscientists**

Beth:  (13 bya) "When we saw a movie and they found fossils and tried to name the age."

Eon:  (5 bya) "That’s the Big Bang date; when it happened."

Matt:  (>25 bya) "When the Big Bang happened, so I put the time I thought it was."

**Plants Appeared (420 mya): MS Protoscientists**

Beth:  (5 bya) "The wizard person come in and showed us on a timeline around the class."

Eon:  (1 bya) "Plants were simple cells and that’s when they appeared."

Matt:  (6 mya) "I have heard of fossils being that old of plants."

**Vertebrate Animals (350 mya): MS Protoscientists**

Beth:  (25 mya) "They have fossils in the ocean where animals developed backbones and they gradually moved to land."

Eon:  (65 mya) "That’s when dinosaurs first appeared."

Matt:  (65 mya) "When a fish started walking on land."
Thinking Patterns of MS Protoscientists

These findings describe the thinking patterns of MS Protoscientists. Their thinking is clear and organized around geologic time which gives the science facts and vocabulary intelligibility, plausibility, and fruitfulness.

- They have moved away from the dinosaur theory in the pretesting, e.g., changing from a dinosaur drawing as first animal to a marine animal in posttest.

- They are thinking with science facts and vocabulary, e.g., simple cells, fossil evidence, and evolution ideas.

- They are thinking with geologic time itself.

However, hints of dual concepts are still present. A dinosaur focus appears in Beth's CES justification, "It [the jellyfish] could have been here when or before the dinosaurs...." Eon persists with the notion that the dinosaur was the first vertebrate animal. Matt suggests a dualist pseudoscience-protoscience construction in his warrant, "how long it took for animals to come after the creation."

Deep-seated Alternative Framework (Driver, 1993)

The researcher argues that the persistent dinosaur theory in MS Protoscientists' thinking, even after approaching correct science and significant individual conceptual change, suggests that the dinosaur organizing concept may be a "deep-seated alternative framework" (Driver, 1993). Driver (1993) defines a deep-seated framework as an "alternative framework common to the thinking of many children." She explains that in the process of "sense making", when the student "is faced with novel phenomenon", he or she "tries to interpret the
unfamiliar analogy with familiar experiences. Some student explanations for unfamiliar phenomenon are transitory (idiosyncratic suggestions by individual pupils). However, other ideas or alternative frameworks are much more deep-seated. More deep-seated frameworks are common to the thinking of many children" (pp. 24-25).

In this study, the dinosaur theory emerged as a deep-seated framework in middle school students' thinking about geologic time. At the end of the study, thirty-three percent of the students (Prescientists) used dinosaurs as an organizing concept as shown in Table 4.

Beth 12: Jellyfish

Beth’s Justification: “I think it was the jellyfish. I think that because on the timeline, they were the first animal after the simple cell and super cell creatures.”

Figure 5. MS Protoscientist’s Concept Evaluation Statement—drawings and justifications of protozoan, first animal.

Middle School Scientists

The Process of Science

Lipps (1998) describes science as a disciplined way of observing events or things and drawing conclusions by gathering, evaluating, and using evidence. Science is a process of understanding phenomena that uses a clear and rational way to build knowledge of the real world by drawing conclusions from strong evidence. Lipps (1998) explains that science is never really finished or complete, but
"requires constant testing of those beliefs and ideas with all the data. Science is a way of viewing the world that uses repeatable evidence and hypothesis testing" (p.3).

Criteria for MS Scientist Category

Middle School Scientists demonstrate accurate science knowledge by providing reasonable science-based answers on the three key index-event questions on the Geologic Timeline Survey, correctly using science vocabulary, and providing a reasoned justifications for their answers. This is the only category that required correct quantitative time of index time-events on the geologic timeline. MS Scientists' thinking moved along a continuum from strong scientist thinking to weak scientist thinking. The students were classified as strong scientists or weak scientists based on the following criteria.

The criteria for the MS Strong Scientist category are accurate science knowledge as evidenced by placing at least two of the three index time-events within the accepted time range on the geologic timeline. MS Weak Scientists correctly placed only one of the three index time-events on the timeline. The strong scientists have all knowledge structures in place in their theoretical framework: quantitative geologic time, qualitative geologic time, drawings, evolution concepts, and science vocabulary. Weak scientists have tenuous quantitative geologic time structures, preliminary qualitative geologic time structures, rudimentary evolution concepts, and some science vocabulary in place.

However, all MS Scientists have made the critical intellectual leap to imagine a single-celled organism as the
first animal, the protozoan. The MS Scientist must have the general thinking ability and science knowledge framework in place to make the intellectual leap to imagine and to defend a single-celled organism as the first animal.

Modal Profile of the MS Scientist Group

Composite of the Scientist Group

Eleven percent of the students fell into this category. At the beginning of the study, only 4% of the students were in the MS Scientist group. The MS Scientist category is 100% male and their average age is 11.7 years old.

Organizing Concept

The most common organizing concept of this group is geologic time. These students have organized their thinking with geologic time itself, e.g., sequential (or chronological) time, relational time (x event occurred before y event), and evolutionary time (change-over-time). When geologic time becomes the students' organizing concept, they have successfully integrated content and structure. These concepts will be discussed throughout the following sections.

MS Scientists

Most of the students in this group are serious thinkers who are interested in science. They are a heterogeneous group of average to above average students. As shown in Tables 8 and 9, their dominant organizing concept is geologic time (67%) and they are most familiar with the time the earth formed (67%).
Table 8

Organizing Concepts of Sixth Grade Scientists

<table>
<thead>
<tr>
<th>Organizing Concept</th>
<th>N</th>
<th>Percent Category</th>
<th>Percent Study</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geologic time</td>
<td>4</td>
<td>67</td>
<td>7</td>
</tr>
<tr>
<td>Evolution concepts</td>
<td>1</td>
<td>17</td>
<td>2</td>
</tr>
<tr>
<td>Science studies</td>
<td>1</td>
<td>17</td>
<td>2</td>
</tr>
</tbody>
</table>

N=63 N=57

Table 9

MS Scientists Correct Responses to Index Events on Geologic Timeline

<table>
<thead>
<tr>
<th>Quest. Correct time</th>
<th>Accepted Range</th>
<th>N</th>
<th>Percent Category</th>
<th>Percent Study</th>
</tr>
</thead>
<tbody>
<tr>
<td>Earth Forms</td>
<td>4.6 bya</td>
<td>4</td>
<td>67</td>
<td>7</td>
</tr>
<tr>
<td>Dino Extinct</td>
<td>65 mya</td>
<td>1</td>
<td>17</td>
<td>2</td>
</tr>
<tr>
<td>Humans</td>
<td>2-4 mya</td>
<td>1</td>
<td>17</td>
<td>2</td>
</tr>
</tbody>
</table>

N=6 N=57

Thinking about Index Time-events

Earth Formed (4.6 bya): MS Scientists

Mark 12: (10 bya) "5 bya from when the universe exploded."

Bill 12: (4.5 bya) "I know from a video."

Sam 12: (4.6 bya) "From the teacher's timeline."

Dino Extinct (65 mya): MS Scientists

Mark: (500 mya) "They disappeared 500 mya because I know they ruled pretty long."

Bill: (65 mya) "Everybody knows that the dinosaurs disappeared 65 mya."

Sam: (4 mya) "From the teacher's timeline."

Humans Appear (1-2 mya): MS Scientists

Mark: (1 mya) "I think they appeared 1 mya because I think I read it in a book."

Note: N=Number of students in Scientist category.

"Total number of student who took the Geologic Timeline Survey.

"Video on Evolutionary Time.
Bill: (100 tya) "I took a guess."

Sam: (50 tya) "When life formed."

Universe Formed (13 bya): MS Scientists

Mark: (15 bya) "It formed 15 bya by a big explosion."

Plants Appeared (420 mya): MS Scientists

Mark: (25 mya) "They appeared about 25 mya after first life was in the ocean."

Vertebrate Animals (350 mya): MS Scientists

Mark: (7 mya) "They appeared before the humans cause we developed from monkeys."

Bill: (400 mya) "I know they came before dinosaurs and after plants so I just picked a spot between there."

Thinking Patterns of MS Scientists

Integrating Content and Structure

MS Scientists’ common ground is that they are all good thinkers. They combine two forms of thought described in the literature (Driver, 1983, p.58), e.g., correct form of thought or logical operations (Piaget, 1929; Lawson, 1995) and correct structuring of content (Ausubel, 1958; Novak, 1978). They also use evidence, data, content knowledge, thinking patterns, and a scientific worldview to build an interpretive framework or a fruitful personal theory about the concept geologic time. Driver (1983, p. 42) defines an interpretive framework as a construction of the mind that has to be invented. Correspondingly, the tenets of both the Piaget School and ACM School assert that each individual organizes and structures his own knowledge.

MS Scientists use both Piagetian logical structures or operations and Ausubel’s knowledge framework or structure to
construct a fruitful understanding of geologic time. Driver (1983) reminds the science education research community not to view Piaget's theory of children's cognitive thought and Ausubel's theory of meaningful learning as mutually exclusive. She argues, "... Many substantive concepts in the sciences take their meanings not simply through the network of other substantive concepts to which they relate, but through the nature or structure of the relationship between them. Content and structure should be complementary considerations of curriculum design" (p.58).

Hypothetico-deductive Thinking Level

MS Scientists reflectively consider problems at Lawson's hypothetico-deductive level of thinking. Although the students do not consistently use the hypothetico-deductive thinking and have not developed all of the characteristics of the hypothetico-deductive thinker, they are approaching thinking in that way. They are searching for relationships and patterns to bring coherence to the events on the geologic timeline, e.g., "the earth in relation to the universe is very young." Lawson (1995) describes the characteristics of this thinker: (1) imagines possible relations of factors, (2) deduces the consequences of these relations, and (3) empirically verifies which of those consequences actually works.

MS Scientists' Thinking about Geologic Time

These students effectively use time as an organizing concept: sequential (chronological) time, relational time, and/or evolutionary time to order the succession of events on the geologic timeline. Sequential time is chronological time in a quantitative sense. Relational time is placing
event X before or after event Y, and evolutionary time is change-over-vast-periods of time. Relational time and evolutionary time are categorized as Piaget's qualitative time. MS Scientists use all forms of time to order the events on the timeline and provide warrants for their responses. The student with the most intelligent, plausible, and fruitful theory synthesized sequential, relational, and evolutionary time to construct a unified personal theory of the natural history of the earth and life on earth.

MS Scientists have rudimentary science facts and an early scientific theory in place. In sixth grade, the MS Scientists "know" before they acquire the technical vocabulary to articulate and justify what or how they know. Their vocabulary reflects evolution concepts: simple cell, adaptation, evolve, evolution, first life in the ocean, and "after it became super cell and then fish...."

Strong scientists (67%) and weak scientists (33%) alike have the conceptual structures in place to make the intellectual leap to imagine the first animal, the protozoan, as a single-celled organism.

The researcher is aware that in current biology an animal is defined as an eukaryotic multicellular heterotroph whose cells lack a cell wall. However, biology textbooks also refer to an animal ancestor (before tissues and body symmetry developed) - a "first animal" as a single cell (Strauss & Lisowski, 1998, p.503). Some textbooks list the protozoa as the first invertebrate animal species (Ridley, 1996, p.266). This study uses the student's understanding of the single-celled organism as the first animal as the intellectual leap that indicates scientific thinking.
These are the conceptual structures MS Scientist have in common:

1. Content knowledge: a concept of the single-cell organism as an early form of life on earth and recognize the single cell as an animal cell.

2. Some science vocabulary in place.

   **Weak scientists**: Big Bang, fossils, simple cell, super cell, dinosaurs, first birds, first reptiles, millions, billions, time.

   **Strong scientists**: Big Bang, evolve, extinct, geology, fossils, earth time, one-celled creatures, multi-celled creatures, transform, measurement of time, evolution, adapt, adaptation, dinosaurs, billions of years, millions of years, simple cell, super cell.

3. Understanding of the quantitative time of the three index time-events.

   **Weak scientists**: earth formed.

   **Strong Scientists**: earth formed and one other event, e.g., dinosaur extinction or first prehistoric humans appeared.

4. Understanding of **geologic time**.

   Chronological time: Succession of events in geologic time (Piaget’s quantitative time).

   Relational time: Event X occurred before or after event Y (Piaget’s qualitative time).

   Evolutionary time: Change-over-vast-periods of time (Piaget’s qualitative time).

**The Intellectual Leap**

Driver (1983) describes the intellectual leap as a paradigm shift. She explains that in “the process of making sense,... Not only do children have to comprehend the new model or principle... but they have to make the intellectual leap of possibly abandoning an alternative framework which until that time had worked well for them”
The results of this study show that students must make the conceptual change and have the ability to entertain the possibility of the new construct. Driver (1983) also suggests

Before pupils can be expected to abandon their old ideas, they have at least to be able to comprehend the ones which are presented to them. This may involve an imaginative act to consider the possibility of the new idea without necessarily believing it to begin with (p.45).

This imaginative act is illustrated by the responses of a young MS Scientist, Jim, who moved from a dinosaur focus (prescience) in the pretest drawing to a science focus (science) in the posttest. In the posttest, he drew the bacteria as the first animal and defended his idea in this way, "Because that’s what scientific studies say, and I saw it on a video." Jim’s weak scientist responses are much different from the strong scientist, Al. Al drew a cell as the protozoan and confidently wrote, “Everything evolved from a cell.” Young Jim has neither the science vocabulary nor science theory in place, but he can imagine the single cell as the first animal and make the intellectual leap.

According to Driver (1983) the initial structure needed to make the intellectual leap, which results in a paradigm shift, may "involve an imaginative act to consider the possibility of the new idea without necessarily believing it to begin with" (p.45). The author agrees with Driver, but suggests the intellectual leap is an intermediate stage in student understanding before the paradigm shift and not synonymous with a paradigm shift. Dr. Husain Sarkar, reflecting on the educational outcome of understanding rather than belief, suggested there may be an intermediate
stage before the paradigm shift (personal communication, March 21, 2001).

Driver's phrase "an imaginative act to consider the possibility of the new idea" also reminds the researcher of Lawson's hypothetico-deductive thinker who is able to reason with the possible and consider alternative hypotheses. Therefore, the researcher posits the intellectual leap requires an integration of content knowledge (e.g., Ausubel's knowledge structured as specific concepts) and Piaget's general thinking skills. In this study, the intellectual leap is an intermediate stage in conceptual change, not a paradigm shift.

Bill 12: Simple cell

Bill's Justification: "The first animal was a cell. This cell had no nucleus or control center, "brain". So it was basically a dumb cell. It lived in the oceans. It could split apart to make two cells."

Mark: A Simple celled animal

Mark's Justification: "The first animal was found in the ocean. It was a simple celled animal and was small. After that, it became super cell and then fish and soon ..."

Figure 6. MS Scientists' Concept Evaluation Statement - drawings and justifications of the protozoan, first animal.

In the course of the study, the CES has become a powerful indicator of the student's science content knowledge and conceptual ecology.
Educational Outcome: Knowledge or Belief

Cobern (1995) investigated the question, Is belief or understanding the goal of science instruction? Several studies have found that students could understand evolutionary theory without believing it (Bishop & Anderson, 1990; Demastes, 1994; Cobern, 1995; Holtman, 2000). The National Academy of Sciences states, "Children’s personal views should have no effect on their grades. Students are not under a compulsion to accept evolution. A grade reflects a teacher’s assessment of a student’s understanding ...it is quite possible to comprehend things that are not believed" (NAS, 1998, p.39). The consensus view of the science education community is that understanding, not belief, is an acceptable educational goal. The researcher agrees with this position and additionally states that if Science requires belief, it becomes a dogma with dogmatic authority and abandons the very nature of Science.

