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Elementary and secondary science teachers negotiation of controversial science content: The relationships among prior conception appropriation, thinking disposition, and learning about geologic time

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I am submitting herewith a dissertation written by James Harold Roberson entitled "Elementary and secondary science teachers negotiation of controversial science content: The relationships among prior conception appropriation, thinking disposition, and learning about geologic time." I have examined the final electronic copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Education.

Rita A. Hagevik, Major Professor

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Elementary and Secondary Science Teachers Negotiation of Controversial Science Content: The Relationships among Prior Conception Appropriation, Thinking Disposition, and Learning about Geologic Time

A Dissertation Presented for the Doctor of Philosophy Degree
The University of Tennessee, Knoxville

James Harold Roberson
May 2011

DEDICATION

This dissertation is dedicated to Terri, Rachel, and Olivia for their love, support, understanding, and patience.

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ABSTRACT

An individual's values and attitudes become integrally connected to their prior knowledge and conceptions regarding science and science content. Sometimes the nature of a natural phenomenon and the scientific explanation for the phenomenon is controversial. A controversial scientific concept is one that evokes emotion and forces individuals to assess the values associated with this content and make assessments of their attitudes toward it. This is especially true during learning. The purpose of this study was to provide evidence on how prior knowledge and existing conceptions are related to open-mindedness when learning science content that is regarded as controversial. The participants for this study consisted of 7 elementary science teachers and 8 secondary science teachers that attended a year-long professional development program designed to build content knowledge in geology and the geosciences and provide pedagogical information and support for teaching science. The teachers' use of their prior conceptions was determined through the coding of interviews based on the four appropriation modes of Integration, Differentiation, Exchange, and Bridging. Analysis revealed 53% of the teachers differentiated their existing conceptions from new geologic time conceptions, while 47% integrated new conceptions with their prior conceptions. In addition, 40% of the teachers exhibited a bimodal appropriation of their existing conceptions. Bridging and exchange were the secondary appropriation modes observed among bimodal appropriators. The teachers' overall level of open-mindedness, as determined by the AOT was categorized as high. However, the teachers' level of open-mindedness as determined by their interview responses was predominantly low. There was no change in the level of geologic time knowledge possessed by the teachers from pre to post to post-post-program activities. No relationships were found between the teachers' thinking disposition and their level of geologic time knowledge, nor where there any relationships found between the teachers’ prior conception appropriation and their geologic time knowledge or their appropriation and thinking disposition.

Keywords: conceptual change, controversial concepts, existing conceptions, open-minded, prior knowledge, geologic time

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CHAPTER I

INTRODUCTION

Twenty-five years have past since the American Association for the Advancement of Science launched its long-term initiative to reform K-12 education in science, mathematics, and technology called Project 2061. These recommendations as well as specific learning goals were established and compiled into a document entitled *Science for All Americans* (AAAS, 1990). This document focused on the need for the citizens of the United States to possess a degree of scientific literacy that would enable them "to develop the understandings and habits of mind they need to become compassionate human beings able to think for themselves and to face life head on. It should equip them to participate thoughtfully with fellow citizens in building and protecting a society that is open, decent, and vital (p. xiii)". Among these recommendations were those termed as *values and attitudes* because they reflect an individual's position towards learning, ways of thinking, and ways of acting. It should be understood that science works to reinforce general societal values through the systematic application of integrity, diligence, fairness, curiosity, openness to new ideas, skepticism, and imagination. Furthermore, *Science for All Americans* acknowledges that new scientific knowledge can be surprising, troubling, and uncomfortable for an individual (AAAS, 1990).

What an individual knows about science concepts is termed pre-conceived or prior knowledge. Prior knowledge is developed through interactions with the natural world, social interactions, and educational experiences (Piaget, 1971). The knowledge frameworks and conceptions that people develop become deeply rooted and therefore difficult to alter, change, or remove (DiSessa, Sherin, 1998; Hewson & Hewson, 1983; Vosniadou, Brewer, 1987). When instruction takes place, science learning can occur through two modes; enrichment of existing knowledge or by a complete restructuring of knowledge. Both modes produce different results from a cognitive perspective (Carey, 1985; DiSessa & Sherin, 1998; Scott, Asoko & Leach, 2007; Vosniadou, 2007; Vosniadou & Brewer, 1987). Due to the complex interaction of methods, environment, and content, science and scientific information is challenging to teach and learn. Moreover, the production and representation of scientific information is itself problematic from the perspective of teaching and learning. For example, Snir, Smith, & Raz (2003) describe how the use of models, the fundamental tool used in science for explanatory purposes, poses challenges for science learners due to misconceptions regarding models themselves. In order for an individual to incorporate a scientific model into their knowledge framework and it function appropriately, the learner must understand that models are not true descriptions of natural systems, they are limited in scope, are evaluated based on their explanatory power, and that natural phenomena can be modeled in more than one way (Snir, et al., 2003). The mutual inclusivity of the need to not only understand specific science information, but to also understand how the information is generated and represented through the scientific enterprise compounds this problematic nature (Anderson, 2007; Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002; Snir, et al., 2003).

A person's repertoire of prior knowledge that is functional during learning encompasses all knowledge they possess regardless of the content being learned. There is no domain specificity regarding the content being learned and the framework of prior knowledge utilized during the process of learning (Banet & Ayuso, 2003). This situation gives rise to the interpretation and internalization of new content information through the help of existing knowledge frameworks that are unrelated or inappropriate to the content being learned, and thus results in the construction of incomplete, inadequate, or erroneous knowledge frameworks. Thus, a learner generates what is regarded as a misconception (DiSessa & Sherin, 1998). The new (*mis*)conception becomes part of the person's prior knowledge for learning any further additional information.

When a learner is presented with new science information, they have to become aware of their existing prior knowledge and conceptions. During this time, the learner must realize that their existing conceptions are not adequate for developing a complete understanding of the concept. As a result, they must establish dissatisfaction with their existing conceptions. Piaget (1971) termed this situation cognitive disequilibrium. A learner will not initiate a major change in their existing conceptual framework if they do not conclude that what they currently know is incapable of answering questions pertaining to the content (Posner, 1982). There are a variety of reactions to new science information as it is filtered through a learner's prior knowledge frameworks during learning. Chinn and Brewer (1993) established seven different responses by science students when presented with new science information that contradicts what they already know and believe. Of the seven responses presented, only one resulted in the student making a change to their existing knowledge framework, while the other six responses were mechanisms used to either discount the new information in some way or to reinterpret it to allow it to work within their existing framework (Chinn & Brewer, 1993). This highlights the complex situation of realizing that an existing conception is inappropriate.

There are many factors at play during learning, including personal factors that have an effect on how and what gets learned during science instruction. Motivation, intentions, and the desire to engage with the content are essential to learning science (Sinatra, 2002; Sinatra, Southerland, McConaughy, & Demastes, 2003). These factors are related to and are part of being open to new ideas within the framework of the scientific enterprise encompassing research, teaching, and learning. Not only is it necessary to be open to new ideas during the discovery process of scientific information, but there is a necessity for an openness to new ideas as one learns about a science concept. Prior knowledge, existing conceptions, and beliefs can constrain not only the outcome of a learning episode but can constrain the way an individual thinks during the process (Schoon, 1998).