However, Matthews, as a philosopher of science, (1996, p. 92) rightly states, "We do feel uncomfortable with this outcome, but the move from understanding to belief will frequently- for those who value consistency and rationality - entail a change in metaphysical, ontological, and epistemological commitments." In other words, moving from understanding to belief denotes a paradigm shift.

Kuhn’s teaching model in The Essential Tension (1977) elucidates the science argument for understanding (not necessarily belief) as a classic teaching method. A father teaches his son to classify waterfowl as swans, geese, and ducks by a trial-and-error observation method. In the course of the afternoon, the child has learned to correctly group...
the animals by observation of descriptive characteristics and perhaps behavioral characteristics without learning definitions and correspondence rules. He was "programmed to recognize what his prospective community already knows...." (Kuhn, 1977, p. 312), but does he know what the terms swan, goose, or duck mean in terms of criteria, generalizations, or rules? Kuhn calls the former type of learning "assimilation of examples" and states that "shared examples have essential cognitive functions prior to a specification of criteria with respect to which they are exemplary" (p. 313).

This supports the science education community's position that understanding, not necessarily belief (particularly belief in biological evolution concepts), is an acceptable and realistic educational outcome at the middle school level.
CHAPTER 6

CASE STUDIES

Introduction

Modal profiles are a method to examine and present group data from a panoramic perspective. In keeping with the philosophy of a mixed model study, the researcher now uses case studies to zoom in to examine the individual representatives of each category and to elaborate the findings of the modal profiles.

At the beginning of the study, many students volunteered as case study participants. Although this pleased the teacher/researcher, it made the process of selecting that group difficult. Ten students were chosen from the field of students based on their answers on the pretest Concept Evaluation Statement (CES), e.g., the drawings on the protozoan, first animal. The researcher chose that measure because student drawings and their warrants for the drawings are powerful, unambiguous depictions of both their understanding of a concept and their conceptual ecology or worldview. All ten students completed the study and from this bank of students, four were finally selected as representatives of each group, that is, MS Scientist, MS Protoscientist, MS Prescientist (misconceptions), and MS Pseudoscientist (creationist).

The findings from the case studies are presented in a format which is closely aligned with the manner in which the data were collected and analyzed. First, the researcher discusses the student’s academic and family background. The researcher attempted to keep these variables very similar in the final case study participants, that is, the
grade point average (GPA), socioeconomic background, regular school attendance, positive attitude toward school and science, and a well-adjusted student.

Next, the research questions provide the framework for examining each case study: (1) Research Question 1 (RQ1): What are middle school students' conceptual understandings of the science concept of deep time, geologic time?, (2) RQ2: What conceptual changes occur in students' understanding of the natural history of the earth and life on earth as a result of instruction using a geologic time curriculum?, and (3) RQ 3: How do students' conceptual ecologies/worldviews influence their understanding of the history of the earth and life on earth?

To examine the individual's concept of deep time (RQ1), the researcher first examined his or her understanding of the cognitive construct of millions of years ago and billions of years ago. The researcher examined geologic time with these selected index time-events (1) When did the earth form?, (2) When did dinosaurs become extinct?, and (3) When did the first prehistoric humans appear on earth? Multiple methods and instruments were used to measure these concepts, such as the closed-ended and open-ended responses on the Geologic Timeline Survey, a CES which is a drawing of first animal, two formal content knowledge tests, journal writings, and interviews.

Conceptual change was examined specifically in RQ2 by two separate content knowledge tests, the Earth Science Test and the Evolution Test. The pre-and post-content knowledge tests measured overall conceptual change. This study also used many other methods to assess how the students' ideas
changed over time. The subconcept-themes that emerged from the analysis of these data were evolution or change-over-time, extinction, the fossil record, dinosaurs, genes, and disease. The researcher defines subconcept-themes as recursive ideas which appear in a student’s writing and thinking about main concept, geologic time. These are the concepts that the student seemed to wrestle with in constructing his or her thinking about deep time. The subconcept-themes first appeared in the journal writings. Then they were examined subjectively by the journal writings, interviews about instances, and student drawings; and objectively by a subset of questions from the evolution and Earth Science formal tests (see Appendices D and E).

The researcher used two interviews about instances, the Prehistoric Animal Card Problem (May) and the Fossil Timeline Problem (June). The Prehistoric Animal Card Problem contained a set of seven prehistoric animal cards of characteristic, but unfamiliar, animals of the Paleozoic Era (570-225 mya), the Mesozoic Era (225-65 mya), and the Cenozoic Era (65 mya–0 present). The student was first asked to observe and describe each card. Then, the student was asked to put the cards in the order that could tell the story of how life developed on earth. Two cards emerged as the main focus of case study analysis, (1) crossopterygian, a fish walking on land, and (2) archaic mammals, a genetic mixture of large catlike and ratlike animals.

In the Fossil Timeline Problem, the student placed actual fossils on a timeline. The students had created the timeline earlier as an exercise in scale in math class. This timeline began at 4.6 bya or 4,600 mya when the earth
formed and moved through geologic time to the present. The scale on the timeline was 1 millimeter = 1 million years; the adding machine timeline was 4.6 meters in length. The case study participants placed these fossils on the timeline: fish, shark’s tooth, squid, segmented worm, choral cephalopod, trilobite, ammonite, mammal bones, and dinosaur bones.

The CES used was the Greek word for first animal is protozoan. Draw the first animal and write a paragraph about why you think it is the first animal on earth. This measured conceptual change in the crucial concept: protozoan, first animal.

The final research question, RQ 3 How do students’ conceptual ecologies/worldviews influence their understanding of the history of the earth and life on earth?, was explored by examining the students’ open-ended responses on the pre-and post-tests of the Geologic Timeline Survey (also referred to as the geologic timeline in this section) and CES responses. A post-study interview in May of 2000 examined the student’s worldview. The post-study interview occurred a year after the study: (1) to assess the stability of the study concepts over time and (2) to establish the religion and religiosity of the student. The researcher did not want to know the religious background of the student during the study.

Discussion of Conceptual Ecology or Worldview

Conceptual ecology is the rational and not-so-rational concepts that comprise the student’s understanding of an idea, also known as the worldview. Demastes has asserted that the student’s conceptual ecology has the power to
determine what learning can take place (in Good et al., 1992, p. 97). The conceptual ecology includes, but is not limited to, an individual's rational, emotional, and metaphysical beliefs.

This researcher finds conceptual nets a useful metaphor to understand the notion of conceptual ecology and to explain how it is used as a mechanism in an individual's understanding. A parable by the astronomer Arthur Eddington explains how conceptual nets are used as a mechanism for understanding a phenomenon and illustrates the workings of a worldview.

A fisherman who, after a lifetime of fishing with a net having a three-inch mesh, concluded (falsely, of course) that there were no fish in the ocean smaller than three inches.

Nord points out the moral of the story is,

Just as one's fishing net determines what one catches, so it is with conceptual nets; what we find in the ocean of reality depends on the conceptual net we bring to our investigation (Nord, 1999, p. 29).

This researcher posits that conceptual nets correspond to an individual's conceptual ecology or worldview and determine what knowledge will be "caught" and what knowledge will be "lost". The student conceptual nets which emerged in this study are science nets, protoscience nets, prescience nets, and pseudoscience nets.

According to Nord (1999), scientists generally use a scientific conceptual net to "catch dimensions of reality" (p. 29) and theologians use another. He explains that the scientific net uses the scientific method, scientific laws and information, empirical evidence, and instruments or sense perception for precise measurements to understand the
world. Theology nets capture dimensions of "reality" that slip through scientific nets. Nord (1999) continues, theology nets capture "transcendent dimensions of reality" which do not depend on "universal causal laws", but use "moral and religious experience as evidence " and understand "meaning and purpose" in the natural world in terms of how they fit into a narrative of "divine causality" (p. 29).

**Dialogue between Science and Religion**

McGrath (1998) describes three ways individuals relate science and religion: confrontation, distinct, and convergence. The confrontation approach views science and theology as irreconcilable and represents the stance taken by religious fundamentalists (e.g., religion trumps science) and the atheistic scientists (e.g., science trumps religion).

Distinct and convergence approaches are non-confrontational models. The distinct position applies a demarcation between science and religion and asserts the two domains are incommensurable. Each has its own methods and different assumptions which are so separate that the two have no bearing on each other. They can be true or false only on their own terms. This is the approach taken by the science education community. Science is "necessarily silent on religion and neither refutes nor supports the existence of a deity or deities" (NABT, 2000). Many religious liberals also take the view that the "scriptures were never meant to be a science textbook" (Nord, 1999, p. 29).

The convergence approach assumes that there must be way to integrate science and religious views. This model acknowledges that science and religion can conflict and can
reinforce each other because they both make claims about the same world (Nord, 1999, p. 30).

Haught (2000, pp. 25-38) offers the theological correlates to confrontational, distinct, and convergence approaches as opposition, separatism, and engagement, respectively.

Case Study, MS Scientist

Description of student

Gary (a pseudonym), an 11 year-old male, is smaller than his classmates, but he more than holds his own in high-level thinking. At the end of the sixth grade, his report card shows that he is an average student, GPA 2.624. On the Iowa Test, his National Percentile Ranks are Reading 35, Mathematics 38, Science 36, Social Studies 71, and Reference Skills 35. This is his second year at River Town Middle School; before he attended a Catholic School in Lafayette, Louisiana for grades K-4. Gary appears poised and confident in class discussions and interviews with the researcher.

He was born in New Orleans and now lives in River Town with his mother, stepfather, and younger sister. His mother and father completed college; his stepfather completed high school. His mother works in the post office at a Navy base in New Orleans, and his stepfather works for a gasoline distributor.

Understanding of Geologic Time

To examine the student's understanding of geologic time, the researcher first explored the individual's concept of millions of years ago and billions of years ago and then surveyed his understanding of specific geologic time
events, e.g., earth formed, dinosaurs became extinct, and first prehistoric humans appeared.

**Millions and billions of years**

At the beginning of the study, Gary related the concept of a million years ago to dinosaurs and Jesus. A year after the study, he associated that concept with a number. His reply to the question, What ideas first come to your mind when you think of geologic time? in the post-study interview was "a number going backwards and just keeps going...like a movie." In the same interview, Gary describes geologic time as "A very long period of time because it shows everything - geologic time shows all of time."

**When did the earth form?**

As a result of the Geologic Time Unit, Gary's understanding of the age of the earth moved from incorrect (17 bya) on pretest to correct (4.5 bya) on posttest. His responses on the content knowledge test items on the age of the earth corroborate these results. His responses on the Earth Science and Evolution Tests also indicate that he has successfully constructed the quantitative time the earth formed as 4.5 billion years ago. However, he did not apply the correct theory to warrant his answer. On the Evolution Posttest, Gary responded that he based answer on plate tectonic theory instead of the correct response, radioactive dating of rock formations. From the triangulation of journal entries, student interviews, Geologic Timeline Survey responses, and formal tests, the researcher concludes that the student has successfully constructed a scientifically acceptable concept of the quantitative age of the earth.

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When did dinosaurs become extinct?

Gary has surprisingly little to say about dinosaurs in his reconstruction of geologic time. Although he has not constructed the correct quantitative time of dinosaur extinction (65 mya), he has moved to a more reasonable understanding of the time of the event. In January, he placed dinosaur extinction at 900 mya; in May, he placed the event at 45 mya.

The results on the formal tests demonstrate that Gary has constructed necessary content knowledge related to dinosaur extinction, extinction, and dinosaurs and humans. His responses establish that he understands dinosaurs and humans did not exist together on earth and extinction is the elimination of a species of animals from the earth. Dinosaurs are a peripheral concept in Gary’s schema of geologic time, not a central organizing idea. Generally, he only speaks of dinosaurs when asked direct questions about them.

Importantly, in the Fossil Timeline Interview, he recognizes that the extinction of dinosaurs, "opened a space for mammals." That is, he understands that dinosaur extinction created a niche for the radiation of small mammals. This response also documents that he is thinking beyond just the description of the extinction event (e.g., empirical-inductive thinking) to proposing a result of the event (e.g., hypothetico-deductive thinking).

When did the first prehistoric humans appear on earth?

Gary’s thinking about the quantitative time of prehistoric humans appear on earth has moved from an implausible time on the timeline pretest (400 mya) to a much
improved time on the posttest (9 mya). Although he does not have the correct time, he has correct science explanations for the appearance of prehistoric humans. His warrants indicate, in Piagetian terms, that he has accommodated and maintained stable constructs about the concepts that human ancestors were primate animals and that humans evolved or changed-over-time from one form of creature to another. In January 1999, he says, "I chose 400 mya because people were apes and monkeys at least one time." In the post-study interview (May, 2000), he describes the prehistoric humans as "A monkey because prehistoric humans were part of the primates." When the researcher asked how the first humans appeared on earth, Gary said, "I’m guessing. There were some other creatures like fish. They jumped on land and started evolving into other creatures." These findings show Gary has constructed correct or approaching correct long-term concepts about how humans appeared on earth.

Summary of Gary’s thinking about geologic time

The researcher argues that Gary has constructed the most fruitful understanding of geologic time according to Piaget’s fundamental concepts of time, e.g., seriation, simultaneity, and duration. First, Gary reports that he thinks of geologic time as "a number", "a very long period of time", and "all of time." Then, he demonstrates Piaget’s rational time by using relational time (e.g., event X occurred before or after event Y) and simultaneity (e.g., X and Y occurred together). Furthermore, his geologic timeline responses confirm that he understands the relations of succession and duration based on the patterns of logic, e.g., he establishes a chain between causes and effects and
explains the latter in terms of the former. He has constructed both number and logical processes in his thinking about geologic time. In his understanding of the quantitative time of key events on the geologic timeline, he has constructed a sufficient understanding of relative quantitative time.

Gary’s responses on the geologic timeline, formal tests, journal writings, and interviews indicate that he has constructed long-term knowledge structures about the concepts and time-events investigated in this study, e.g., the formation of the earth, dinosaurs and extinction, the appearance of prehistoric humans, and certain evolution concepts. His strongest comprehension of quantitative time is the formation of the earth; his weakest is the appearance of humans. However, all of the index time-events and concepts need correction, refining, and enlarging.

These findings critically point out that students need much time and exposure to the “big ideas” in science to assimilate and accommodate the concepts.

Conceptual Change

The formal pre- and post-tests on Earth Science and Evolution concepts provide a measure of Gary’s conceptual change. At the end of the study, Gary ranked 1 out of a class of 55 on the Earth Science Test and 12 out of a class of 50 on the Evolution Test. Although Gary did not take the Earth Science pretest, the posttest results establish that it is his science domain of greatest knowledge. The formal tests demonstrate overall conceptual growth in both areas, earth history and evolution concepts as shown in Figure 7.
Further exploration of Gary's understanding of geologic time and evolution concepts reveal his growing understanding of deep time and his conceptual change over the period of the study. In April 1999, Gary's journal response to What happened to the different species of animals over billions or millions of years? confirm that clear, nascent evolution concepts are in place.

I think when fish lived, some fish developed lungs of air and water which made amphibians. Then they turned into reptiles and birds and mammals formed on their own.

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In a later journal response, *How have animals changed over time?*, Gary proposes a mechanism for evolutionary change.

...a disease that formed to make different creatures smaller....I believe that a disease [caused] their growth to be smaller than they were. Then they gave the disease to their children and so on...