Being open to new ideas is a hallmark of thinking disposition and allows a learner to interact with the content effectively. Thinking disposition is an individual factor that can affect a learner's perception and reasoning associated with science content, especially when faced with controversial socio-scientific topics. Science often produces information that fuels debate. Problems, issues, and findings are put forth that spur debate between and among the science community and broader societal groups. Topics such as global warming, genetic engineering, energy conservation, evolution, and the age of earth are examples. Topics considered controversial are affected and shaped by the prior knowledge frameworks of an individual associated with that particular topic. Controversial science topics are comprised of scientifically derived information and knowledge that has conceptual and technological connections with prevailing social institutions (Sadler, 2004). In this sense, these topics can be regarded as socio-scientific issues. Often, these topics are laden with emotion and deeply imbedded within social contexts (Sinatra & Mason, 2008). The decision to purposefully learn all, part, or none of the content of a controversial topic is the result of the learner's thinking disposition (Sinatra, et al., 2003).

There is a definite benefit for individuals to have a certain degree of science content knowledge. Possessing a good foundation of science information allows individuals to make informed choices and decisions that affect their lives. It is well understood that people have a substantial amount of knowledge that is acquired through experience with the natural world, as well as being involved in social contexts. Such knowledge is obtained in the absence of formal instruction and is a priori. This prior knowledge is strongly held and supported by the individual. Such strongly held beliefs and views affect any subsequent science learning by the individual. Therefore, science educators must expose and assess a learner's prior knowledge before they can deliver content as effectively as possible. In addition, there are factors unique to the individual that bears weight on effective science teaching and learning. These factors are functional at the cognitive level that dictates the actions a learner chooses when learning science, and thus are intentional in character. Such factors describe how a learner thinks and perceives new science information and whether they will be "open" to the information. A learner's openness to new ideas is directly related to their open-mindedness and disposition of thinking (Sinatra, et al., 2003; Stanovich & West, 2007).

Statement of the Problem

Several factors interact during science learning that affect how a learner perceives, interprets, and internalizes a particular science concept. Such factors are prior knowledge, beliefs, epistemological position, and various social inputs (Anderson, 2007; DiSessa & Sherin, 1998; Vosniadou, 2007). In order for a person to experience a change in a particular science conception, they must realize that their existing conception is inadequate. This occurs when an individual becomes dissatisfied with their existing conception and realizes a need for a more fruitful alternative (Anderson, 2007; DiSessa & Sherin, 1998; Posner, 1982; Scott, et al., 2007).

To be effective in the science classroom, science teachers are tasked with a variety of duties. Of these many tasks, determining students' prior knowledge, misconceptions, and alternate conceptions regarding science content is considered to be vitally important (Beeth, 1998; Beeth, 1999; Snir, et al., 2003). In addition, a task of the science teacher is to bring students to the realization that their existing conceptions are not adequate enough to answer potential questions. Within this frame, it is generally accepted that in order to take part in learning new conceptions or to make the appropriate modifications to existing conceptions, an individual should be open to considering new ideas or knowledge. This degree of openness is directly related to how an individual thinks (Stanovich & West, 1997, 2007). Learning involves the consideration of two sets of information; information already possessed and the new information being presented during instruction. Juxtaposing the two sets of information results in the learner establishing how the two will be related to one another (Anderson, 2007; Barbour, 1997). The relationship determined by the learner is a function of the learner's openness to new ideas (Stanovich & West, 1997, 2007). Considering a science topic to be controversial adds to the complex nature of learning science. Controversial science topics range from evolution to AIDS (Keselman, Kaufman, Kramer, & Patel, 2007). The objective of this study was to provide an analysis of how science teachers used their existing conceptions along with their degree of open-mindedness when learning about geologic time, a controversial science topic.

Statement of the Purpose

The purpose of this study was to provide evidence on how elementary and secondary science teachers' prior knowledge and existing conceptions were related to their open-mindedness when learning science content that is regarded as controversial. The teachers were randomly selected from a larger group of teachers that choose to be a part of the TENNMAPS Math and Science Partnership grant-funded program, which focused on providing content information in Earth Systems Science. This study offers insight into the connections between prior knowledge and open-mindedness when learning geologic time. Very little research has been done on the learning of controversial issues in the Earth Sciences (Trend, 1998, 2000). It is critical to the learning of science for science teachers to recognize how prior conceptions and open-mindedness impact science learning.

Research Design

Background

Studies on learning and conceptual understanding of science have been underway for over a century (Hall, 1903; Piaget, 1930). In 1982, Posner, Strike, Hewson, and Gertzog (1982) assembled information from both cognitive science research and science education research to put forth a model for conceptual learning specific to science education. Shortly after, research on conceptual change, prior knowledge, prior conceptions, misconceptions, and alternative conceptions in science education increased several-fold. In 1970, Helga Pfundt began compiling a bibliography of articles related to conceptual change research that had been published in the top-tier science education research journals. The 2009 addition contains approximately 8400 entries of empirical research related to conceptual change learning spanning from 1900 to 2009 (Pfundt & Duit, 2009).

Reform efforts to improve science teaching and learning for kindergarten through high school students have been ongoing for over six decades (Atkin & Black, 2003). In 1985, a reform effort called *Project 2061* was launched and quickly gained substantial momentum. *Project 2061* saw the development of three reform documents, *Science for All Americans, Benchmarks for Science Literacy*, and *Atlas for Science Literacy* (AAAS, 1990). The introduction of these documents spurred the development of science content teaching and learning through the organization of science content standards by national organizations and state agencies. Part of these collective efforts was to ensure teachers were equipped with the knowledge and tools to effectively implement teaching strategies that are content rich. In order to make sure teachers are well prepared, external professional development activities, funded by federal and state agencies and supported by local educational associations, were carried out. Many of these activities involved immersing in-service teachers in specific content instruction that provided them with a strong knowledge base.

This was the case for the current study. The TENNMAPS professional development workshop series was designed to enhance content knowledge and support k-12 teachers in the area of earth systems science. The program was funded through a grant called the Math and Science Partnership (MSP) from the U.S. Department of Education and the State of Tennessee. The TENNMAPS MSP (Clark, et al., 2007) was a three-year professional development program whose primary instructional component took place over a consecutive ten-day period during the summer for a total of 60 contact hours and four follow-up days of six contact hours each for a total of 24 additional contact hours, two in the fall and two in the spring. TENNMAPS is the Tennessee-specific expansion of SE MAPS, a highly successful National Science Foundation-sponsored interdisciplinary educational product originally developed for eight states. The professional development program was designed to provide teachers of science with earth science content, coupled with demonstrations and hands-on activities that could be easily translated to the classroom since teaching examples are literally “out the teachers’ back door”. The professional development instruction was designed to visualize environmental earth-science relationships (e.g., effects of geologic processes, topography, drainage, vegetation, effects of interaction with human activity), and then use these to investigate thought-provoking open-ended problems by studying visible manifestations of cultural activities on maps and imagery (e.g., strip mining, pumped hydroelectric storage, agriculture, and urbanization). The TENNMAPS partnership included sixteen school districts, the Northeast Professional Development Center, scientists from three Universities, and science educators. Teachers (grades 2 – 12) who taught science at least one period a day attend the workshop in groups encouraged by their principals who were in turn part of the partnership.

The first year of the workshop series was considered a pilot year where the instructional format, calendar, and specific topics were assessed to determine if they were successful in meeting the program’s objectives. In addition, data sources for the study were identified, and a Form-B was submitted by the researcher and approved by the Institutional Review Board at the University of Tennessee to conduct the study. The second year was the data collection year where all data utilized for this study was collected. The third and final year involved the implementation of the TENNMAPS program to a third cohort of attendees, and data collection for subsequent analysis and reporting to the supporters of the program.