Gary also posits a disease as the mechanism for change in animals in the *Prehistoric Animal Card Problem*, and this concept emerges as his subconcept-theme. He is considering the archaic mammals of the Paleocene Era (66-55 mya), e.g., the *Ptilodus*, *Protictis*, and the pantodont, *Pantolambda*. A large ratlike animal dominates the foreground and two other large catlike and/or doglike mammals are in the background. Gary has never seen these animals before; they are very exotic mammals that look like two modern-day animals physically combined. When the researcher asks him to describe what he sees, he responds

... they really were bigger back then.... they got smaller and smaller. Cause...a bacteria or a disease made them smaller like animals today. Like the average rat is ... doesn’t look that big [today]...

Although his mechanism for change-over-time is incorrect, he recognizes that animals were very large in the prehistoric past, became smaller over time, and that animals somehow passed that trait on to their children. However, he does more than make this observation, he also asks a causal question, "What caused the animals to get smaller?" and proposes a hypothesis, "a disease." The study measures indicate that he has not constructed the concept of genes and heredity as a mechanism for evolutionary change.
Nevertheless, in his thinking and within his experience, he is searching for a mechanism to explain how species changed over-time. He is using hypothetico-deductive thinking (e.g., questioning and proposing alternative hypotheses) rather than empirical-inductive thinking (e.g., describing what one sees).

Like the thinking of some preDarwinian scientists and Darwin himself in the history of science, Gary can imagine the possibility of dynamic change in species over time, although he has not constructed the correct mechanism for the change. Also, he can intellectually grasp and accept the possibility that these unusual animals actually existed on earth. These thinking processes demonstrate Lawson's thinking with the possible, another characteristic of hypothetico-deductive thinking or adult-like thinking.

Concept Evaluation Statement: Protozoan, First Animal

In this study, student drawings and justifications for the drawings are prime measurements of student understanding because they are self-evident. Therefore, student drawings of the first animal are powerful indicators of student knowledge and conceptual change. Gary's CES drawing conveys his understanding of the first animal, protozoan as shown in Figure 8.

The Intellectual Leap

His pre- and post-test responses to the CES demonstrate that Gary has made the conceptual change to understand the single cell as an animal and as the first animal - the intellectual leap. The ability to think with the possible and imagine the likelihood of a single cell being the first animal on earth, is hypothetico-deductive thinking.
Gary considered making the intellectual leap at the beginning of the study, but he was not sufficiently prepared. The researcher argues he needed more science content knowledge, that is, an enriched concept of animal, instruction about the characteristics of plant and animal cells, and cognizance of deep time, to enable him to confidently achieve the conceptual change.

Gary’s thinking demonstrates the beginning of Lawson’s hypothetico-deductive thinking, e.g., generates causal questions, proposes alternative hypotheses, imagines experimental or correlational events to test his hypotheses, makes predictions, and thinks with the possible. His thinking skills enable him to make the intellectual leap.
Conceptual Ecology and Worldview

Science and religion

Gary’s responses on the Geologic Timeline Survey, content knowledge tests, journal entries, and interviews about instances clearly indicate that he uses a scientific net or worldview to understand geologic time. In addition to these assessments, the researcher measured the student’s worldview straightforwardly with two methods, the Concept Evaluation Statement (CES) and a post-study interview. The researcher argues that a student’s drawing and his or her warrants for that drawing are objective, unambiguous representations of the individual’s worldview or conceptual ecology because they require very little interpretation or inference from the researcher. Furthermore, the student’s conceptual ecology or worldview was examined with a subset of questions about science and religion in the post-study interview. These questions directly asked how do you deal with these two different points-of-view (see Appendix F).

First, the researcher will discuss the Concept Evaluation Statement (CES) results. Then, she will address the post-study interview findings.

During the study, Gary’s CES responses denoted a scientific worldview as evidenced by his drawing of a single-celled organism as the first animal. He used scientific vocabulary and referenced science concepts to warrant his understanding. He carefully separated religious explanations from scientific explanations (see Figure 8). This demonstrated that he used a distinct or separatist approach (McGrath, 1998; Haught, 2000) which applies a demarcation between religion and science.
However, the post-study interview revealed a very different frame-of-mind. In the post-study interview, Gary responded to a self-report questionnaire and a series of interview questions designed to determine his religiosity and to discover how he understood and reconciled the two different worldviews. Gary said he was Catholic and attended a Catholic school in grades K-4. In the self-report, he described himself as "somewhat" religious. He attends church about once every three months, prays regularly privately, and prays at all meals.

During the post-study interview, the researcher briefly explained to Gary that religion and science use two distinct points-of-view to understand and explain the same phenomena, the formation of the earth and the development of life on earth. This issue was not addressed during the study. After this discussion, the researcher asked Gary how he handled those different positions.

Gary nonchalantly informed the researcher that he integrates the scientific and religious explanations and eloquently described his method, "I usually just compare them and mix the ideas together. Like I do a Venn diagram in my head...." This is the convergence or engagement approach (McGrath, 1998; Nord, 1999; Haught, 2000).

Gary did not assume a conflict between science and theology on these issues, and in his own thinking, he was attempting to reconcile the two worldviews. However, he did not question the religious worldview in the same manner that he questioned science. In fact, he appeared to accept the religious worldview without questioning. Then the researcher asked which worldview he would choose if he were
forced to make a choice. He said, "The religious because I'm a Catholic, and that's what I believe." This response begged the question does his religious beliefs interfere with his being curious about or understanding the scientific explanation. Gary answered simply, "No. I like them both."

From this evidence, the study measures and Gary's self-report, the researcher concludes that he uses a dualist approach, that is, a distinct-convergence or a separatist-engagement approach to understand geologic time. Although Gary used a distinct approach, not a convergence approach, in the science classroom, it is interesting to know that he attempts to integrate the two worldviews. Based on the study evidence alone, the researcher did not suspected a religious influence on Gary's thinking about geologic time.

Case Study, MS Protoscientist

Description of Student

Michael is twelve years old; a quiet, content boy with a slow, contemplative smile. Tall and dark-haired, he is well-mannered, respectful, and very bright. The teacher has taught him previously in summer science programs and Saturday Science Programs in the neighboring city of Baton Rouge. He is very interested in science, particularly space and astronomy. At the end of the year, his GPA is 4.0; his composite National Percentile Ranks on the Iowa Test are Reading 79, Math 75, Science 75, Social Studies 80, and Research Skills 93.

Michael was born in Baton Rouge and previously attended Christian Way School (pseudonym), a protestant school (K-5) in Baton Rouge, Louisiana. He has been a straight A student throughout his school career; this is his first year at
River Town School. An only child, he lives with his father and mother. Michael reports his mother completed college and is an accountant; his father finished high school and manages a local rental company.

Understanding of Geologic Time

In January 1999, Michael was in a dual category MS Protoscientist/Prescientist which means he was thinking about the problem of geologic time with both science and prescience schema. He used both science explanations and dinosaurs to explain events in geologic time.

Million and billions of years

Michael’s initial thinking about a million years ago and a billion years ago is not documented. Nevertheless, a year after the study, Michael has the following concepts in place. He has a qualitative concept of geologic time as a really long time and associates million of years to dinosaurs, billions of years to little fish. These responses indicate that he is understanding geologic time in terms of the kind of animals living at each time period. His answer to the critical question, What first comes to your mind when you think of geologic time?, discloses that Michael first thinks of dinosaurs and the Big Bang. The association of geologic time to dinosaurs demonstrates to the researcher how deep-seated a dinosaur focus is in his thinking.

When did the earth form?

During the study, Michael’s quantitative understanding of the time the earth formed moved from 25 bya (pretest timeline) to 4.5 bya (posttest). The pre- and post-tests in Earth Science and Evolution confirm that he knows the
correct time the earth formed. Therefore, the teacher concludes he has successfully constructed the concept of the age of the earth.

When did dinosaurs become extinct?

Michael is confused about the time dinosaurs lived, and by the end of the Geologic Time Unit, he does not know the date of dinosaur extinction. On the geologic timeline pretest, he said dinosaurs became extinct 45 mya. However, on the posttest, he put dinosaur extinction at 50 tya" and referred to the fossil record to justify his answer. All study measures indicate Michael has very stable, correct concepts of dinosaurs and humans, evolution concepts, and dinosaur extinction. He knows that dinosaurs and humans did not exist together and that dinosaurs became extinct long before human appeared on earth. However, he is having difficulty understanding the quantitative time of dinosaur extinction.

When did the first prehistoric humans appear on earth?

Michael is very perplexed about the time prehistoric humans appeared on earth. On the geologic timeline in January, he thought that prehistoric humans appeared 20 tya because he added up the B.C. years and the A.D. years. In May, he said prehistoric humans appeared 1 tya based on the fossil record.

The formal Earth Science pretest and posttest also record Michael's confusion about the time prehistoric humans appeared. In January, he correctly said that radioactive dating cannot show the exact age of the oldest human fossil, but on the posttest, Michael said the oldest human fossil

"Tya means a thousand years ago.
was 5,642 years old. Although he correctly refers to the fossil record as evidence for the age of the oldest human fossil, he is confused about the process and precision of radiometric dating. Both study measures indicate Michael is uncertain about the quantitative time that prehistoric humans appeared on earth.

A year later, Michael describes the first prehistoric humans as "hairy" and "all beat up and scratched...from hunting and all." When the researcher asked how these humans got on earth, Michael replied, "They evolved from other organisms."

**Summary of Michael's thinking about geologic time**

Michael correctly understands some fundamental concepts about the age of the earth, dinosaur extinction, prehistoric humans, and evolution concepts. His weakest concepts are about prehistoric humans. Although he does posit they evolved from other organisms, he does not identify the organism, and he has not successfully constructed the quantitative time they appeared. Nevertheless, he is aware that prehistoric humans appeared very near present time in geologic time, and he waffles between 20 tya to 1 tya.

The researcher argues that although Michael has constructed a viable understanding of qualitative geologic time by using chronology; causation (e.g., event x appeared before event y); deduction (e.g., reasoning from cause to effect to create a seriation); and is forming an understanding of quantitative geologic time, he needs more experience with the concept.

First, the data show that his understanding of geologic time is related to the animals that appeared in a certain
time period. This method of understanding is valid and was used by early scientists in proposing the relative dating of the fossil record. However, the conceptual flaw in Gary's personal theory is that he has an impoverished view of animal. In the class activity, Classification of Animal-Not Animal, Michael only identified mammals, birds, and common marine animals as animals. He did not consider invertebrates or single-celled organisms as animals. His concept of animal may limit his thinking, prevent him from understanding the single cell as an animal, and impede him from making the intellectual leap.

Second, although Michael has constructed a useful understanding of relative geologic time, he needs more exposure to the concept to develop and refine his thinking. Conceptual Change

The comparison of pre- and post-tests in Earth Science and Evolution specifies Michael's concept knowledge change for the duration of the study (see Figure 9). Although his score on Earth Science concepts remained the same, his score on evolution concepts denotes a negative change. His class rankings on the Earth Science and Evolution post-tests respectively were 6 out of a class of 55 and 12 out of a class of 50.

Michael has many knowledge structures firmly in place; nevertheless, he still needs to clarify and correctly form key concepts such as evolve, adaptation, extinction, genes, and heredity. Although he often writes about the struggle for survival, he does not connect that concept as a cause of extinction or natural selection. His wavering answers on the content knowledge questions about extinction illustrate
that his ideas are still not firmly established. He needs much more time and exposure to these concepts.

Michael frequently speaks or writes about the struggle for survival, and it emerges as his subconcept-theme. In the Fossil Timeline Problem, Michael consistently applies the struggle for survival as a warrant for placing the fossils on the geologic timeline.

...(700 mya) I think that’s when fish started living. Came to be and just started swimming around. Trying to fight other animals for things to eat.
Later in the same interview, he uses the **struggle for survival** to explain why he placed dinosaurs bones at 230 mya.

I think that was the Jurassic Period when dinosaurs were around fighting, dying and all that.

Michael does not use the word **extinction** in his writings or comments, but implies it in his journal entry, **What happened to the different species of animals over the billions or millions of years of earth time?**

They evolved to walk on land, lay eggs, [have] eyes, and feet. Then they all died. After that animals that don’t lay eggs evolved. And not long after that, humans came. That’s where we are now.

In May 1999, Michael thinks about **geologic time** in terms of the **struggle for survival**. In the journal entry, **How have species of animals changed over geologic time?** he writes

Animal species change over millions of years to have a **better chance of surviving**. Another form of change is adaptation. Both of these happen from **genes passed down from parent to offspring**.

Michael’s journal writings demonstrate that he understands the concepts of **evolve**, **genes** as the mechanism for species change-over-time, and the **struggle for survival**. He also knows that **prehistoric humans appeared** recently in **geologic time**.

Furthermore, the formal Evolution Test indicates he has developed the knowledge structures of **evolve** and **genes**, but they need refining to become well-formed concepts. The test confirms that he understands **organisms evolve to become**
well-suited to their environment, but can never become perfectly adapted to their environment because the environment keeps changing. However, he does not exhibit a well-formed concept of the role of genes and traits in the process of heredity. His responses show a conflation of the ideas of heredity and adaptation in a Lamarkian fashion. For example, he incorrectly answered. It is true that if every cow for many successive generations had its tail cut off at birth, eventually there would be a time when cows were born without tails. The reason that he provided for his answer was eventually the population would adapt.

He applies the term genes without understanding the process of inheritance; he uses the word genes in many instances when he is actually describing adaptation. Although Michael has nascent concepts about genes as a mechanism for change in species over time, he needs more experience with the concept.

Interestingly, this knowledge structure (e.g., genes) prevents him from thinking with the possible and imagining the existence of the archaic mammals in the Prehistoric Animal Card Problem. Michael claims that the archaic mammals of the Paleocene Epoch could not have existed in geologic time in terms of species and genes. When asked to explain the archaic mammals, Michael replies, "They look... deformed" and "They look kinda strange.... They don’t seem like they would really exist. The creatures of a monkey and a hyena mixed.... Scientists would have to... be able to take their genes and put them together and grow’um."

Michael describes one archaic mammal as "half tiger and half wolf" and the other as "half monkey and half wolf or
hyena*. He does not think they actually existed on earth because the two different species of animals could not mate. His concept of genes becomes a conceptual trap preventing him from thinking with the possible or formulating alternative hypotheses to understand creatures he has never seen before.

Michael is not able to make the intellectual leap to grasp the single-celled organism as the protozoan, first animal at the end of the study. However, he has experienced conceptual change in his understanding of first animal by moving from a dinosaur (pretest) to a centipede living in water (posttest).

Pretest 2/22
Protozoan, Dinosaur

Justification: "I have always been taught that they were the first animal on earth...."

Posttest 5/24
Protozoan, Centipede

Justification: "My animal is like a centipede that lived in water. I think he is the oldest because of all the fossils I have heard of this is the oldest.... I have seen fossils and reenactments of it."

Figure 10. Michael's Concept Evaluation Statements - protozoan, first animal.

In his justification of the posttest drawing, he writes "I have seen fossils and reenactments of it." This refers directly to the Geologic Time Unit learning experiences.
related to ammonites, e.g., the video *Mary Anning, the Fossil Hunter* and the Fossil Timeline Problem. In his writings and interviews during the study, he makes no references to single-celled organisms. He only mentions single-celled organisms in the post-study interviews a year later.

**Conceptual Ecology and Worldview**

Michael is a MS Protoscientist; his thinking is approaching correct science. He uses specific scientific language and concepts to describe the ideas embodied in deep time. Although he has many correct knowledge structures in place, he has not made the intellectual leap to imagine the single-celled organism as the protozoan at the end of sixth grade. His limited concept of an animal may have prevented him from this. He understands the protozoan as a centipede-type animal who lives in water.

**Science and Religion**

**Conceptual ecology**

Michael has a high level scientific understanding of geologic time and uses a scientific worldview to understand the events in deep time. In the post-study interview, Michael informed the researcher that he is Baptist and considers himself religious. He reports that he attends church services nearly every week, says grace at meals at least once a week, and prays privately quite often. The sixth grade was his first year at River Town Middle School; he attended a Christian school for grades K-5.

Michael fully understands the opposing positions of science and fundamentalist religion on explanations of the formation of the earth and the development of life on earth.
His stance on the two points of view is "The science view is the more logical one. The religious view... Maybe God put the organisms on earth and made them evolve... I think the science explanation is the more logical, and I think it would be the right one."

Michael assumes a protoskeptic disposition and employs the confrontation or opposition approach in which science trumps religion (McGrath, 1998; Nord, 1999). He highly values the scientific view and seems to have abandoned the religious explanations of the natural history of the earth and life on earth. For an instant, he considers the convergence approach, e.g., "Maybe God put the organisms on earth and made them evolve...", but quickly he rejects that idea. When the researcher asks Michael which view he would choose, he answers, "I would probably choose the science one. Unless they could prove to me there was a Garden of Eden. They can't do that." In conclusion, Michael is a dualist who uses a distinct-confrontation approach to understand the science-religion argument.

Case Study, MS Prescientist

Description of Student

James is a charming 12-year-old male who is very popular with both his peers and his teachers. He was born in Baton Rouge and has spent all of his school career at River Town Primary School and River Town Middle School. His GPA at the end of the year 3.125; he is an above-average student. On the Iowa Test, his National Percentile Ranks are Reading 59, Mathematics 52, Science 67, Social Studies 51, and Reference Skills 56. James has perfect attendance for the year and is a very serious, well-rounded student.
He has lived with his maternal grandparents for the past nine years as an only child. Both of his grandparents are college graduates. His grandfather is a sign painter and his grandmother a homemaker. He considers himself religious. Table prayers are said at least once a day in the home. Although he does not pray privately, he prays at religious services which he attends every week. His religious background is Baptist and Catholic.

Understanding of Geologic Time

**Millions and billions of years**

At the beginning of the study, James uses puzzling and unrelated analogies to understand a million years and a billion years. He related millions of years to an encyclopedia and internet and billions of years to a fossil and a live animal. During the study, his schema of million years and billion years does not show a consistency in his method for "marking" time. However, a year later, he does demonstrate a schema to mark time; he uses distance rather than duration or number to understand a million years ago. He explains a million years ago is "closer to us" and "it would be quicker and easier to go [back in time] to a million than a billion years." His concept of time as physical distance indicates a concrete, empirical concept of time rather than an abstract-rational concept of time which is a system of time, e.g., the causal processes of time succession, simultaneity, and duration (Piaget, 1927, pp. 2-3). The following section is a discussion of James’ understanding of the index time-events in geologic time: formation of earth, dinosaur extinction, and appearance of prehistoric humans.
When did the earth form?

On the Geologic Timeline Survey pre-and post-tests, James thinks that earth formed at the beginning of time (e.g., a quantitative time > 25 bya). At the end of the study, he gave "the earth formed when the universe formed" as his warrant for this improbable time. While this may indicate the influence of a pseudoscience point-of-view, the formal tests indicate that he is waffling between extremes in his understanding of this time. These data reveal that James' understanding of the age of the earth is still unformed and very confused. On the Geologic Timeline Survey, he placed the event at the extreme upper level quantitative time (> 25 bya), and on the content knowledge tests, he put the event at 10,000 years. His ideas about geologic time are in a state of confusion. The researcher posits that James has not successfully constructed the time of the formation of the earth at 4.5 billion years ago. Therefore, he has no point of reference for other time-events. Since he has no point of reference (e.g., quantitative times of index events in deep time), he is experiencing great difficulty in developing a systematic understanding of quantitative or relative geologic time.

When did dinosaurs become extinct?

James shows a similar perplexity in understanding the quantitative time that dinosaurs became extinct and other facts about dinosaurs. On the Geologic Timeline Survey posttest, he says dinosaur extinction occurred 10 mya and posits disease or freezing as the cause of dinosaur extinction. Other test measures record his confusion and/or contradictory thinking at the end of the study. On the
Earth Science posttest, James says **dinosaurs and humans did not exist on earth at the same time**. However, on the corresponding questions on the Evolution Posttest, he says that **humans were too small to have much impact on dinosaurs**. He exhibits unsystematic and contradictory thinking about dinosaurs by not reflecting or questioning his own thinking and displays the characteristics of Lawson's empirical-inductive thinking or child-like thinking.

Dinosaurs figure prominently in James' understanding of **deep time** as demonstrated in his responses in the **Prehistoric Animal Card Problem** (May 1999). James is considering the picture of a crossopterygian, the group from which amphibians are thought to have evolved in the late Devonian Period (345 mya). The colored picture shows a large fish walking on its fins on the beach. A second crossopterygian is swimming in the water along the shoreline. James describes the picture as "a fish coming on land" and explains "...like an amphibian... They're born on water. They are able to walk on land or go back to the water if they feel like it." When the researcher asks if the picture could be a real event in the history of the earth, he says, "I guess so because dinosaurs... certain dinosaurs lived in water, and they were able to walk out on land." As the conversation continues, James explains that since dinosaurs lived on land and water, fish could have left the water and begun living on land or lived on both land and in water.

James uses **dinosaurs** as a central organizing concept in his thinking about **geologic time**. Dinosaurs, as a recursive theme, is discussed throughout his case study.
When did the first prehistoric humans appear on earth?

The pre-and post-tests results show James does not understand the quantitative time of when prehistoric humans appeared. Again, he is waffling between extremes in his thinking about the time of the event. On the geologic timeline, he indicated prehistoric humans appeared at 500 mya (pretest) and 1 tya\(^2\) (posttest). At the end of the study, James' warrant for placing prehistoric humans at 1 tya was because they were formed from dinosaur bones.

A year later, these concepts are still intact and reappear in the post-study interview. James describing prehistoric humans says, "They looked like we do today, but they weren’t as healthy." When the researcher asked how these prehistoric humans got on earth, James replies, "They formed from the remains of animals that were on earth before humans. ... Dinosaurs."

The triangulation of data from the geologic timeline, formal tests, student writings, and interviews; as well as the stability of these concepts over a long period of time, confirms that James uses dinosaurs as a ubiquitous organizing concept in his thinking about geologic time.

Summary of James' thinking about geologic time

James does not exhibit a systematic understanding of number or relative quantitative time in his thinking about geologic time. The study data indicate that he uses a dinosaur focus to understand geologic time. He uses dinosaurs both to order events in geologic time and as the logic to warrant his answers, e.g., dinosaurs establish the chain between causes and effects in geologic time.

\(^2\)Tya = thousand years ago.
The resulting misconceptions support a web of extremely confused thinking.

Conceptual Change

The formal tests indicate a positive conceptual change in evolution concepts and a negative conceptual change in Earth Science concepts. This paper discusses James’ responses to the subsets of questions on the Earth Science and Evolution Tests related to the research focus. However, the negative change on the Earth Science Test also includes concepts which are not a part of this study, e.g., the cause of night and day, the solar system, and stars. At the end of the study, James ranks 20 out of a class of 50 on the Evolution Test and 27 out of a class of 55 on the Earth Science Test. Figure 11 indicates James’ conceptual change in the pre/post tests scores on Earth Science and Evolution concepts.

Figure 11. James’ pre-and post-tests on the formal knowledge, earth science and evolution.
James' thinking about deep time develops around a subconcept-theme, the fossil record. This theme appears very early in the study in his analogy for geologic time, e.g., "A billion years is like fossil and live animal."

In April 1999, James responds to the journal prompt, What happened to the different species of animals over billions or millions of years?

[They] Laid down and died. The sand and other kind of rocky soil. I know this because in some parts of the world you can find fossils. Fossils are the imprint where the bone laid and got hard.

Later in April, he again focuses on the fossil evidence in the journal entry, What does the geologic timeline tell you about the development of life on earth?

... animal fossils were not starting to be discovered until about 550 million years ago. I know this because scientists are able to take samples of the ground to see how old it is. They check for fossils all in the earth's surface...

James is demonstrating Lawson's empirical-inductive thinking pattern, e.g., fact-gathering with observation and organizing those facts to develop a theory to understand geologic time. He finds the fossil record compelling evidence for his conceptual net about geologic time, but his thinking is also trapped in that net. His thinking is similar to the early thinking about geologic time in the history of science, e.g., Hutton and Darwin. As Gould wrote (1987, p. 86), "The classical data of historical geology are fossil and strata." James uses the fossil record as empirical evidence in developing his theory of specific time-events in geologic time, just as early scientists. However, he does not use the fossil evidence to produce a
fruitful theory about geologic time. The researcher argues he cannot relate the fossil record to time because he has not constructed a systematic understanding of geologic time as evidenced in an earlier discussion. Therefore, he does not perceive the fossil record as a dynamic history of deep time, but seems to understand it as a static record of the dead. James is thinking about the fossil evidence rather than thinking with the fossil evidence.

He is using Lawson's empirical-inductive thinking, e.g., child-like, unsystematic thinking which uses observation and description of the obvious (what he sees). He neither reflects on (evaluates) nor questions his thinking. Therefore, he does not generate alternative hypotheses or link his ideas to other facts and knowledge of deep time. He offers no mechanism for change-over-time which demonstrates he does not ask the causal question, What caused change-over-time? However, his dinosaur theory produces troubling misconceptions.

At the end of the study, James still conceptualizes the protozoan first animal as a dinosaur as shown in Figure 12. His dinosaur concepts have been modified to 1) a benign dinosaur, 2) a water habitat, and 3) an amphibious animal. James alluded to these ideas in many of his interviews and writings during the study, but he synthesized them in the posttest drawing of the first animal.

In the post-study interview, the researcher asked James to explain how or why he used dinosaurs to explain the events in geologic time. He replied, "Dinosaurs were the first animal formed." His ubiquitous use of a dinosaur organizing concept is deeply troubling to the
teacher/researcher. Again, he seems to use a concept that is known to him to make sense of a concept that is foreign to him, the Vico Principle. McGrath (1998, p. 167) explains this phenomenon by quoting Giovanni Vico, "It was a distinctive property of the human mind, that whenever men can form no idea of distant and unknown things, they judge them by what is familiar and at hand."

Pretest 2/22
Protozoan, T-Rex

Posttest 5/24
Protozoan, Dinosaur

Justification: "This dinosaur T-Rex is a very messy eater. ...I know this from history books and the bible."

Justification: "It lives in water and can swim a. and walk. It is a dinosaur that can go in and out of water."

Figure 12. James' Concept Evaluation Statements - protozoan, first animal.

Conceptual Ecology and Worldview

MS Prescientists hold misconceptions about geologic time, that is, false or incorrect science concepts. Sometimes, these students do not use the correct science vocabulary, and sometimes, they do. In either case they do not know the meaning of the words. The identifying misconception of this group is that they use a dinosaur theory to explain the events in deep time.
Science and religion

James considers himself religious. Table prayers are said daily in the home. Although he does not pray privately, he prays at religious services which he attends every week. His religious background is Baptist and Catholic.

James uses the distinct or separatist approach to understand the events in geologic time during the study. In his writings and interviews, he references science (fossil record) and prescience concepts (dinosaurs) as warrants for his answers. He becomes aware that religion and science propose two different explanations for the events in geologic time when the researcher briefly discusses that with him in the post-study interview.

During that interview, James explains how he understands science and religious explanations of the events in geologic time. He says, "In separate ways. You can think God made the earth, plants, etc., or you can think that animals formed from dead fossils of dead plants or from seeds that were just there." He continues, "In some ways, they could be the same. For instance, you could think God formed the universe and earth or [think that] the stars and universe formed and came together over time. And it could be the same thing." Finally, he reports that although the religious view does not keep him from being curious about the scientific explanations, he would choose the religious explanation that "God formed all living things around him."

The study data indicate James used a distinct or separatism approach to understand geologic time during the period of the study. However, in the post-study interview, when the researcher forthrightly asks how he deals with
these two different explanation, he suggests it might be possible to integrate the two explanations, a convergence or engagement approach. Therefore, James uses a dualist approach, distinct-convergence or separatism-engagement approach to understand the science and religious views.

Case Study, MS Pseudoscientist

Description of Student

Megan is an alert, bright-eyed twelve year old who smiles easily and still wants to "please the teacher." She is a popular confident sixth grader. Her GPA at the end of sixth grade is 4.0; her National Percentile Ranks on the Iowa Test are Reading 46, Mathematics 51, Science 36, Social Studies 41, and Reference Skills 37. Megan has attended River Town School for all of her school career (K-6) and has consistently been an above-average student.

She was born in Baton Rouge and lives in River Town with her mother and father. Megan is the oldest of two children. She told the researcher both her mother and father graduated from business school. Presently, her father is a chemical plant operator and her mother is a homemaker.

Understanding of Geologic Time

Millions and billions of years

Megan did not have a journal entry at the beginning of the study of analogies for a million years ago and a billion years ago. However, in the May 2000 post-study interview, she described a million years ago as "not as long as bya, but still long ago" and a billion years ago as "long ago". She explained the difference between a million years ago and a billion years ago as "the difference between 1,000 and
"Her answer to the post-study interview question, When you think of geologic time, what comes to your mind first? was “[I]Think about a million years ago or a billion years ago. Time before humans.” When she thinks about geologic time, first, she thinks in terms of a great numbers of years, e.g., millions or billions. Then, she relates that time to humans. The researcher suggests Megan’s anthropocentric focus is a characteristic of Piagetian egocentric thought or child-like thinking.

When did the earth form?

In the course of the study, Megan’s quantitative understanding of the age of the earth moved from incorrect (10 bya) to correct (4.6 bya). However, her warrants for her geologic timeline answers are flawed. In the beginning of the study, Megan relates the time the earth formed to dinosaurs, but at the end of the study, she says, “...the earth formed with the universe”, a fundamental creationist perspective.

The Earth Science and Evolution Pretests and Posttests also indicate a general positive conceptual change in her concepts about the age of the earth. After analyzing these measures, the researcher concludes the student is moving toward a correct understanding of the age of the earth, but exhibits some confusion about the method used to measure the age of the earth, e.g., radiometric dating. Therefore, she needs more exposure with the subject to construct a well-formed concept.

When did dinosaurs become extinct?

Megan does not demonstrate the correct quantitative time of dinosaur extinction. On the geologic timeline, she
places dinosaur extinction at 10 mya on the pretest and at 5 mya on the posttest. Her justification for her posttest answer is that as dinosaurs disappeared "mammals were heard of and we have been known for a long time." Here she exhibits a web of generally incorrect concepts. She correctly relates the appearance of mammals to dinosaur extinction, but she connects those mammals to humans, not the small mammals of the Cretaceous Period. Again, she persists in anthropocentric thought by personally identifying with the prehistoric humans by using the personal pronoun we. The formal tests indicate she correctly understands that dinosaurs and humans did not exist together, yet she connects them very close in geologic time, e.g., dinosaurs became extinct 5 mya and prehistoric humans appeared 1 mya.

Megan uses science, prescience (dinosaurs) and pseudoscience (fundamental creationist) conceptual nets to understand deep time. The researcher asked Megan to explain how she used dinosaurs in her thinking about geologic time. Without hesitation, she answered.

When most people think about time - a long time ago. Most people think about dinosaurs and most people relate to dinosaurs. Dinosaurs are the "big thing" - more movies and things about dinosaurs.

When did the first prehistoric humans appear on earth?