Study Sample

The sample for this study was drawn from a group of teachers that attended a ten-day workshop that focused on increasing content knowledge in Earth Systems Science. Seven elementary teachers and eight secondary teachers were randomly selected from the 47 total teachers that attended the workshop.

Elementary teachers were classified as teachers that taught in the grade range of 2nd through 6th during the school year prior to attending the program. In addition, the teacher taught at least one class period per day of science instruction. For example, some of the teachers provided "whole –class" instruction where they taught all subjects including science, while others taught science solely. The secondary teachers were individuals that taught science for grades 7th through 12th during the school year prior to the program.

Participants who attended the program ranged from high school physics teachers to elementary school librarians. A selection criterion dictated that the study participants must have either taught science solely or taught science regularly (i.e. at least one lesson a day or periodically throughout the school week). The reason for this criterion was due to other data being collected concurrently that was predicated on a participant being a "science teacher". For example, the participants were surveyed on their perceptions of science teaching self-efficacy prior to the program and upon completion of the program.

Research Questions

The following three research questions directed this study:

1. How do elementary and secondary science teachers appropriate their existing conceptions regarding geologic time when learning about concepts that are inconsistent with their existing knowledge and conceptions?
2. How is thinking disposition related to the learning of geologic time concepts?
3. What relationships are evident among the teachers' appropriation of prior conceptions, thinking disposition, and learning about geologic time?

Methods and Procedures

This study is categorized as a qualitative *concurrent triangulation design* (Creswell, 1994, 2009). The investigation consisted of multiple case studies analyzed within cases and across cases. Quantitative data were collected concurrently with the qualitative interview data. The quantitative data were analyzed separately and subsequently used to expound and enrich the interpretation of the qualitative data.

Semi-structured interviews were conducted by the researcher with the teacher participants. Initially, the interviews were open-coded by hand to determine if any patterns or themes emerged that were related to the research questions and could be utilized in establishing a coding scheme. The interviews were coded using a set of codes adopted from Hewson and Hewson (1983). These researchers conducted a study to analyze the effects of a special teaching strategy based on a group of learner's alternative conceptions involving mass, volume, and density. They described four possible approaches to teaching science concepts. The four possible teaching approaches relate to the interaction of the learner's prior knowledge and alternate conceptions, and reflect how a learner negotiates their existing conceptions. These teaching approaches outlined by Hewson and Hewson (1983) are consistent with the conceptual change model proposed by Posner, et al (1982). Furthermore, Hewson and Hewson (1983) point out that learning does not occur by the simple addition of new information to existing knowledge frameworks, but instead it involves some form of interaction between them. Interactions occur between new information and existing knowledge to allow the new information to be assimilated or accommodated with the existing knowledge (Hewson & Hewson, 1983; Hewson, 1981; Posner, 1982). Learning as conceptual change speaks to the changes that occur among a learner's existing conceptions when confronted with new science information (DiSessa & Sherin, 1998; Hewson & Hewson, 1983; Posner, 1982; Scott, et al., 2007; Vosniadou & Brewer, 1987). The influence of the status of the science information, controversial or non-controversial, on the basic underpinnings of learning as conceptual change has not been elaborated. None the less, it can be assumed that the model outlined by Posner, et al (1982) and furthered by others refers to all science content. Furthermore, there is no domain specificity regarding the content being learned and the framework of prior knowledge utilized during the process of learning (Banet & Ayuso, 2003). Following are the coding categories derived from Hewson and Hewson's (1983) suggestions for fostering specific interactions among a learner's existing conceptions and new science information that were used for the study:

1. *Integration*. New concepts are integrated with the learners' existing conceptions. Modifications to existing conceptions, the new conceptions, or both take place during learning.
2. *Differentiation*. Existing conceptions and new conceptions are regarded as separate and independent of one another and become compartmentalized by the learners. However, they are related based on the problem both sets of conceptions are seeking to answer.

3. *Exchange.* The learner's existing conception is exchanged or replaced by the new conception.
4. *Bridging.* A link is established between the new conception and the learner's experience that creates meaning for the new concept and allows the learner to realize the concept is intelligible and plausible.

The four approaches comprised the four categories of the coding scheme. The categories indicated the interaction between the teachers' existing conceptions and geologic time concepts. Utilization of these four categories permitted a typological focus to the data analysis (Hatch, 2002). The qualitative analysis software QDA Miner (Provalis Research) was used to code and analyze the interview data with the four relationship category codes. Inter-rater reliability was established for the coded interviews by the researcher and three assistants. The assistants were colleagues of the researcher at the community college where the researcher was employed. The colleagues consisted of an Assistant Professor of Science and former high school biology teacher, an Assistant Professor of Psychology, and an assistant in the developmental study skills lab.

Two quantitative measures were administered to the participants, the Geoscience Content Inventory and the Actively Open-Minded Thinking Scale. The Geoscience Content Inventory (GCI) (Libarkin & Anderson, 2005b) was administered before and after the program to measure the participants' knowledge regarding pertinent Earth Systems Science concepts. The Statistical Package for Social Sciences (SPSS v17.0) was used to analyze the data from the GCI. A repeated measures t-Test was conducted to determine any statistical differences from pre-instruction to post-instruction of the ten-day component of the program (pre/post) and again after the subsequent follow-up days of the program (pre/post/post). To analyze the participants' degree of openness to new ideas or open-mindedness, the Actively Open-Minded Thinking Scale (AOT was given to the participants prior to any Earth Science instruction. The AOT is a measure consisting of six thinking disposition subscales that are summed to give a value that is interpreted as an individual's degree of open-mindedness (Stanovich & West, 1997). SPSS v17.0 was used to generate AOT descriptive statistics for analysis. In addition, a repeated measure t-Test was conducted to determine any difference between pre-program and post-program returns on the measure.

The patterns and relationships among prior conception appropriation, thinking disposition, and learning geologic time were analyzed through the use of matrices. Each factor, prior conception appropriation, thinking disposition, and learning geologic time, represented a category for analysis. Each category was given a numerical code. Therefore, each teacher was given a 3-digit classification code. The codes were then placed in two or three level matrices to analyze for patterns and relationships.

Assumptions of the Study

The following assumptions underlie this study:

1. The TENNMAPS Earth science program's focus was to provide content instruction to inservice teachers.
2. The participants were comfortable with sharing their thoughts during the interviews.
3. The participants were honest and sincere in their answers to the interview questions and their answers to the Actively Open-Minded Thinking Scale.

4. The participants answered the questions to the Geoscience Content Inventory to the best of their knowledge.

Limitations of the Study

The following limitations underlie the study:

1. The participants were limited to teachers that attended the TENNMAPS Earth Systems science program.
2. The participant sample was limited to only those teachers attending the program that taught science regularly.
3. The amount of interview data was limited by the availability of the participants.
4. Data validity and reliability were limited to the validity and reliability of the instruments as determined by the developers of the instruments.

Importance of the Study

Research related to prior knowledge, existing conceptions, and conceptual change learning in science education has been underway for over seventy-five years. In that time, research has focused on cognitive aspects and social aspects to define factors that have direct and indirect relationships on the learning of science (Scott, et al, 2007). This study focused on the analysis of prior knowledge and open-mindedness and their effect on the conceptual learning of a science topic that is specifically regarded as being controversial. The domain in which the new information resides (general or controversial) adds to the developing strata of influences on their conceptual understanding of the new concept.

An individual's prior knowledge or existing conceptions make up a learner's framework of information that allows them to engage with any new content being learned. As this engagement unfolds, the learner must decide whether or not what they already know is adequate and appropriate to allow them to fully understand a new concept being presented. Certain beliefs and cognitive positions held by learners direct how they interpret new science information, and the learner's interpretation is affected by their existing knowledge. Pintrich and Sinatra (2003) express that there is a need to understand how cognitive and metacognitive strategies, such as open-mindedness, are used by a learner to make any necessary changes to their existing conceptions. They further explain that very little work has been done to highlight how conceptual learning processes are affected by the domain a learner assigns to the concept. This study analyzes how learners' thinking disposition interacts with their existing conceptions when learning science content that is categorized as controversial science information (Anderson, 2007; Sinatra, et al., 2003).

Research into the conceptions pertaining to geologic time has been minimal to date (Trend, 2000, 2001). Studies that have been conducted have only sought to identify and evaluate the character of a learner's conceptions (Libarkin, Kurdziel, & Anderson, 2007; Trend, 1998, 2000, 2001). Furthermore, virtually no attention has been paid to the relationships among prior conceptions, thinking disposition, and learning geologic time concepts. It has been determined that learners carry prior knowledge and possess particular habits of mind that can act as barriers to conceptual understanding of science topics (Schoon, 1998) including controversial ones such as geologic time (Trend, 2001). Knowledge of such relationships is beneficial to the learner to allow them to fully evaluate new science information to enable them to build appropriate conceptions that are strong, robust, and stable. Furthermore, it is important for teachers to be aware of these relationships in order for them to implement lessons that will foster in their students the construction of appropriate conceptions that are strong, robust, and stable.

Definition of Key Terms

Alternate conception – knowledge framework a person has for a particular concept that is not in accord with that regarded by experts; synonymous with misconception.

Appropriation – Setting apart, authorizing, or assigning some specific purpose or use.

Cognitive disposition – a stable psychological mechanism responsible for characteristic behaviors and tendencies where knowledge and beliefs are used to dictate learning goals; synonymous with thinking disposition and open-mindedness (Stanovich, 1999; Stanovich & West, 1998).

Conception – specified knowledge information pertaining to a particular topic

Conceptual change – a learning process where a learner makes a conscious change to what they already know about a particular topic (Posner, 1982).

Existing conception – knowledge and information an individual possesses prior to any instruction regarding a particular topic; used interchangeably with prior conception and prior knowledge.

Geologic time – the succession of eras, periods, and epochs as considered in historical geology; considers all factors including the formation of the universe and the evolution of the planet and its inhabitants.

Misconception - knowledge framework a person has for a particular concept that is not in accord with that regarded by experts; synonymous with alternate conception.

Open-mindedness – the degree an individual is open to considering new ideas regarding a topic. It is a function of an individual's thinking disposition and used interchangeably (Stanovich, 1999; Stanovich & West, 1998).

Prior conception - knowledge and information an individual possesses prior to any instruction regarding a particular topic; used interchangeably with existing conception and prior knowledge.

Prior knowledge - knowledge and information an individual possesses prior to any instruction regarding a particular topic; used interchangeably with prior conception and existing conception.

Thinking disposition - a stable psychological mechanism responsible for characteristic behaviors and tendencies where knowledge and beliefs are used to dictate learning goals; synonymous with cognitive disposition and open-mindedness (Stanovich, 1999; Stanovich & West, 1998).

Organization of the Dissertation

This dissertation includes five chapters.

Chapter one consists of the introduction to the study, statement of the problem, statement of the purpose, research design, research questions, methods and procedures, assumptions of the study, limitations of the study, the importance of the study, and the definition of key terms.

Chapter two provides the review of the research literature pertinent to the study, and it is reported in seven sections. The sections are conceptual change learning, prior knowledge and conceptions, determining assessing and remediating learners' prior knowledge, prior knowledge and reasoning ability, thinking disposition, controversial science topics and geologic time, and summary. The conceptual change learning section is divided into three subsections; introduction, conceptual change process, and changes in a learner's science conceptions. The prior knowledge and conceptions section is divided into two sub-sections, introduction, and role of a learner's prior knowledge and conceptions. The determining, assessing, and remediating learners' prior knowledge is sub-divided into two sections, determining and assessing, and remediating.

Chapter three describes the research design. This chapter includes the study rationale along with the research questions, the research context, a description of the participants, the research methodology, the data sources, a description of the data analysis, a description of the construction of cases, and a description of the construction of the cross-case analysis.

Chapter four reports the study's results and findings. The beginning of the chapter provides the organization of the chapter. The results are presented in three sections in relation to the study's research questions. These sections are entitled appropriation of prior conceptions, relationship between thinking disposition and learning geologic time concepts, and relationship between prior conception appropriation, thinking disposition, and learning geologic time. The last section of this chapter presents the findings of the study.

Chapter five contains the conclusions, implications for learning controversial science concepts, and recommendations for further research. The chapter begins with a description of the organization of the chapter and is followed by a summary of the study.

CHAPTER II

REVIEW OF THE LITERATURE

This chapter provides a review of the literature pertaining to research focusing on conceptual change learning and specific factors that influence the process and outcome of such learning. Figure 1 outlines the interconnectedness of specific factors, directly related to the study's research questions, which influence conceptual learning of science concepts. Conceptual learning through conceptual change stands at the center of the matrix. Factors including prior knowledge, thinking disposition, and reasoning ability interact with one another through specific aspects to influence conceptual learning. The overlapping section between prior knowledge and thinking disposition is labeled with a question mark. The connection and relationships between these two areas is unknown due to limited research in this area and represents the focus of this study.

The central thread of *conceptions* runs through the body of the review from the general perspective of conceptual change learning to the actual conception of geologic time. This review is presented in five sections represented in the following outline:

1. Conceptual Change Learning
    a. Introduction
    b. Conceptual Change Processes
    c. Changes in a Learner's Conceptions
2. Prior Knowledge & Conceptions
    a. Introduction
    b. Role of a Learner's Prior Knowledge & Conceptions

        i. Conceptual Integration
        ii. Differentiation
        iii. Conceptual Exchange
        iv. Conceptual Bridging
    c. Determining, Assessing, and Remediating Prior Knowledge
        i. Determining and Assessing
        ii. Remediating
    d. Prior Knowledge and Reasoning Ability
3. Thinking Disposition
4. Controversial Science Topics and Geologic Time
5. Summary

Section 1 provides an overview to conceptual change learning in science education. It is divided into the three sections of introduction, an explanation of processes and mechanisms involved in conceptual change, and research and information regarding actual changes in learners' science conceptions.

Section 2 focuses on a learner's prior knowledge and existing conceptions regarding science concepts. The section provides an introduction to what is regarded as prior knowledge, research on the prior knowledge a learner possesses, specific roles that a learner's prior knowledge takes during conceptual change learning, and the relationship between a learner's prior knowledge and their ability to reason effectively during conceptual change learning.

Section 3 gives a description of thinking disposition and how this construct is related to open-mindedness, its relationship to reasoning ability, the connection to prior knowledge, and how learning controversial science concepts can be influenced by the relationships.

Section 4 expands on controversial science concepts and their definition. In this section, the controversial concept geologic time is highlighted. Geologic time is the conception of focus in this study.

Section 5 provides a summary of the literature review. It ties sections one through four together and offers a concise description of the contents of each section and their connectedness.