Although Megan has an acceptable understanding of quantitative time that prehistoric humans lived on earth, she is confused about the event. On the geologic timeline pretest, she said prehistoric humans appeared 3,000 years

\[\text{Accepted time range for the First Prehistoric Humans in the study is 1-2 mya.}\]
ago because it is almost the year 2,000. However, on the posttest timeline, she said prehistoric humans appeared 1 million years ago because "We came right after dinosaurs disappeared 5 mya." On the formal Earth Science Posttest, she said the oldest human fossil was 5,642 years old. These responses indicate her confusion about the time prehistoric humans lived.

A year later in the post-study interview, the researcher asked Megan to describe early humans. She said, "[They] Kinda looked a little like animals because they were made of so many different things. Then over time, they began to look like us. I know from Catechism, we came from God. But we could have come another way ... from animals." Then the researcher directly asked how did humans get on earth. Megan answered, "Catechism said God made them and put them on earth."

Megan's responses indicate that she is in a pluralist category moving between science ideas, prescience (misconceptions) notions, and pseudoscience (fundamental creationist) ideas. Although she is constructing correct or approaching correct science knowledge about geologic time and is open to science explanations, her dominant conceptual net is pseudoscience.

Summary of Megan's understanding of geologic time

At the end of the study, Megan seemingly has constructed the most accurate understanding of quantitative geologic time. She correctly placed two of the three index time-events on the geologic timeline (e.g., earth formed and prehistoric humans appeared). However, the misconceptions which appear as her warrants for those time-events lead the
researcher to question her understanding. Megan said the earth formed with the universe (4.6 bya) and prehistoric humans appeared (1 mya) right after dinosaurs disappeared (5 mya). Her correct quantitative time answers appear to be rote answers as she neither considers nor questions how her answers correspond logically to other events in geologic time.

In the post-study interview, she correctly relates geologic time to number, but immediately articulates an anthropocentric focus by also associating it with the "Time before humans." In her thinking about geologic time, she uses chronology and attempts to establish causal relationships between events by relating the index time-events to the appearance of humans. This anthropocentric focus is an ineffective referent because the appearance of humans is a very small, recent part of deep time. The result is she does not have an understanding of relative geologic time, as the MS Scientist and MS Protoscientist have. In other words, although she has acceptable science answers of some parts of geologic time (e.g., rote answers of quantitative time), she has not connected the big picture (e.g., an understanding of deep time as a system).

**Conceptual Change**

At the end of the study, Megan ranked 15 out of a class of 55 on the Earth Science Test and 4 out of a class of 50 on the Evolution Test. Her scores on both Earth Science and Evolution concepts indicate knowledge growth. As shown in Figure 13, Megan has experienced concept knowledge growth as a result of the Geologic Time Unit.
Extinction is Megan's subconcept-theme. She writes about it in her journal entry, *What happened to the different species of animals over billions or millions of years?*

Some of the animals that became *extinct* were dinosaurs, arthropods, and others. Most of the animals we have today were shaped different back then. Most of the animals became *extinct* because of the giant ooze, fossils, and some animals were too small.

In the *Prehistoric Animal Card Problem*, Megan considers the crossopterygian card (e.g., a fish walking on the shore) and uses extinction to support the premise that this animal existed in the development of life on earth.
[This animal existed] because these aren’t animals that we have today. You know they had a big old extinction and most of the ocean creature-animals all became extinct. All at one time. So that’s probably what happened to this specific animal.

Megan’s responses to the questions about extinction on the Evolution Test indicate her understanding is approaching correct science. However, she still shows child-like thinking by thinking in terms of human action on the system or anthropocentric thought. She claims that all of the species that ever lived on earth became extinct because of humans changing the environment. Furthermore, she neither reflects on nor questions the plausibility of her thinking, that is, how could human action on the environment cause the Permian extinction when humans didn’t exist at the time.

Megan’s responses reveal her thinking about deep time moves along a continuum from science, protoscience, prescience, and pseudoscience. However, her primary thinking level is pseudoscience. She recognizes, understands, and even appreciates the viability of the science explanation of deep time, but she continues to explain events in geologic time from a pseudoscience perspective.

She attempts to apply a demarcation between science and religious explanations in the classroom and succeeds most of the time. However, the Concept Evaluation Statement unquestionably demonstrates a fundamental creationist perspective. In the post-study interview, she states she would choose the pseudoscience explanation over the science explanation. Nevertheless, her personal preference and religious training did not prevent her from understanding or learning the science explanations.
Megan’s journal writings and interviews demonstrate the growth of her science knowledge. In April 1999, Megan writes about the journal prompt, What does the geologic timeline tell you about the development of life on earth?

The geologic timeline tells me about the beginning of the earth... the precise date (4,500) the earth started to now.... about first life, oldest reptile to oxygen atmosphere forms. It tells me that fish came before dinosaurs. Fish were the first animals to be made. Human beings were last to be made ...

Megan writes about speciation in her journal entry, Explain how species of animals changed over geologic time.

Animals change by being separated from other animals of their type. But it does not take a few years for this to happen, it takes millions and billions of years. They change because of speciation and because the animals are not by each other to see what they do or eat.

She explains the concepts of evolution, speciation, and geologic time in a scientifically acceptable manner. However, she is using empirical-inductive thinking in that she accepts these concepts without questioning and she does not pose the causal question, What caused animals to change over time?, or propose alternative hypotheses. When Megan discusses the Prehistoric Animal Cards (archaic mammals) with the researcher, she says she doesn’t think the archaic mammals really existed because they look like two animals mixed together. This indicates she is not thinking with the possible, and she does not offer an alternative hypothesis to account for the existence of the animals.

She provides correct answers in her writings about concepts like evolve, speciation, and geologic time, but her writing appears like rote answers. She neither reflects on
nor questions her answers. As bright as she is, she just knows the "right" answer and spews it out.

After all of Megan's correct and nearly correct science concepts, her concept and warrants for the first animal have not changed, "The protozoan is a fish because God made it." She uses direct references to God in her explanation of events in geologic time as shown in Figure 14. The researcher has argued that the CES is the most powerful and lucid measure of the student's understanding of the concept and worldview.

Pretest 2/22
Protozoan, Fish

Posttest 5/24
Protozoan, Fish

Figure 14. Megan's Concept Evaluation Statements - protozoan, first animal.

Conceptual Ecology and Worldview

MS Pseudoscientists use the words God, Bible, a creation story, or reference to religious teachings to explain the events in the formation of the earth and the deep time.

Science and religion

In the post-study interview, Megan tells the researcher that she is Catholic and describes herself as religious.
She attends religious services every week, offers prayers at meals in her home at least once a day, and prays regularly (e.g., once a day or more).

Megan confidently discusses her ideas about the science and religious explanations of the concepts in geologic time. "I think they're really different. Scientists make it sound more possible and really real - like a theory. And religion makes it sound like "poof," it just happened." Megan says although she "likes learning about the science way", she would choose "the religious way because that's what I was taught and learned more about." She doesn't question her religious teaching.

Megan uses the distinct or separatism approach, (e.g., religion and science are separate), to understand the scientific and religious explanations of deep time. She recognizes the rationality of the scientific explanation when she says, "Scientists make it sound more possible and really real...." However, she states she prefers the religious explanation.
Chapter 7
CONCLUSIONS AND IMPLICATIONS

Conclusions

The purpose of this exploratory, mixed model study was to discover Sixth Grade students’ understandings of the natural history of the earth and the development of life on earth as a function of deep time. To accomplish this, the researcher examined these three broad concepts based on the research questions: (RQ1) students’ understanding of geologic time, (RQ2) students’ conceptual change as a result of the Geologic Time Unit, and (RQ3) students’ conceptual ecologies or worldviews. Multiple research methods, quantitative and qualitative, were used to examine both the large group and four case study representatives from that group. The findings of this study are based on the triangulation of the results from these methods in a repeated-measures design. First, the primary findings from the large group analysis (N = 59) will be discussed. Then the results of the case studies (N=4) will be reported.

Large Group Findings

The Geologic Time Knowledge Continuum describes the broad knowledge levels and thinking patterns about geologic time which the large group share (see Figure 15). Analysis of the group data indicated the students’ understanding of geologic time. The students’ understanding of the index time-events moved in a continuum from pseudoscience (fundamental religion understanding or metaphysical misconceptions) to prescience (everyday-knowledge or secular misconceptions) to science (correct or approaching correct science understanding). The researcher’s
conceptualization of the Geologic Time Knowledge Continuum resulted from the categories of student knowledge which emerged from the analysis of the group data, e.g., MS Scientist, MS Protoscientist, MS Prescientist, and MS Pseudoscientist. The criteria used for placement in each of those categories are shown in Appendix I.

![DTS6 Students' Knowledge Continuum](image)

**Figure 15.** Deep Time Study students' knowledge continuum.

**Triangulation of Measures**

A mixed model study is a strong study design which uses both quantitative and qualitative methods in all phases of the research. In this repeated-measures study, the triangulation of the findings from the large group measures, e.g., Geologic Timeline Survey, Concept Evaluation Statement, word association, and formal tests, provides a composite measurement of the students' knowledge level at the beginning and end of the study.

**Quantitative measures**

Quantitative measures were used to assess content knowledge in Earth Science and evolution. Based on the concerns of the test reviewers, the researcher qualified...
findings of the formal tests in Data Collection and Analysis Section, "to be interpreted cautiously." There was very little change in the pretest and posttest mean scores in the Earth Science formal test as shown in Table 10.

Table 10
Descriptive Statistics of Earth Science Content Knowledge Tests

<table>
<thead>
<tr>
<th></th>
<th>M</th>
<th>SD</th>
<th>KR-20</th>
<th>SEM</th>
<th>R(%)</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pretest</td>
<td>26.42</td>
<td>2.178</td>
<td>0.329</td>
<td>1.784</td>
<td>0-55</td>
<td>53</td>
</tr>
<tr>
<td>Posttest</td>
<td>27.73</td>
<td>2.814</td>
<td>0.543</td>
<td>1.901</td>
<td>0-55</td>
<td>55</td>
</tr>
</tbody>
</table>

At the end of the study, the researcher had only 46 paired test scores; therefore, the sample size on this measure was reduced to 46. An alpha level of .10 was used for all statistical tests. The result from the t test of Earth Science concepts was not statistically significant, \( t(45) = 0.64, p < .10 \), two-tailed and did not reject the null hypothesis of no difference.

The formal evolution tests yielded similar results (see Table 11).

Table 11
Descriptive Statistics of Evolution Content Knowledge Tests

<table>
<thead>
<tr>
<th></th>
<th>M</th>
<th>SD</th>
<th>KR-20</th>
<th>SEM</th>
<th>R(%)</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pretest</td>
<td>32.11</td>
<td>3.654</td>
<td>0.461</td>
<td>2.682</td>
<td>11-51</td>
<td>54</td>
</tr>
<tr>
<td>Posttest</td>
<td>33.66</td>
<td>3.499</td>
<td>0.379</td>
<td>2.757</td>
<td>16-51</td>
<td>50</td>
</tr>
</tbody>
</table>
The result from the t test of evolution concepts was not statistically significant, \( t(45) = 0.31, p < .10 \), two-tailed and did not reject the null hypothesis of no difference.

Wandersee, Mintzes, & Novak (1994, p. 201) commenting on standardized tests, reminds researchers, "[of the] great deal of meaning...tied to a single score" and warns against the "uncritical use of standardized tests, even though irrelevant to the instructional goals of the intervention."

The researcher decided to use the formal tests of content knowledge with full prior awareness that they could prove problematic. She did not change the tests (e.g., rewrite the questions in simpler language) because she wanted an objective measure of the broad concepts and wanted test results which could be compared with other middle school students in the country. Interestingly, the subsets of questions on Earth Science and evolution concepts related to this study proved very insightful in the cross-case study analyses. An examination of the student's responses indicated subtle changes in their understanding of the concept.

**Qualitative measures**

The triangulation of the group data on the qualitative measures lead to the formation of the knowledge levels of the group (N=57) as shown in Figure 16. Series 1 is the pretreatment triangulation and Series 2 is the posttreatment triangulation.

From these study findings, e.g., the Geologic Time Knowledge Continuum and the DTS6 Students' Knowledge Levels, the researcher developed a formula to measure estimated knowledge growth or conceptual change based on Popper's
(1959) tetradic schema for the growth of knowledge in science and technology.

Figure 16. Students' knowledge levels after pre-and post-treatment triangulations of group qualitative data (e.g., geologic timeline survey, concept evaluation statement, and word association). \( N = 57 \).

Popper proposed a formula to measure knowledge growth in science.

\[ P_1 \rightarrow TT \rightarrow EE \rightarrow P_2 \]

- \( P_1 \) = Starting Problem
- \( TT \) = Tentative Theory [trial]
- \( EE \) = Process of Error Elimination
- \( P_2 \) = Problems with which we end
This schema includes both objective and subjective knowledge. Popper (1992, p. 11) writes, "The progress made or the growth of our knowledge achieved, can usually be estimated by the distance between \( P_1 \) and \( P_2 \). In brief, our schema says that knowledge starts from problems and ends with problems (so far as it ever ends)."

First, the findings of this study (\( N = 59 \)) and an earlier study (\( N = 107 \)) caused the researcher to posit that the Geologic Time Knowledge Continuum may represent a natural pattern in the development of students' thinking about deep time.

Next, she defined the knowledge levels and assigned them the following ordinal values. (A) Knowledge Level 1, the MS Pseudoscientist has an understanding that is based on oral tradition or religious teaching, that is, information passed down from thousands of years of tradition. (B) Knowledge Level 2, the MS Prescientist has an understanding based on common or everyday knowledge and experience. (C) Knowledge Level 3, the MS Protoscientist has an understanding based on mixed science concepts (correct and incorrect ideas). (D) Knowledge Level 4, the MS Scientist has an understanding based on current science knowledge or approaching correct science.

\[\text{The study's sample size is } N = 59. \text{ However, the sample size in the reported data changes because in the prolonged engagement, not all students were present for all tests or activities.}\]
MX Knowledge-Level, a Dualist or Pluralist is a sliding knowledge level based on competing constructions which can fall at any point along the continuum and indicate the best candidate for conceptual change. The MX Knowledge-Level is assigned the value of the dominant category."

Then, she applied Popper's tetradic schema of knowledge growth or conceptual change to the knowledge levels of the students in this study.

A visual representation of the researcher's DTS Knowledge Growth Formula is shown in Figure 17. Within this schema, both the magnitude and direction of conceptual change is measured. Each knowledge level (KL) is assigned a numerical scale value from one to four which may be positive or negative depending on the direction of the change. The Pseudoscience Knowledge Level is given a scale value of one and the scale increases incrementally by the value of one (1) to the Science Knowledge Level scale value of four (4). When applying the formula, KL_i is the scale value of the student's initial knowledge level after the triangulation of all pretest measures. Correspondingly, the scale value of KL_f is the student's ending knowledge level after the triangulation of all posttest data. Within the treatment (the teaching unit), the students propose Tentative Theories (TT) and test, revise, and refine them by Critical

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MX means mixed knowledge level which uses dualist or pluralist categories, e.g., MS Protoscience/MS Prescience or MS Pseudoscience/MS Prescience/MS Protoscience.

MX Pseudo/Pre may be assigned a scale value of KL_1 or KL_2 depending on which knowledge level is dominant.
Discussion” (CD) which corresponds to Popper's trial (TT) and error elimination (EE) respectively. The end result is a measurement of the student’s knowledge growth (KG) or conceptual change. For example, if the student’s knowledge level was Pseudoscience (KL₁) in the pretest triangulation and Protoscience (KL₃) at the posttest triangulation, his knowledge growth or conceptual change is measured as follows.

Knowledge Growth Formula: KG = KL₂ - KL₁

Knowledge Growth = Post-treatment - Pre-treatment
triangulation        triangulation

Formula

KG = KL₂ - KL₁

Triangulation of KL

KG = KL₃ - KL₁

KG = 3 - 1

Knowledge Growth KG = 2

Using this formula, the conceptual change or knowledge growth of the students (N = 55) in this study is shown in Figure 18. Fifty five percent of the students showed no conceptual change or knowledge growth, forty-five percent experienced a positive conceptual change, and two percent demonstrated a negative conceptual change.

Critical discussion in the classroom is the dialogue and debate during the student’s informal presentations of ideas, understandings, and answers to science questions. However, reasons and evidence for all responses must also be offered and other students can respectfully challenge, counter, or support those explanations and warrants. Critical discussion in this study is a combination of Plato’s tether, e.g., knowledge requires right reasons and reasoning, and Popper’s inter-subjective testing, e.g., the testing, questioning, and debate of scientific ideas by the science community.

170
DTS6 Knowledge Growth Formula

DTS Students' Knowledge Continuum

<table>
<thead>
<tr>
<th>Pseudoscience</th>
<th>Prescience</th>
<th>Science</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metaphysics</td>
<td>Common-sense</td>
<td>Correct Science</td>
</tr>
<tr>
<td>Superstition</td>
<td>Everyday-Knowledge</td>
<td>Approaching</td>
</tr>
<tr>
<td>Religion</td>
<td>Misconceptions</td>
<td>Correct Science</td>
</tr>
<tr>
<td>(Popper, 1959;</td>
<td>(Popper, 1959;</td>
<td>(Popper, 1959;</td>
</tr>
<tr>
<td>Lipps, 1998)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

KNOWLEDGE GROWTH FORMULA

KL_{4} - TREATMENT - CRITICAL DISCUSSION - KL_{2}

KNOWLEDGE GROWTH (KG) = KL_{f} - KL_{i}

Figure 17. Deep Time Study's knowledge growth formula based on Popper's tetradic schema for growth of knowledge.

In Figure 17, KL means knowledge level and KG is knowledge growth. The knowledge levels pseudoscience, prescience, protoscience, and science are given the scale values of 1, 2, 3, and 4 respectively. The knowledge levels are based on the student knowledge continuum.
Summary

These findings illustrate the difficulty middle school students experience with the concept geologic time. The researcher posits this difficulty occurs because deep time entails a system of concepts of a system or misconceptions depending on the student knowledge level. However, the researcher argues geologic time is a logical precursor to the students' understanding of evolution concepts and therefore, a necessary concept in the middle school science curriculum. Many of the students (33%) have critical misconceptions about dinosaurs, yet dinosaurs form the core of their prescience knowledge (everyday-knowledge) about geologic time. All data analyses indicate the Prescience category (secular misconceptions) dominates student
understanding of geologic time in the sixth grade. The prescience category is characterized by a ubiquitous dinosaur focus and trivial knowledge about dinosaurs.

The knowledge levels which emerged in this study (1) provide the framework of the student's knowledge, (2) are the student's personal theory used to understand geologic time, and (3) define the student's epistemology, that is, what evidence and warrants count as knowledge and what evidence and warrants are disregarded or ignored. Popper's definition of theories also describes how the students' knowledge levels function in their understanding of geologic time.

Theories are nets cast to catch what we call 'the world': to rationalize, to explain, and to master it. We endeavor to make the mesh ever finer and finer (Popper, 1959, p. 59).

**Case Study Findings**

**Geologic Time**

The case study results indicate that quantitative time and some understanding of number (e.g., millions and billions) provide the framework for student's thinking about geologic time. The researcher argues that the development of an understanding of the quantitative and qualitative time of these geologic time-events, that is, the formation of earth, dinosaur extinction, and appearance of prehistoric humans, is an important heuristic for students to manipulate their thinking about deep time. This viable understanding entails the chronological ordering of events, an understanding of the relationship (before-after) between some key events in geologic time, and an awareness of change-over-long-periods-of-time (e.g., change in the earth,
plants, and animals). It allows students to construct a clear schema or personal theory about the natural history of the earth and life on earth. Therefore, time itself (e.g., both quantitative and qualitative geologic time) becomes a necessary framework or organizing concept for students' understanding of deep time.

**Conceptual Nets**

The case study students provided an in-depth view of the knowledge levels or conceptual nets that emerged in this study, e.g., pseudoscience, prescience, protoscience, and science. The researcher discovered that, in addition to these broad conceptual nets, each student also used ever finer, idiosyncratic nets to 'catch' information about geologic time. In this study, the students wrestled with these recursive subconcept-themes in their thinking about geologic time: extinction, the fossil record, humans in geologic time, evolve, genes and the process of inheritance, and the struggle for survival. Some subconcept nets allowed fruitful student thinking; others became conceptual traps from which the student's thinking could not escape.

Nevertheless, the most limiting factors to student thinking were the broad conceptual nets of misconceptions, specifically prescience (dinosaur focus) or pseudoscience (religious explanations). These were the most constraining to a student's thinking because they entail not just one misconception, but a system of misconceptions about geologic time.

**Knowledge and Belief**

In attempting to understand the student's construction of knowledge about the origins of the earth and life on
earth, the researcher selected and/or designed the study's instruments based on Plato's tether. Nola (1997) explains that Plato's definition of knowledge puts "some objective constraints" on what can be accepted as right or true knowledge and that "not all ideas constitute knowledge." Nola argues, and the researcher agrees, that in science and science education "right reasons and reasoning" are required to produce right knowledge" (pp. 57-61).

To achieve this, the researcher not only examined the individual's ideas, but also explored his or her reasons and evidence to support his/her assertions. These methods investigated the students' reasons and reasoning about the deep-seated epistemological issues entailed in the concept deep time.

**Interface of Science and Religion**

The researcher was confident that the study instruments provided a penetrating understanding of student thinking in the large group data collection and analysis. However, the case study findings disclosed yet another level of student thinking about these two epistemologically divergent worldviews, that is, the scientific and religious explanations of the formation of the earth and life on earth. Shipman, Brickhouse, Dagher, & Letts (1999, p. 8), in their research on the dialogue between science and religion in a university classroom (N =340), found that whole class data could not really determine what students

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Plato's definition of knowledge is illustrated by the following propositions. $A$ is some person. $p$ is the content of a belief held by $A$. $A$ knows that $p = \text{Defn.}$ if 1) $p$ is true (Truth Condition); $A$ believes that $p$ (Belief Condition); and 3) $A$ has a tethering reason (justification, evidence) for $p$ (Justification Condition). (Nola, 1997, pp. 57-61).
thought about the science/religion issue. This researcher does not agree. She argues that both knowledge of the group and the individual are necessary to assess the students' understanding. The analysis of the large group data defines and describes the students' knowledge, and the thick description of case study data elaborates and refines the large group findings.

The case study students' self-report on how they perceive their own thinking revealed that some students used a very different method of understanding the science/religion conflict than the large group study indicated. The manner students handled the competing explanations of religious and science ideas was, in most cases, not a concise application of confrontational, distinct, or convergence approaches as the empirical data, (e.g. large group data) demonstrated. More often, the student report revealed that he used a dualist approach, an integration of distinct and convergence approaches or distinct and confrontational approaches. The exception was the Pseudoscientist. Her responses on the formal study measures (e.g., the concept evaluation statement) corresponded to how she privately thought. She successfully used the distinct approach both in the classroom and in her private thinking. Dr. Lorna Holtman (personal communication, January 25, 2001) commented on dualist thinking in her recent study of college students' understanding of evolution concepts (Holtman, 2000). She said, "...confrontational and divergent [approaches] were the extremes of those students who were "fighting" evolution. Convergence was common among those who wanted to
reconcile, hence they were in essence "dualists"... My convergent thinkers were really your dualists and ...this was quite common in my study."

The DTS6 study found two levels, public and private, in a student's thinking about the events in geologic time. The researcher found an empirical level of thought. A public, outer world of student thought and understanding detectable through careful observation and measurement. Later, she uncovered a private, inner world of thought which the empirical data do not indicate. The inner world of thought was unquestionably revealed by the student's self-report and the researcher's post-study interviews. However, it was sometimes disclosed or suggested from student's Concept Evaluation Statement drawing and justification and the student's reasons and evidence in the open-ended responses on the Geologic Timeline Survey.

This indicates to the researcher that the strategy which emerged in the classroom and which the case study students successfully applied was a demarcation between science and religious explanations of the events in geologic time. This occurred spontaneously without the teacher specifically articulating or even suggesting a demarcation between science and religion. Therefore at the public

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*Empirical level of thought is public, observable student thinking. The assimilating mode of concept development.

*Inner level of thought is private, personal student thinking. The accommodating mode of concept development.
thinking level, the students were able to assimilate \textsuperscript{5} science explanations of the natural history of the earth and the development of life on earth to varying degrees. As a classroom teacher, the author was able to achieve her teaching goal, that is, for students to begin to develop an understanding of the scientific explanation of the events in geologic time, though not necessarily a belief in their truth. The research literature is replete with studies that establish the difficulty students, from the primary school to the university level, experience revolving around the science/religion conflict about the development of the earth and life on earth (Bishop & Anderson, 1990; Demastes, Good, & Peebles, 1994; Demastes, Settlage, & Good, 1995; Jackson, Meadows, & Wood, 1995; Dagher & BouJaoude, 1997; Samarapungavan & Wiers, 1997; Loving & Foster, 1997; Shipman, Brickhouse, Dagher, & Letts, 1999; Holtman, 2000). This researcher agrees that the science/religion argument is problematic.

However, the DTS6 students' natural construction and application of a demarcation between science and religion begs the question \textbf{How did these sixth grade students avoid the conceptual trap of the science/religion conflict?} The researcher suggests, in this study, three factors

\textsuperscript{5} I am using assimilate to describe knowledge acquisition in the sense of Piaget's equilibration theory. Although I realize Piaget states the processes of assimilation and accommodation occur together (Lawson, 1994, p. 139), I am separating them for the sake of clarity in this discussion. Therefore, assimilate or assimilation describes student thinking which is the "taking in" of things/ideas and accommodation is the mental reorganization process required to achieve equilibration/equilibrium" (R. Good in personal communication February 20, 2001). Accommodation or accommodate describes the student who has completed the process of assimilation and has successfully integrated these new structures into his conceptual schema.
contributed to this outcome: (1) the science curriculum, (2) the teacher's philosophy, and (3) the teaching method, that is, respectively the topic geologic time, the teacher as a facilitator of knowledge, and critical classroom discussion. These components obtusely developed critical thinking and required a demarcation between ideas.

However, the case study data reveal that on the private and personal thinking level, the demarcation between science and religious explanations were blurred. As a science educator, the author has nothing to say about personal beliefs or interpretations which did not appear within the classroom situation during the study (e.g., students' drawings, writings, and critical discussions). The author reminds the reader that the private level of student thinking was revealed in the post-study interviews one year later. As a researcher, she thinks the students' dualist approach to understanding geologic time may warrant further investigation of how students attempt to accommodate science concepts at the private thinking level. However, she questions the validity of investigating private thinking which did not emerge in the study setting. As a result of the study findings, the teacher/researcher supports the science education community's position that a demarcation between science and religion is necessary in the science classroom. Further, she suggests that in the middle school

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5 Geologic time, although an abstract time concept, offers a very concrete presentation of the evidence of the natural history of the earth and the development of life on earth.

*Critical classroom discussion is a public forum where to present answers and ideas, the students must also present their reasons and reasoning about the ideas presented. This method is based on Plato's tether and Popper's inter-subjective testing in the community of scientists.
science classroom, the conflict between science and religion is mediated by the teacher. Her or his philosophy, presentation, and methodology creates a positive or negative attitude toward learning new and different explanations of the natural history of the earth and the development of life on earth. This study found the middle school students were at least curious and at most open to science explanations of these topics. Perhaps, early middle school is the most fruitful time to present this controversial topic to school students because they are the most receptive to new and challenging ideas, that is, they are more open and the least resistant.

Finally, the case studies established that religion and certain religious affiliations do not necessarily indicate fundamental creationist thinking or result in difficulty or resistance to understanding events in geologic time and evolution concepts as some researchers have suggested.

Well-established religious belief systems, which may conflict with scientific theories ...are examples of prior knowledge in the form of internally coherent "alternative frameworks" that can be extremely resistant to change (Jackson et al. 1995, p. 587).

To the contrary, this study indicates that southern religion does not prevent students from understanding geologic time concepts. All of the students in the case studies reported that they were religious and that their religious teachings did not prevent them from being curious and learning about the science explanation of deep time. A more troubling understanding of geologic time was fostered by the education community itself in the dinosaur misconceptions of the MS Prescientists (33%). Nonetheless,
the problem the post-study interviews did reveal related to science/religion issue was that the students did not question their religious teachings in the same manner that they question science - if they question those teachings at all. That is, they did not ask the skeptic's question, "Can you prove it?" and did not ask causal questions or propose alternative hypotheses. All the students participated in critical discussions and tests of science explanations, yet three out of the four did not apply the same critical discussions and tests to the religious explanations of geologic time. However, at their private thinking level, they granted equal status and validity to the religious explanation of geologic time-events as the science explanations.

Implications

This study carries implications for all stakeholders in the science education community and contributes to theory, methodology, and curriculum design. The study discovered a pattern of student thinking about geologic time and the associated misconceptions in both the large group analysis and case study findings. It also illustrates the importance of employing a systematic examination of the student's personal theory about geologic time - a holistic picture of student thinking. The researcher asserts that the study clearly demonstrates the rich data and understanding of the topic which results from examining the student's web of conceptual systems.

The findings carry several other important implications for research community. First, this study suggests researchers should look at the big picture - the whole of
students' understanding of a science topic, not just the parts. A pragmatist research paradigm which uses narrative modal profiles that combine quantitative and qualitative data is well suited for this type of holistic research. Wandersee et al. (1994) guide the science education research community to a pragmatist research paradigm which employs a "nomothetic (science-centered) research dimension" and an "idiographic (personal knowledge-centered) research dimension." He further comments, "We see a place for both kinds of research...an emerging synergy" (p. 180). A mixed model study design, according to Holtman, offers a "refreshing way to analyze and present data." (L. Holtman, personal communication, December 10, 2000).

Finally, this study finds the use of dinosaurs in science teaching and the science curriculum problematic. Dinosaurs are a high-profile, high-interest vertebrate animal in the field of education and have become a cultural icon in American society. Gould (1991, p. 78) rightly calls it dinomania. The findings of this study suggest the use of dinosaurs in science teaching is an overused topic in the primary and middle schools. The students' use of a dinosaur theory to explain geologic time frames their thinking with a narrow understanding which is burdened with misconceptions and a limited awareness of the big picture - other great stories of the natural history of earth and the evolution of life. In light of this, the researcher argues dinosaurs, as a glamour-science topic, should be used judiciously - if at all - by science educators. The story of the dinosaur, bound in geologic time, is only one great evolutionary story. The author asserts that it has been over told.
Many equally fascinating evolutionary stories can and should be presented to middle school students, e.g., the evolution of the camera-type eye, the evolution of the modern-day horse, or the great extinctions in geologic time.

In conclusion, the teacher/researcher argues that the study indicates that as science educators, we must be very cautious that our pedagogy does not produce trivial explanations for the magnificence of the formation of the earth and life on earth as evidenced by the deep-seated dinosaur misconceptions.

Future Research

The researcher recommends the replication of this study in other regions and grade levels to test the study’s findings: (1) the Geologic Time Knowledge Continuum, e.g., middle school students’ natural thinking patterns about deep time, (2) the Knowledge Growth or Conceptual Change Formula, (3) students’ public and private thinking about the interface of science and religion in reference to geologic time, and (4) refinement of the pragmatic research paradigm, e.g., the mixed model study design with narrative modal profiles.
REFERENCES


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Kansas pro-creationists lose school board seats. (2000, Nov. 25). *Saturday State-Times/Morning Advocate*, p. 2F.