Conceptual Change Learning

Introduction

The conceptual understanding of a science concept is predicated on several internal cognitive factors that include the learner's existing knowledge, notions, and misconceptions, along with several external factors that contribute to facilitating conceptual understanding, such as the teacher, the way the content is presented, and the classroom environment (Schnotz, 1999). Inclusive to the effectiveness of both internal and external factors for fostering conceptual change is the necessity for a learner to recognize that a conflict exists between their existing knowledge and the appropriate conception being taught (Chinn, 1993; DiSessa & Sherin, 1998; Pintrich, Marx, & Boyle, 1993; Posner, 1982; Vosniadou & Brewer, 1987). However, it has been put forth by several conceptual change researchers that conflict and dissatisfaction between a learner's existing conceptions and new science information are not sufficient enough to cause the learner to change their conception (Dole & Sinatra, 1998; Pintrich, Marx, el al., 1993; Sinatra & Pintrich, 2003). The learner possesses beliefs, motivation, and related affective characteristics that work to oppose any efforts by an educator to institute a change regarding a particular conception(Linnenbrink & Pintrich, 2002; Pintrich, 1999; Sinatra, Southerland, McConaughy, &

Demastes, 2001). Affective characteristics include a range of qualities of which one includes a person's thinking disposition. An individual's thinking disposition has been determined to be directly related to their degree of open-mindedness (Stanovich, 1999; Stanovich & West, 1997).

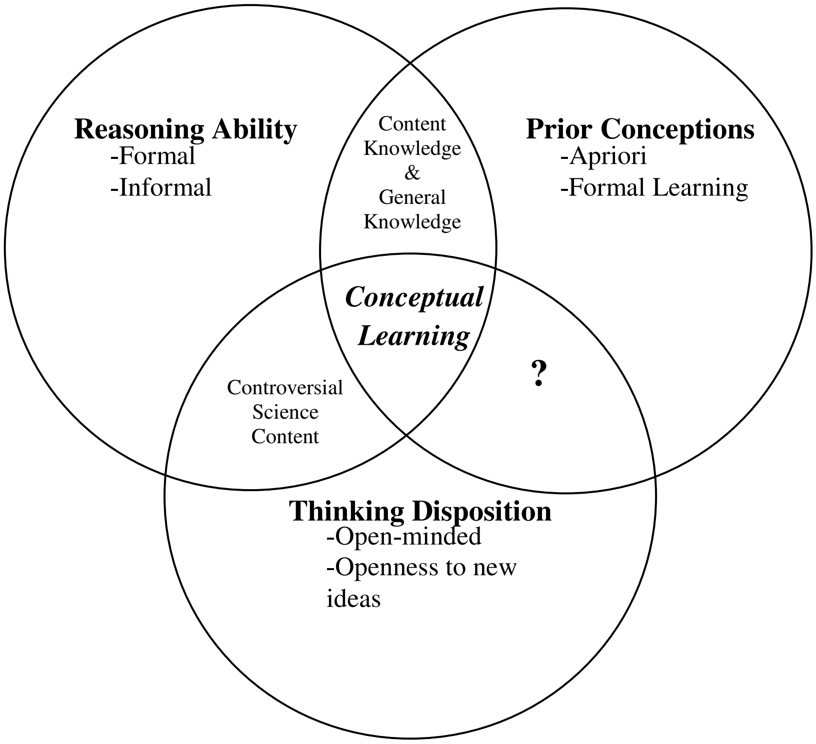

Figure 1. Relationship of factors that influence conceptual learning of controversial content

Conceptual change learning is a constructivist view of learning adopted by science educators that draws elements from cognitive psychology and theories developed by Jean Piaget (1930, 1971, 1972, 1974) that explain how science knowledge is internalized during learning (Dole & Sinatra, 1998; White & Tisher, 1986). In their seminal paper, Posner, Strike, Hewson, and Gertzog (1982) developed a model, the Conceptual Change Model (CCM), to explain the conditions required to bring about conceptual change when learning science. In developing the

CCM model, Piaget's constructs of assimilation and accommodation were used to explain some of the processes at work during conceptual change learning. Within the CCM model, assimilation represents weak restructuring of existing knowledge frameworks, while accommodation represents radical and strong restructuring. Accommodation is regarded as the hallmark of conceptual change since it produces strong, stable, knowledge frameworks in the learner.

Posner, et al (1982) outlined a set of conditions that must be fulfilled before a leaner can experience accommodation of a new science concept; 1) there must be dissatisfaction with their existing conceptions, 2) any new conception must be intelligible to the learner, 3) any new conception must appear initially plausible to the learner, and 4) a new concept should be fruitful in explaining a variety of phenomena related to the original concept. A learner will use their existing knowledge to influence how they learn the new concept in accord with the conditions of accommodation and ultimately affect what is learned. In this frame, a learner's influential existing knowledge is referred to as their conceptual ecology. A learner's conceptual ecology consists of their existing knowledge that is categorized into several domains which function to direct and influence the character of any accommodation of a new concept. The components of a learner's conceptual ecology consist of anomalies, analogies and metaphors, their epistemological commitments, their metaphysical beliefs about science, their metaphysical concepts of science, and any other knowledge they possess that can be called upon while making sense of new science information.

The CCM has been fruitful in providing many avenues of research and analysis directed toward science teaching and learning. Work in conceptual change learning expanded to where these avenues could be categorized as either analyzing the processes of conceptual change or the products of conceptual change learning. Compounding these efforts was the issue of whether conceptual learning was purely cognitive, algorithmic, and mechanistic, or if it was related to more affective and intentional factors. Efforts to elucidate the processes and products of conceptual change initially focused on what occurs cognitively for an individual (Carey, 1985; Posner, 1982; Vosniadou, 1994; Vosniadou & Brewer, 1987). From these studies, it was determined that some form of cognitive dissonance, cognitive conflict, or cognitive disequilibrium was the driving force behind an individual experiencing conceptual change, and as a result, a learner would undergo some form of knowledge restructuring (Carey, 1985; Posner, 1982; Vosniadou & Brewer, 1987). This restructuring can be radical or minimal. Radical restructuring involves major revisions of existing knowledge frameworks, or the construction of completely new frameworks. These radical processes are associated with accommodation. Minimal restructuring of knowledge frameworks involves slight changes to allow for easy integration into the existing framework. Assimilation is the integration of new knowledge into existing frameworks with minimal alterations (Chinn & Brewer, 1993; Posner, 1982; Trundle, Atwood, Christopher, 2002).

However, it became apparent that other factors were involved in learning science other than just cognitive mechanisms. Pintrich, Marx, and Boyle (1993) provided an analysis and description of a more holistic view of learning and conceptual change that accounts for motivation and affect along with cognitive mechanisms. In doing so, a description of the two views was generated. The traditional, cognitive view with its adherence to logic and rational decision making was termed “cold” conceptual change. The newer focus incorporating affective elements, such as beliefs, warrants, motivation, and sociocultural implications was termed “hot” conceptual change (Pintrich, et al., 1993; G. M. Sinatra, 2005). Currently, many researchers interested in conceptual change incorporate elements of affect when studying science learning processes and their outcomes. These investigations include such elements as motivational, social, and contextual aspects (Alsop, 2005; Blown & Bryce, 2006; Deniz, Donnelly, & Yilmaz, 2008; Gorodetsky & Keiny, 2002; Sinatra & Pintrich, 2003). However, there are still those that focus only on cognitive events, especially when investigating learning and conceptual change regarding specific science content (Keselman, et al., 2007; Trundle, Atwood, R. K. , Christopher, 2002). Even though focused studies on specific content might forego the incorporation of affective components, they are very important in providing insight into the character of students' science conceptions, as well as suggesting teaching strategies that result in effective science learning (Keselman, et al., 2007; Trundle, Atwood, & Christopher, 2007a).

There are several directions researchers can take when studying conceptual change learning in the sciences. Some researchers focus on the processes of conceptual change, or what takes place regarding existing mental structures during conceptual learning. Others look at changes in a learner's specific conceptions as they learn specific science content. In addition, there are researchers that address teaching strategies that are effective in addressing a learner's existing conceptions and initiating a conceptual change. It is common in the research design to have process, product, or teaching strategy integrated into a single study. For instance, Sanger and Greenbowe (2000) addressed college students' alternate conceptions regarding electron flow with a conceptual change teaching strategy involving computer animations and verbal discussions. Exemplifying the possibility of the permutations of conceptual change research, Windschitl and Andre (1998) integrated a conceptual change process focus, analysis of specific conceptions, and the results of two different teaching strategies in their study of a constructivist versus an objectivist approach to instruction on college students' learning of the cardiovascular system as influenced by the learner's epistemological position. However, one aspect that is common among all conceptual change research studies is recognition of the learner's existing knowledge and their existing conceptions.

Conceptual Change Process

Analysis of the processes of conceptual learning in the sciences has spanned several decades (DiSessa & Sherin, 1998; Piaget, 1930, 1974; Posner, 1982; Vosniadou, 1994; Vosniadou & Brewer, 1987). This domain of research has sought to determine the types of mental structures that are formed or modified, and the cognitive and contextual conditions that direct the formation or modification of mental structures. The CCM is considered a fruitful framework to describe the processes, conditions, and outcomes of conceptual learning in the sciences.

Carey (1985) conducted further work with the CCM to emphasize domain specific approaches to conceptual learning and knowledge restructuring. Carey (1985) proposed that either weak or strong knowledge restructuring occurs during learning, with strong restructuring being the type sought after for the generation of proper conceptual understanding. Weak restructuring involves the establishment of a relationship between existing concepts the learner holds and any concepts being learned (Carey, 1985; Scott, et al., 2007). In strong restructuring, the learner changes or completely replaces their existing conception to that of the new concept (Carey, 1985; Scott, et al., 2007; Vosniadou & Brewer, 1987). Vosniadou and Brewer (1987) used weak and strong restructuring perspectives to show how children acquire knowledge about the Earth. For strong restructuring to take place, children must change the conceptions they hold regarding certain physical characteristics of Earth, change the structure of these conceptions, and come to a realization of the different questions the new conceptions can answer.

Conceptual learning can be viewed as developing a framework of theories that can be related to one another to further the understanding of a particular concept. Looking at how students come to understand physics, Vosniadou (1994) argued that a framework of naïve theories is established very early on in a learner's life and forms their explanation for reality, the existence of objects, and what constitutes knowing and knowing. A learner eventually builds specific theories about natural phenomena through the interpretation of information from the prevailing culture with their previously established framework theories. Thus, conceptual change occurs through the modification and enrichment of the learner's specific theories, or when existing beliefs and presuppositions of pertinent framework theories are revised (Vosniadou, 1994). While investigating the process of how year 1 (kindergarten) students gain an understanding of living things, Venille (2004) found that the students predominantly assimilated the information into their pre-existing framework theories.

DiSessa and Sherin (1998) described how concepts are not necessarily discrete knowledge entities but consist of many parts that constitute a system of knowledge for a particular phenomenon, such as the movement of physical bodies, and that it is necessary to understand the system in order to establish what actually changes during conceptual change. DiSessan and Sherin (1998) contend that a learner ultimately decides how and where to classify the new information cognitively during conceptual change learning. To do this, the learner utilizes knowledge gained from experiences with the natural world called phenomenological primitives to allow them to intuitively categorize any new information (DiSessa, 1993). In addition, the learner calls upon a group of cognitive strategies called coordination classes that include ways of determining and integrating observations for proper classification of information into their knowledge systems (DiSessa & Sherin, 1998).

Many of the research studies on conceptual change processes have focused solely on individual cognitive mechanisms. However, it has been determined that there are affective components that underlie conceptual change learning processes. Pintrich, et al (1993) presented a conceptual change model that accounts for the role of goals, values, self-efficacy, and control beliefs in mediating conceptual change processes for a learner. The authors highlight how accounting for these variables can build a picture of an individual's intentions during learning, and thus whether a conceptual change will be instituted as a result of instruction (Pintrich, et al., 1993).

Changes in a Learner's Science Conceptions

Most often, a study on conceptual change focuses on conceptual learning within a specific domain of science. Vosniadou (1994) elaborated on her model of conceptual change through the analysis of how an individual learns physics concepts. She described how children develop special framework theories to explain natural phenomena as they interact with physical objects. DiSessa (1993) investigated the development of an epistemology for learning the basic concepts of physics. DiSessa and Sherin (1998) described the changes in physics conceptions to illustrate the function of a learner's knowledge systems during conceptual learning processes. Diffusion and vascular circulation are specific biological concepts that have been analyzed in regard to why these concepts are misconceived (Chi, 2005).

Changes in conceptions for an individual can be determined through studies that focus on the level of conceptual knowledge for a particular concept before and after instruction. Several studies have assessed aspects of learning the concepts of the moon and its phases. Trundle, Atwood, and Christopher (Trundle, et al., 2007a) analyzed fourth grader's conceptions of lunar concepts and moon phases before and after specific instruction. Changes in pre-service elementary teachers' lunar and moon phase conceptions after instruction have been analyzed as well (Trundle, Atwood, & Christopher, 2006; Trundle, Atwood, & Christopher, 2007b; Trundle, Atwood, & Christopher, 2002). Sinatra, et al (2003) evaluated content knowledge and conceptions associated with biological evolution held by college students in a non-majors biology class after the course had been completed. Hynd (1994) chose to analyze the changes the understanding of Newton's laws of motion among ninth and tenth grade students. In addition, Newton's laws of motion concepts have been evaluated among eleventh and twelfth grade high school students (Eryilmaz, 2002). Atom, molecule, and bonding concepts have been emphasized in a number of studies (Ben-Zvi, 1986; Cervellati, 1981; Griffiths, 1992; Harrison, & Treagust, 2000; Sewell, 2002). Keselman, et al (2007) focused on increased conceptual understanding of HIV and AIDS among middle school students.

There are several ways to approach a study on conceptual change. A researcher can choose to assess the prior conceptions a learner has regarding a specific science concept, or analyze how a certain prior conception facilitates or hinders further learning, or describe and analyze a new teaching strategy designed to identify and correct inappropriate conceptions. Regardless of any specific focus of research into conceptual change, the presupposition is that a learner holds conceptions that are inappropriate or inconsistent with what is held within the scientific community. The conceptual change model proposed by Posner, et al (1982), and elaborated by others (Carey, 1985; DiSessa & Sherin, 1998; Vosniadou, 1994) are examples.

Specifically, this study focuses on determining and assessing a learner's prior knowledge regarding a particular science concept (see Figure 1).

Prior Knowledge and Conceptions

Introduction

Conceptual change of a science topic by an individual is based on the learning of new science information that is obtained early from personal experiences with the physical world, as well as interactions with peers and authority figures from their social milieu. Within the context of conceptual change learning, knowledge and information a learner already has before any formal instruction is regarded as prior knowledge. All conceptual change learning theories and models involve an accounting of a learner's prior and existing knowledge. In addition, the models and theories function to describe the mechanisms a learner uses to access and utilize their pre-existing knowledge, as well as the general function of it. However, there are several terms used and applied to priori knowledge and prior conceptions that cause confusion.