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APPENDIX B

GEOLOGIC TIMELINE SURVEY

Name: ____________________ Age: _____ Gender: M F
Date: ____________________ Class: ____________

Part I: Student directions. 1. Write the letter of each event on the timeline at the time you think it occurred. 2. In the space under each question, completely explain your reasons or evidence for placing the event at that point-in-time. Please use complete sentences.

In the history of the deep time, when did the following events occur:

a) When did first plants appear on land?
   Evidence: ____________________________________________
   __________________________________________________

b) When did the universe form?
   Evidence: ____________________________________________
   __________________________________________________

c) When did dinosaurs first appear on earth?
   Evidence: ____________________________________________
   __________________________________________________

d) When did they disappear?
   Evidence: ____________________________________________
   __________________________________________________

e) When did the earth form?
   Evidence: ____________________________________________
   __________________________________________________

f) When did prehistoric humans first appear?
   Evidence: ____________________________________________
   __________________________________________________

g) When did the first vertebrate animals (animals with a backbone) appear on land?
   Evidence: ____________________________________________
   __________________________________________________
APPENDIX C

CONCEPT EVALUATION STATEMENT

Name:__________________ Date:______________

Part II: The word protozoan is Greek for "first animal". What was the first animal to appear on earth and what did it look like?

Draw a picture of the "first animal" to appear on earth. Write a paragraph or two explaining your animal, its living habits, and environment. Provide reasons and evidence to back up your drawing.

Drawing:

______________________________
Paragraph:
APPENDIX D

EARTH SCIENCE TEST

Subset of Earth Science test questions used in DTS-6 taken from Phillips (1992) Middle School Test of Earth Science Misconceptions. The number of the subset test items is the number that appears in the Phillips' test.

1. The earth’s age can most easily be measured in:
   a. Thousands of years.
   b. Millions of years.
   c. Billions of years.*
   d. Trillions of years.
   e. I have no idea.

3. All mountains now in existence developed:
   a. At the time the earth formed.
   b. Soon after the earth formed.
   c. Long after the earth formed.*
   d. Scientist have no way of learning when these mountains first appeared.
   e. I have no idea.

5. Which of the following statements is most likely true about soil?
   a. Most of the soil we see today formed when the earth formed.
   b. Soils were formed by ancient farmers in order to grow crops.
   c. The earth is always producing material for new soil.*
   d. Scientist have no way of learning when soil formed or where it came from.
   e. I have no idea.

7. Which of the following statements is most likely true about the earth’s atmosphere?
   The atmosphere:
   a. Contained enough oxygen to keep mammals alive when the earth formed.
   b. Did not contain enough oxygen to keep mammals alive until soon after the earth formed.
   c. Did not have enough oxygen to keep mammals alive until long after the first life appeared.*
   d. Scientists have no way of learning what the atmosphere was like before mammals appeared on earth.
   e. I have no idea.

** Indicates the correct answer.

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10. **Radioactive dating shows that the oldest human fossil ever found is exactly.**
   a. 5,642 years old.
   b. 55,642 years old.
   c. 555,642 years old.
   d. Scientists have no way of learning the exact age of the oldest human fossil.*
   e. I have no idea.

11. **Which of the following statements about dinosaurs is most likely true?**
   a. Dinosaurs became extinct long before humans appeared on earth.*
   b. Humans developed weapons just before dinosaurs became extinct.
   c. Although cavemen hunted dinosaurs, they did not make them extinct.
   d. Scientists have no way of learning if humans and dinosaurs lived at the same time.
   e. I have no idea.

12. **Fossils indicate that life formed on earth**
   a. At the same time the earth formed.
   b. Within the first million years after the earth formed.
   c. About a billion years after the earth formed.*
   d. Scientists have no way of learning when life first appeared.
   e. I do not know.

15. **Our solar system was probably formed**
   a. When the universe formed.
   b. Soon after the universe formed.
   c. Many billion years after the universe formed.*
   d. Astronomers have no way of learning when the solar system formed.
   e. I have no idea.

19. **Most astronomers believe that the universe**
   a. Has always been here & has no definite beginning.
   b. Formed from a huge explosion & has been changing ever since.*
   c. Formed with all the planets, stars, & galaxies at the same time.
   d. Astronomers have no way of learning when or how the universe began.
   e. I have no idea.
APPENDIX E

EVOLUTION TEST


1. Of all the species of animals that ever lived on earth, what percentage do you think have become extinct?
   a. 99% *
   b. 75%
   c. 50%
   d. 25%
   e. 1%

2. The reason for my answer in (1) is because
   a. The early dinosaurs and many other organisms that lived during that epoch went extinct.
   b. Most organisms have a difficult time adapting to environmental change and the earth has been changing for millions of years.*
   c. Humans are changing the environment dramatically and that is causing the extinction of many species.
   d. Most organisms don’t go extinct - they evolve into a different type.
   e. Scientists make claims but they cannot back them up.

3. After each mass extinction, new types of organisms develop because of
   a. Genetic variation in the surviving organisms.
   b. Differences in the environment compared to past environments.
   c. The unique combination of populations present at that time.
   d. The relatively great opportunities provided by man unfilled niches.
   e. All of the above. *

4. A species is best illustrated or described by
   a. Mus musculus, a type of mouse.
   b. A group of closely related individuals in a given geographical area.
   c. All the organisms in the world that are of a given closely-related genetic type and capable of interbreeding with one another.*
   d. (a) & (b)
   e. (a) & (c)
5. If a cow for many successive generations had its tail cut off at birth, eventually there would be a time when cows would be born without tails.
   a. True
   b. False *

6. The reason for my answer to (5) is
   a. Acquired traits are not generally inherited.*
   b. Eventually the population would adapt.
   c. Organs and other parts of organisms which are not used tend to atrophy and gradually disappear.

7. One reason why dinosaurs became extinct is that early humans hunted them for food.
   a. True
   b. False *

8. The reason for my answer in (7) is
   a. Humans and dinosaurs did not live on the earth at the same time.*
   b. Humans were too small to have much impact - other dinosaurs did more harm.
   c. Humans may have contributed to dinosaur deaths but a large meteorite that hit earth did much more damage.
   d. Humans did challenge dinosaurs but the volcanic eruptions of the time were even more lethal to dinosaurs.
   e. (b), (c), & (d)

11. Which of the statements below is more scientifically correct?
   a. Organisms evolve so that they are perfectly suited to their environment.
   b. Organisms evolve so as to become well-suited to their environment.*
   c. Organisms don't really change over time.

12. The reason for my answer in (11) is
   a. Each species of organism remains the same over time, and new species may arise.
   b. Evolution is a steady progression toward ever higher degrees of perfection.
   c. Organisms can never become perfectly adapted to their environment in part because the environment keeps changing.*
   d. There is a constancy within each species.

Cave salamanders are blind. These salamanders have eyes, but their eyes are nonfunctional.
23. By what mechanism do you think blindness most likely first appeared in cave salamanders?

a. Random error in germ cell DNA.*
b. Gradual decrease in sight in all cave salamanders do to living in dark.
c. Loss of sight due to lack of need.
d. (b) and (c)

24. By what mechanism do you think blindness became established in the cave salamander population?

a. Salamanders didn’t need to see and so didn’t mind being blind.
b. Salamanders couldn’t survive in the caves unless they were blind.
c. Blindness was either an evolutionary neutral or favorable mutation. *
d. The dark environment caused the change - perhaps due to disease.
e. (a) & (b)

30. Which of the number below represent the best estimate of the age of the earth?

a. 10,000 years.
b. One million years.
c. One billion years.
d. 4.5 billion years.*
e. One trillion years.

31. The reason for my answer in (30) is because

a. Based on tectonic plate theory.
b. Derived from the theory of the Big Bang.
c. Based mainly upon radioactive dating of rock formations.*
d. Derived from the fossil record.

35. The term extinction in neo-Darwinian theory usually refers to

a. The death of all members of a local population of organisms.
b. The death of every member of a species.
c. The death of a group of organisms being studied.
d. The loss of a given type of organism from the face of the earth.
e. (b) & (d) *
APPENDIX F

DTS-6 POST-STUDY INTERVIEW QUESTIONS

Interview 1 (5/22/00)

1. Describe the first prehistoric human.
2. How did they get on earth?
3. What does 0 on the Geologic Timeline mean?
4. What does mya" mean (as a unit)? bya"?
5. Did you understand the geologic timeline?
6. What is the difference between mya & bya?
7. How did plants and animals get on earth?
8. How do you think animals change over time?
9. Is geologic time talking about a short period of time, a long period of time, or a very long period of time? Explain.
10. If you used dinosaurs to explain how things happened in geologic time, explain how that helped your thinking. How did that help you think about geologic time?

Interview 2 (5/25/00)

1. Do you consider yourself religious?
2. How often do you attend religious services?
3. How often do you say grace at meals?
4. How often do you pray privately?
5. The ideas of science and religion use two different points-of-view to explain the formation of the earth and the development of life on earth. How do you deal with those two points-of-view?
6. If you had to choose between the religious explanation and scientific explanation of the formation of the earth, and life on earth, which would you choose? Why?
7. Does the religious beliefs interfere with your understanding the scientific explanation?
8. Did you learn about geologic time or evolution concepts in science this year (7th grade)?
9. When you think about geologic time (mya, bya), what is the first thing that comes to your mind?

"mya = million years ago.
"bya = billion years ago."
APPENDIX G

GROUP ANALYSIS OF STUDENT GEOLOGIC TIMELINE RESPONSES

Study: __________ Location: __________ Date: ______

N = ______

Analysis of Student Responses:
Main Category: ___ MS Scientist; ___ MS Protoscientist;
___ MS Mixed Concepts; ___ MS Prescientist;
___ MS Pseudoscientist ___ MS No Cat

Descriptive Statistics:
Main Category: MS Scientist N = ____ PCT ____ Avg. Age. ____
Gender: Male N = ___ PCT ___ Female N = ___ PCT ___

Main Category: MS Protoscientist N = ____ PCT ____ Avg. Ag. ____
Gender: Male N = ___ PCT ___ Female N = ___ PCT ___

Main Category: MS Prescientist N = ____ PCT ____ Avg. Age. ____
Gender: Male N = ___ PCT ___ Female N = ___ PCT ___

Main Category: MS Pseudoscientist N = ____ PCT ____ Avg. Ag. ____
Gender: Male N = ___ PCT ___ Female N = ___ PCT ___

Main Category: MS MX Concepts N = ____ PCT ____ Avg. Age. ____
Gender: Male N = ___ PCT ___ Female N = ___ PCT ___

Subcategory within main category:
1) Organizing concept in student thinking about personal theories of geologic time.
Organizing Concept Number of STD: PCT of STD:
Dinosaur focus

Plant focus (plants support life)

Human needs

Support life (plants, animals, earth)

Time (sequential time)

Evolutionary Time
(change over time)

Special Creation

Taught in school
I think or I know

MX means mixed concepts, e.g., dualist or pluralist.
APPENDIX H

INDIVIDUAL ANALYSIS OF STUDENT GEOLOGIC TIMELINE RESPONSES

Study: ______________ Location: ______________ Date: ______
N = ____  Researcher: ______________ Phone: ____________

Student Information: Name: _______________ Age: ___
Gender: ___ Race: ___ Grade: ___

Analysis of Student Responses:
Main Category: ___ MS Scientist; ___ MS Protoscientist;
___ MS Prescientist; ___ MS Pseudoscientist; ___ MS MX Concept

A. Main Category: ____________________________

B. Subcategory within main category ______________:
   1) Organizing principle in student thinking about personal
      theories of geologic time.
      __ Dinosaur focus; ___ Plant focus (plants started it all:
         food, O₂, support life);
      ___ Human focus (human needs); ___ Support life focus
         (plants and animals needed to
         support life);
      ___ Time (sequential time); ___ Evolutionary time;
      ___ Relational time (before/after) ___ Special Creation;
      ___ Taught in school; ___ Other_______________________.

   2) Understanding of 3 key events in natural history of
      earth (focused on in the elementary (3-4) and middle
      school (5-8) curriculum.
      Main Category: ____________________________
      [4.6 bya] earth formed: ____________________________
      [65 mya] Dino EXT: ______________________________
      [1-2 mya] Prehistoric humans appeared: _______

   3) Vocabulary used:
      Main Category: ____________________________
4) Personal Geologic Time Scale: Main Category: 
Name: ________________ Date: ________ Age: _____

Time begins Gender: _____ Class: _____
  15 bya
  10 bya
  5 bya
  1 bya
  500 mya
  245 mya
  65 mya
  25 mya
  10 mya
  5 mya
  1 mya
  500 tya
  100 tya
  50 tya
  10 tya
  5 tya
  1 tya
  500 ya
  Present

D) Misconceptions:

E) Drawing Analysis: Main Category: ________________
   Subcategory: ________________

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APPENDIX I

CRITERIA FOR CATEGORIES OF STUDENT THINKING ABOUT GEOLOGIC TIME

**MS Scientist Category**

The criteria for the MS Scientist category are accurate science knowledge as evidenced by placing one or two of the three index time-events within the accepted time range on the geologic timeline and reasonable science-based answers on the open-ended responses. Science-based answers are demonstrated by accurate science content knowledge, correct use of science vocabulary, a reasoned response, sound justification of answers, and correct placement of events on the timeline. MS Scientists used some or all forms of time: Sequential Time, Relational Time, and Evolutionary Time as an organizing concept (OC). An organizing concept is the framework the student uses to organize his/her thoughts about deep time. The MS Scientist is able to make the intellectual leap to posit the single cell as the first animal.

**MS Protoscientist Category**

The MS Protoscientist category does not consider student’s placement of index time-events on the timeline as part of the criteria. Time is only considered if it appears as a warrant in the student’s written responses. MS Protoscientists’ thinking about the natural history of the earth and life on earth is approaching the understanding of currently accepted scientific thinking. The students may use some specific scientific language and some correct science vocabulary (Lee, et al. 1995). These students used
three main organizing concepts, Evolutionary Time, Relational Time, and Dinosaur Focus. These student are not able to imagine the single cell as the first animal.

**MS Prescientist Category**

The prescientist category was composed of the students with secular misconceptions about the natural history of the earth and life on earth. These students either did not use science vocabulary or used the scientific language but did not understand the meaning of the terms. Correct placement of index time-events on the timeline was not part of this criteria. MS Prescientists' OC were Dinosaur Focus, Sequential Time, and Anthropocentric (Humans) Focus.

**MS Pseudoscientist Category**

The criteria for the MS Pseudoscientist category were in the student's justifications of the timeline events and the written defense of CES (drawings), the student used the words God, Bible, religious teachings, or some other direct reference to the Judeo-Christian-Moslem creation story to explain the events in the natural history of the earth. Special creation could neither be implied nor inferred but had to be explicitly stated in the written response. This group did not use science vocabulary and used incorrect science knowledge. MS Pseudoscientists used God Created, Special Creation for Humans, and 6-day Creation as organizing concepts. Placement of the index time-event on the timeline was not included in the criteria.

**MS Mixed Concepts, Dualist or Pluralist**

A mixed concept or dual construction category (Demastes, 1994) was incorporated into the study. These
students indiscriminately mixed evolution or cosmology science concepts with creationist beliefs. In addition, they employed very conflated interpretations and misconceptions of both science and religious concepts to explain the natural history of the earth and the development of life. Their organizing concepts were Evolutionary Time and 6-day Creation, Evolutionary Time and God Created, and Dinosaur Focus, Big Bang and Special Creation for Humans.
APPENDIX J

MODAL PROFILE TEMPLATE

1. Classification criteria for placement in each category from typology.

2. Descriptive statistics for each category: Percentage of students in each category, male/female, average age, top three organizing concepts for group.