Modell, Michael, and Wenderoth (2005) convened a meeting to sort out the definitions and uses of priori knowledge. Attendees of the meeting consisted of biology educators, chemistry educators, physics educators, and cognitive science researchers that focus their work on science learning and science education. The organizing intent of the meeting was based on the general consensus that "…the vocabulary used by investigators studying misconceptions seemed inconsistent" (Modell, et al., 2005). Early on in the meeting, however, it became apparent that sorting out the definition of this particular class of knowledge was not the big issue. The attendees instead came to an agreement that regardless of what one calls priori knowledge, it is the utmost importance that science educators are aware of it, address it, and bring students to a revelation of it, while providing the learner with the tools to appropriately correct any inconsistencies with it (Modell, et al., 2005). Nevertheless, it is appropriate to provide a brief description of the seemingly interchangeable terms associated with this construct.

There are three terms, prior knowledge (Vosniadou & Brewer, 1987), misconceptions (Modell, et al., 2005), and alternate conceptions (Wandersee, 1994), used predominantly in conceptual change research that refers to an individual's existing knowledge and conceptions. Prior knowledge is regarded as simply knowledge that an individual develops during their experiences with the natural world before they are exposed to any specific instruction (Modell, et al., 2005). In addition, prior knowledge includes cultural and personal beliefs and theories (Petrie, 1976). Prior knowledge has been referred to as presuppositions, preconceptions, and naïve theories as well (Vosniadou, 1994). Misconceptions are regarded as knowledge frameworks or mental models that do not conform to accepted models, do not have the level of complexity to solve problems posed to the learner, or are not structured in a fashion that allows them to integrate properly with related models. Therefore, these conceptions are flawed (Modell, et al., 2005). Alternate conceptions are knowledge frameworks that learners develop after experience with particular science information either through formal instruction or informal interaction that allows them to make sense of a broad range of natural phenomena (Smith, DiSessa, & Roschelle, 1993; Wandersee, 1994).

Within the scope of the literature review of this present study, the terms utilized by conceptual change researchers to express priori knowledge will be used in the same manner as each particular researcher used the term when expressing priori knowledge in their study. Furthermore, Hewson and Hewson (1983) identified priori knowledge as consisting of both accepted conceptions and alternative conceptions. Therefore, it is the character of this form of knowledge, being already formed by the learner prior to new or any additional instruction, that makes it appropriate. As Modell, et al (2005) pointed out, it is not specifically what term a researcher or educator uses but the very fact that some respect is being paid to the existence of priori knowledge and its function and effect on learning.

Role of a Learner's Prior Knowledge and Conceptions

The repertoire of prior knowledge an individual possesses is categorized as a learner's conceptual ecology. Within the learner's conceptual ecology, described by the conceptual change model (CCM) proposed by Posner, et al (1982), new concepts become intelligible and plausible. An intelligible concept is one that the individual ultimately understands, understands pertinent aspects of it, and can accept its consistency without having to fully believe it is necessarily true (Hewson & Hewson, 1983; Posner, 1982). The components of a learner's conceptual ecology work in an integrated fashion. For example, analogies and metaphors derived from experience-based prior knowledge are used to assign meaning to a new concept, so that it becomes intelligible (Belth, 1977; Black, 1962; Ortony, 1975; Posner, 1982). If a concept is plausible, then the individual can come to believe that it is true and can integrate it with existing conceptions without too much difficulty. It helps to answer questions previously unanswered questions (Hewson & Hewson, 1983; Posner, 1982). An individual decides a new concept is plausible by reconciling it with prior knowledge components, such as other concepts, metaphysical beliefs and concepts, metaphysical concepts of science, and explanatory ideals composed of knowledge obtained from learning in other contexts, any competing concepts, and specific views of what involves an appropriate explanation of a phenomenon (Posner, 1982).

Hewson and Hewson (1983) investigated the effects of using a learner’s prior knowledge in conjunction with conceptual change teaching strategies on high school students studying physical science concepts involving mass, volume, and density. In their study, it was found that revealing students’ prior conceptions to them through conceptual change teaching strategies was significantly more effective at enabling the student to form the appropriate conceptions (Hewson & Hewson, 1983). Moreover, Hewson and Hewson (1983) outlined four categories of conceptual change teaching strategies that help an individual negotiate the interaction between prior knowledge and any new conception. The process involving of each of the four categories, integration, differentiation, exchange, and conceptual bridging describes how prior knowledge and new conceptions interact during conceptual learning. In addition, the four categories describe the basic functional roles of prior knowledge during learning.

Conceptual Integration. Integration involves the meshing of a new concept with existing conceptions or the integration of two or more different existing conceptions. This occurs once the learner decides that a new concept is intelligible and plausible. When integrating two or more existing conceptions, a learner decides that intelligibility and plausibility can be achieved by merging the existing concepts. This is very similar to Posner, et al’s assimilation outcome where a learner fits a new concept within an existing set of conceptions, or much like Carey’s (1985) weak restructuring that involves minimal changes to existing knowledge frameworks to allow the acceptance of the a concept. While observing kindergarten children’s patterns of conceptual change while learning the definition of “alive”, Venville (2004) determined the students preferred the assimilation of new facts into their existing knowledge frameworks over changing or revising their framework theories and beliefs and reversing what they believe. Ingram and Nelson (2006), described how the freshman students in their college biology course integrated information by fitting together pieces of their existing knowledge.

Differentiation. There are situations where a particular conception a learner holds is a large accumulation of several closely related concepts. The problem lies with the individual's inability to differentiate between the problem-solving ability of the individual concepts of the aggregate conception. Plausibility issues arise when challenged with unique problems and new conceptions introduced to solve them. Therefore, the learner needs to have the ability to differentiate between existing conceptions and their ability to solve separate problems and answer different questions. DiSessa (1998) described this situation occurring when students, while learning physics concepts, improperly categorize concepts into an inappropriate co-ordination class consisting of related concepts. Strommen (1995) found that first-grade students incorrectly described where certain animals lived due to the inability to accurately differentiate between something being an animal versus a plant and where animals can be found.

Conceptual Exchange. Conceptual exchange takes place when an existing conception is replaced with a new conception. This exchange occurs due to an incompatibility between the existing conception and the new one that creates cognitive disequilibrium or dissatisfaction for the learner (Posner, 1982). The learner realizes the existing, prior conception is incapable of answering a question or solving a problem, but a newly introduced conception does have the ability. In addition, an individual can come to realize that an existing conception is no longer plausible in light of the information provided by a new conception. The exchange of an inappropriate existing conception with the appropriate one, in its simplest form, is the basic process of conceptual change learning. Looking deeper into the processes of conceptual learning, investigators have determined that conceptual exchange can take place among the categorization of concepts where the learner reassigns the concept to a more appropriate ontological category. Chi, Slotta, and De Leeuw (1994) posited that students assign concepts to ontological "trees" when they are exposed to science information. Misconceptions are then generated when the student assigns the concept to the wrong tree, such as assigning the concept of heat to a "matter" tree as opposed to a "process" tree. Conceptual change occurs regarding a particular concept when a student realizes through instruction the concept was wrongly assigned and they swap the ontological tree to a new correct tree (Chi, Slotta, & de Leeuw, 1994). DiSessa's (1998) description of conceptual change through categorization and re-categorization of concepts into coordination classes also exhibits conceptual exchange characteristics. On that same token, Chi, et al's (1994) ontological tree swapping can involve a need for differentiation among existing concepts. This would suggest either a hierarchical or stepwise mechanism to conceptual change involving the four process categories. None the less, instances such as this reveal the complex nature of learning.