3. Description of average student in each group.

4. Composite answers for time-events on geologic timeline and most frequent responses in each category.

5. Excerpts from student interviews: Content analysis of student interviews.
APPENDIX K
FLOWCHART OF TIMELINE OF STUDY

Conceptualize Research:
Research Questions
Design Instruments
Spring 98

Apply IRB Exemption
June 98

Science Research Expedition
Hemipilian Megafauna Mexico
July 98

Whole Class Pretest: Deep Time Survey and Earth Science Content Knowledge
Jan. 00

Action Research in Teacher/Researcher's Classroom
Purposeful sampling Fall 99

Pilot Study: Field-test Instruments
Revise Instruments
Analyze Data: Develop categories & Modal Profiles Fall 99

Teach Precursor Concepts:
Solar System
States of Matter
Types of Rocks & Rock Cycle
Acids/Bases Spring 00

Analyze Data
Select Case Studies
Invite students to Participate
Assent and Consent Forms
April 00

Whole-class Treatment:
Teach Geologic Time Concepts:
Activity 1: Classify Animal/Not Animal
Activity 2: Lecture-
(a) Characteristics Plants/Animals
(b) Plant/Animal Cells
Activity 3: Video-
Mary Anning (fossil hunting)
Activity 4: Construct Geologic Timeline
Activity 5: Video-
Prehistoric Life
Activity 6: Animals Change Over Time (Speciation)
April 00

Whole Class Posttest
Deep Time Survey and Earth Science Content Knowledge Test
May 00

Case Study Activities:
Pre/post Treatment Word Lists
Clinical Interviews:
(1) Prehistoric Animal Picture Cards - Student's story: How Life Developed on Earth
(2) Fossils and Geologic Timeline
(3) Fossil record - How Species Change Over Time
Journals and Drawings
Analyze Data May 00

Analyze Data
QUAN: Descriptive Statistics
QUAL: Constant Comparative
Write Dissertation
00

Walk Through Geologic Time
May 00

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APPENDIX L

TEACHER'S PROFESSIONAL GOALS

Professional Growth Plan 1998-99 (Ascension Parish)
Written 9-25-98

I. Objective: What area do you want to strengthen?

1) Organize my 6th grade science curriculum in the framework of geologic time

II. Rationale: Why do you want to strengthen this area?

1) Geologic time/earth history and life science are a major focus of the sixth grade curriculum.

2) National Science Standards and regional and state Science Standards has as goals for students to develop the necessary skills to do science inquiry.

III. What is your Plan of Action and Timeline?

1) Sept. Organize science concepts corresponding to/interfacing with geologic time events.

Oct.-May: Develop and use the timeline as an organizing framework for teaching throughout the year.

IV. What Criteria will you use to evaluate your Professional Growth Plan?

1) Teaching concept organized in the framework of geologic time.

2) Develop a timeline for a visual cue for the correlation of geologic time and the science curriculum: earth history, fossils, and history of life on earth.
### APPENDIX M

**TEACHER LESSON PLAN BOOK**

| Jan. | 6   | Solar System Unit            |
|      | 12  | Scale Model of Solar System  |
|      | 19  | Student give Geologic Time Survey - pretest |
|      | 26  | CES First animal drawing - pretest |

|      | 24  | Learn about Louisiana rocks. earth Stuff Define Louisiana rocks. |

| Mar. | 1   | Discuss rocks and minerals of Louisiana IOWA Tests |
|      | 15  | "SEPUP LAB Defining a Solution Forming a Solution |
|      | 16  | "Do SEPUP LAB |
|      | 17  | Identifying Acid/Bases Lab |
|      | 18  | Parts per million SEPUP serial dilution |
|      | 22  | Combining Different Liquids SEPUP lab |

<p>| Apr. | 7   | &quot;Big Ideas&quot; about acids and bases. |
|      | 8   | Classifying animals Prepare group chart Animals/ Not Animals |
|      | 9   | Present charts to class. Journal entry: What is an animal? Video: On animals. |
|      | 12  | Identify the characteristics of an animal. Journal: Based on last week’s activity What is an animal? |
|      | 14  | Discuss the characteristics of plants and animals. Student read from journals. Discuss characteristic plants/animals. Transparencies. Read Text: Pp. S36-S42. |
|      | 19  | Copy &amp; draw the animal and plant cells. Begin Geologic Timeline 4 and 1/2 meters of adding machine tape. Divide into 50 mm intervals. 1 millimeter = 1 million years. |</p>
<table>
<thead>
<tr>
<th>Apr.</th>
<th>20</th>
</tr>
</thead>
<tbody>
<tr>
<td>Video: Eyewitness Prehistoric Life (35 min.)</td>
<td></td>
</tr>
<tr>
<td>Reflect on species change over deep time.</td>
<td></td>
</tr>
<tr>
<td>Journal: What happened to the different species of animals over billions or millions of years of earth time? Give evidence and examples.</td>
<td></td>
</tr>
<tr>
<td>26</td>
<td></td>
</tr>
<tr>
<td>Work on geologic timeline</td>
<td></td>
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<tr>
<td>27</td>
<td></td>
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<tr>
<td>Complete geologic timeline.</td>
<td></td>
</tr>
<tr>
<td>29</td>
<td></td>
</tr>
<tr>
<td>Journal: What does the geologic timeline tell you about the development of life on earth? Give examples and evidence.</td>
<td></td>
</tr>
<tr>
<td>May</td>
<td>3</td>
</tr>
<tr>
<td>Group animals according to changes.</td>
<td></td>
</tr>
<tr>
<td>Species cards.</td>
<td></td>
</tr>
<tr>
<td>Set up lab in Journal.</td>
<td></td>
</tr>
<tr>
<td>Problem: Group animals according to their characteristics.</td>
<td></td>
</tr>
<tr>
<td>Journal: What happened to the two groups of animals over time? Give examples and evidence.</td>
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<tr>
<td>4</td>
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</tr>
<tr>
<td>Pretest-Word List: List all the words you know about or related to: Geologic time.</td>
<td></td>
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<tr>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Geologic Time Wizard: Experience Walk through Geologic Time.</td>
<td></td>
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<tr>
<td>Journal: Describe what you learned from the Walk through Geologic Time.</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td></td>
</tr>
<tr>
<td>Posttest-Word List: List all the words you know about or related to: Geologic Time.</td>
<td></td>
</tr>
</tbody>
</table>
APPENDIX N

A WALK THROUGH GEOLOGIC TIME

15 bya  Big Bang

5,000 mya  SUN ignites

4,600 mya  Earth forms

- 5-hour days, moon appears 20 times larger (400x area)
- Earth’s CRUST forms
- VOLCANOES ERUPT
- ATMOSPHERE accumulates

4,000 mya  PREBIOTIC SOUP of organic molecules

- SURFACE cools
- RAIN falls, oceans form, EROSION occurs, RIVERS form
- CELLS form, enclosing organic system

3,500 mya  LIFE BEGINS with present genetic code, DNA-to-RNA-to-protein

- Continents form from accumulated lava sinks.

3,000 mya  CRUST now stable enough to hold heavy sediments, lava, without sinking

- CONTINENTS GROW
- MOUNTAIN BUILDING starts

2,500 mya  BACTERIA begin PHOTOSYNTHESIS, OXYGEN released

- RUSTING occurs

1,800 mya  OXYGEN ATMOSPHERE finished

SIMPLE CELLS proliferate

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*This activity is based on Calvin’s work (1996, pp. 248-256) and made up the geologic time scale around the perimeter of the wall in the classroom.*
1,300 mya  SUPER CELL (Eukaryote) evolves between 2,000 and 1,300 million years ago

Appalachian and Caledonian mountain ranges push up

1,000 mya  SUPER CELL SEX begins

20-hour days, moon appears twice present size

680 mya  Jellyfish

570 mya  CAMBRIAN EXPLOSION

500 mya  Jawless fish

400 mya  Land plants, followed by spiders
           Amphibian comes ashore in Greenland

340 mya  Reptiles

225 mya  PERMIAN EXTINCTION

200 mya  Birds
           Dinosaur Days

65 mya  CRETACEOUS EXTINCTION
           Mammals take over

50 mya  Monkeys

2 mya  Homo habilis ICE AGE CLIMATE
           Toolmaking, brain size increase

100,000 ya  Neanderthals and modern-type Homo sapiens appear

           Ice Age oscillations in climate

10,000 ya  LAST ICE AGE ends, agriculture

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APPENDIX O

IRB EXEMPTION

HSSC accession #: ________ LSU Proposal #: ________
LSU Office of Sponsored Research/OSR 388-6891; FAX 6792
LSU: HUMAN RESEARCH SUBJECTS

APPLICATION FOR EXEMPTION FROM INSTITUTIONAL OVERSIGHT

Unless they are formally qualified as meeting the criteria for exemption from Institutional Review Board (IRB) oversight, ALL LSU research/projects using living humans as subjects, or samples or data obtained from them, directly or indirectly, with or without their consent, must be approved in advance by the LSU IRB. This form helps the PI determine if a project may be exempted, and is used to request an exemption.

NOTE: Even when exempted, the researcher is required to exercise prudent practice in protecting the interests of research subjects, obtain informed consent if appropriate, and must conform to the Ethical Principles and Guidelines for the Protection of Human Subjects (Belmont Report) and LSU Guide to Informed Consent; (Available from OSR or http://www.osr.lsu.edu/osr/comply.html).

Instructions: Complete checklist, pp 2-4; if exemption appears possible, follow instructions on p. 4. Otherwise apply to the IRB.*

Principal Investigator Lee Noonan Student? [ ]
Department/Unit Curriculum and Instruction Ph: 545-4059
Project Title Deep Time Study
Agency expected to fund project ________________________________
Subject pool (eg. Psychology students) Middle School 5-9 students
Circle any "vulnerable populations" to be used: [ ]children <18/ the mentally impaired, pregnant women, the aged, others). Projects with incarcerated persons cannot be exempted: apply directly to IRB.

I certify my responses are accurate and complete. If the project scope or design is later changed I will resubmit for review. I will obtain written approval from the Authorized Representative of all non-LSU institutions in which the study is conducted.

PI Signature Lee Noonan Date 6/15/99 (no per signatures)
Screening Committee Action: Exempted Not Exempted *
Reviewer [ ] [ ] Signature Date 6/15/99

Comments cc PI (signed face page only); OSR Director (application with protocol) 117 David Boyd Hall, LSU.

* PI: Obtain a current IRB application packet from the IRB office (8-1492; karenb@lsu.edu; 117 David Boyd Hall, LSU).
APPENDIX P

PARENTAL PERMISSION FORM

Project Title: Middle school students understanding of deep time, geologic time.

Performance Site: River Town Middle School

Investigator: The following investigator is available for questions. M-F, 8:30-9:00 a.m.

Lee Noonan
Education Specialist
River Town Middle School
(540) 225-9953

Purpose of the study: The purpose of the study is to explore middle school students' personal theories and understanding of deep time. This concept is a fundamental part of the 5-8 grades science curriculum and taught in the 6th grade.

Inclusion Criteria: All students in Ms. Pulling's class will be part of the study in normal classroom teaching and routine. Selected students (approximately 10), will be invited to participate on a deeper level.

Exclusion Criteria: Members of the class who are not selected for the personal interviews will be excluded from this part of the study.

Description of the Study: During the last 9 weeks of school the science unit of geologic time will be taught. The first phase of the study will be a survey and pretests that the entire class will take. This activity will be part of the regular class curriculum in Earth Science and enhance student learning but will not be used as a grade. Certain students will be selected by the teacher to be individually interviewed. These interviews may include specific methods to reveal how the student thinks. For example, the researcher may use card sorts, interviews, or computer simulations. At the end of the unit, the whole class will again participate in a survey and post tests. The scores on the pre and post tests will be compared but grades will not be assigned to the scores.

Benefits: The individual students who participate will experience the general positive effects of personal interaction with a supportive adult, as well as earn about how they think and learn. The teacher will learn how students understand a fundamental area of the middle school curriculum and use that information to develop appropriate teaching methods.

Risks: There are no known risks.
Right to Refuse: Participation is voluntary, and a child will become part of the study only if both child and parent agree to the child's participation. At any time, either the subject may withdraw from the study or the subject's parent may withdraw the subject from the study without penalty or loss of any benefit to which they might otherwise be entitled.

Privacy: The school records of participants in this study may be reviewed by investigator. Results of the study may be published, but no names or identifying information will be included for publication. Subject identity will remain confidential unless disclosure is required by law.

Financial Information: There is no cost for participation in the study, nor is there any compensation to the subjects for participation.

Signatures:

The study has been discussed with me and all my questions have been answered. I may direct additional questions regarding study specifics to the investigator. If I have questions about subjects' rights or other concerns, I can contact Charles E. Graham, Chairman, Institutional Review Board, (504) 388-1492. I will allow my child to participate in the study described above and acknowledge the investigator's obligation to provide me with a signed copy of this consent form.

Parent's Signature Date

Investigator's Signature Date

The parent/guardian has indicated to me that he/she is unable to read. I certify that I have read this consent form to the parent/guardian and explained that by completing the signature line above he/she has given permission for the child to participate in the study.

Signature of Reader Date

*This form will be kept for three years in the researchers files.

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APPENDIX Q

STUDENT ASSENT FORM

STUDENT ASSENT FORM
(students aged 8-18)

I, ________________________________, agree to be in a study to find out about middle school students personal theories/understanding of deep time - the history of the earth and life on earth. I understand that I may do special paper and pencil activities, have special problems to solve, and/or be interviewed about my work and/or ideas in science. I can decide to stop being in the study at any time without getting in trouble.

________________________     _________    _________
Student’s Signature         Age         Date

________________________    _________
Witness                    Date

*This form will be kept for three years in the researchers files.

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VITA

Azalie Cecile Pulling was born in New Orleans, Louisiana. She studied elementary education at Florida Southern College in Lakeland, Florida where received a bachelor's of science in 1977. She returned to Louisiana to begin her teaching career, and she has taught in the Louisiana public school system for twenty-two years.

Azalie earned her master of education degree in special education at Northeast Louisiana University in Monroe, Louisiana in 1981. In 1986, she specialized in science and, for the past fifteen years, has taught, studied, and promoted science locally, regionally, and nationally. She was awarded Elementary Science Teacher of the Year in 1989 by the Louisiana Science Teachers' Association. From 1994 to 1998, she served as State Coordinator of NSTA/NASA's Space Science Student Involvement Program. She also served as the education representative on the Chlorine Chemical Council in Washington, DC from 1996 to 1998. In both of these capacities, she promoted science to the American public and presented workshops for teachers at regional and national conventions. In 1998, she received an education specialist degree from Louisiana State University in Baton Rouge, Louisiana.

Azalie was accepted into the doctoral program at Louisiana State University in 1996 and began her pursuit of a doctoral degree in science education. Her academic pursuits will culminate with this dissertation and graduation ceremonies in May 2001 with the degree of Doctor of Philosophy.
DOCTORAL EXAMINATION AND DISSERTATION REPORT

Candidate: Azalie Cecile Pulling

Major Field: Curriculum and Instruction

Title of Dissertation: Middle School Students’ Understanding of the Natural History of the Earth and Life on Earth as a Function of Deep Time

Approved:

[Signature]
Major Professor and Chairman

[Signature]
Dean of the Graduate School

EXAMINING COMMITTEE:

[Signature]
James H. Vanderzee

[Signature]
[Signature]

Date of Examination:
March 21, 2001