Conceptual exchange is regarded as the most appropriate process for learning science concepts. Several studies have described the mechanisms of conceptual exchange and analyzed teaching practices effective at fostering conceptual exchange (Baldy, 2007; Banet & Ayuso, 2003; Ebenezer, Chacko, Kaya, Koya, & Ebenezer, 2010; Harrison, 1996; Hynd, 1994; Rowell, 1990; Trundle, et al., 2002). However, additional research has shown conceptual exchange to be somewhat short-lived (Trundle, et al., 2007b).

Conceptual Bridging. Conceptual bridging is a process where a learner uses existing knowledge and conceptions to build a link between what they already know and understand with new science information. To do this, the learner must place the existing concepts in a context with the new concept that has common attributes. This helps the learner to conclude the new concept is intelligible, plausible, and meaningful (Hewson & Hewson, 1983). Georghiades (2006) states that "Context can range from the setting of a story in a textbook or the circumstances under which a problem seeks a solution, to broader school or social environments of the pupils" (p.30). The key function in this process is the context of existing conceptions and how they relate to a new conception. Contexts fruitful for making meaning involve cognitive processes, but are influenced by context associated aspects of metaphors, interpretive frameworks, emotions, values, and aesthetics (Bloom, 1992). In a study designed to determine how well middle school students can use their knowledge of electrical currents in unrelated contexts, it was determined that the students had difficulty due to their need to first identify their existing knowledge and how it might apply to the problem and then how to apply their existing knowledge in the new setting (Georghiades, 2006). Bryce and MacMillan (2005) studied how high school students used their prior knowledge of action-reaction forces as analogies to bridge the concepts and refine their existing knowledge to foster a better conceptual understanding of the concepts.

Determining, Assessing, and Remediating Learners' Prior Knowledge

The assessment of prior knowledge, conceptions, misconceptions, and alternate conceptions has occurred via several different research methodologies. The two methodologies that have been used extensively are: 1.) The determination, assessment and analysis of specific prior knowledge and science conceptions. 2.) The effects of different instructional strategies on prior knowledge and conceptions. However, a number of studies have both assessed and analyzed prior knowledge and investigated the effects of an instructional intervention on remediating deficiencies in the learners' conceptions (Afra, Osta, & Zoubeir, 2009; Banet & Ayuso, 2003; Johnson, 2002; Piquette & Heikkinen, 2005). Research projects utilizing the two methodologies have carried out data collection methods that included interviews, pre/post-tests, and observations.

Determining & Assessing. Researchers have concluded that understanding the prior knowledge of an individual is essential in order to advance knowledge of a science concept. In their efforts, investigators have worked to clarify what conceptions learners hold regarding particular science concepts, as well as how contextual and affective aspects can influence a learner's conceptions.

A large body of research exists that has uncovered learners' science conceptions, including specific and defined topics within a science discipline. Most researchers choose to focus analysis on two or more related topics within a discipline. A traditional research project concentrating on prior knowledge will have two to three threads weaving it together; assessing and/or analyzing students' existing conceptions, analysis of the effects of a teaching strategy or intervention, the function of contextual and affective elements, and a theoretical frame related to conceptual change theories and models (Afra, et al., 2009; Banet & Ayuso, 2003; J. E. Dove, Everett, L. A. , Preece, P. F., 1999; Johnson, 2002; Piquette & Heikkinen, 2005; Trundle, et al., 2002).

Studies of students' prior knowledge cover a broad range of specific science topics ranging from the physical science disciplines to the biological sciences. In physics and chemistry, topics include electricity (Afra, et al., 2009; Chambers, 1997; Planinic, Boone, Krsnik, & Beilfuss, 2006), evaporation (Canoplat, 2006; Chang, 1999), sound (Eshach & Schwartz, 2006; Linder, 1989), chemical equilibrium (Hackling, 1985; Piquette & Heikkinen, 2005), chemical change (Hesse, 1992; Johnson, 2002), chemical bonding (R. K. Coll, Treagust, D. F., 2002; Unal, Calik, Ayas, & Coll, 2006), and the atom (Ben-Zvi, 1986; Griffiths, 1992; Harrison & Treagust, 2000). In geology and the geosciences, conceptions related to geologic time (Dodick & Orion, 2003; Trend, 2000, 2001), the moon (Barnett, 2002; Jones, 1987; Trundle, et al., 2002), the seasons (Atwood, 1996; Hsu, Wu, & Hwang, 2008; Kikas, 2004), the water cycle (Dove, Everett, Preece, 1999; Taiwo, 1999), and weathering and erosion (J. Dove, 1997) have been investigated. Research into the biological sciences has uncovered alternate conceptions related to human circulation (Windschitl, 1998), evolution (Dagher & Boujaoude, 2005; Demastes, 1995), natural selection (Bishop, 1985) and evolution (Anderson, 2007; Banet & Ayuso, 2003; Bloom, 1989; Sinatra, eta al., 2003; Subbarini, 1983), genetics (Cho, 1985; Mbajiorgu, Ezechi, & Idoko, 2007), microbiology (Hilge, 2001), and cells (Zamora, 1993).

Remediating. Investigators have sought to determine the differences in effectiveness between traditional teaching methods (didactic and teacher-centered) and more constructivist teaching methods (learner-centered and integrated with conceptual change strategies). Edens and Potter (2003) found a significant difference in the conceptual understanding of the law of conservation of energy among fourth and fifth grade students after they were engaged in an instructional strategy that used learner-generated illustrations. The Common Knowledge

Construction Model (CKCM) lesson sequence was shown to significantly increase the knowledge of biological excretion in seventh grade students over students that were not exposed to the CKCM instructional strategy. In addition, qualitative results revealed that students exchanged prior conceptions with new conceptions, representing an improvement in their conceptual understanding after taking part in a CKCM lesson sequence (Ebenezer, et al., 2010). An instructional strategy that focuses on the learners' prior beliefs regarding a science concept called the Dual-Situated Learning Model has been shown to have the ability to foster radical conceptual change regarding matter (She, 2004). Hynd, McWhorter, Phares, and Suttles (1994) compared the effects of three instructional variables, viewing a demonstration, taking part in group discussion, and/or reading a refutational text, on ninth and tenth-grade students' conceptual learning of Newton's laws of motion. Reading a refutational text had the greatest effect on how the students' changed their conceptions, while group discussion of the topic had the least effect (Hynd, 1994). Introducing a critical reasoning and writing activity as an instructional intervention demonstrated significant improvements in seventh grade students' knowledge of HIV and AIDS over just a critical reasoning activity (Keselman, et al., 2007). Trundle, Atwood, and Christopher completed several studies involving instructional interventions aimed at remediating pre-service elementary teachers' conceptions regarding the phases of the moon. In two of the studies, the instructional intervention Physics by Inquiry (McDermott, 1996) appeared to address the deficiencies in prior knowledge and conceptions the students held prior to instruction (Trundle, et al., 2006; Trundle, et al., 2002). After six months, Trundle, Atwood, and Christopher (2007b) re-evaluated the pre-service teachers' conceptual understanding of the moon's phases and found the majority of them retained their scientific conceptions, but some had reverted back to the conceptions they held prior to the intervention.

Instructional aides such as textbooks and computer software/programs are commonly utilized during science instruction. However, traditional texts do not necessarily follow currently recommended constructivist teaching approaches. Special texts have been designed, and their efficacy as an instructional aide tested during instruction. In a study designed to analyze the effectiveness of conceptual change texts, Ozmen (2007) determined that tenth grade students using the newly designed texts experienced a significantly greater decrease in inappropriate alternate conceptions involving chemical equilibrium over students that did not use the texts.

Computer programs offer supplemental instructional experiences other than teacher guided instruction and the use of textbooks. Computer simulations are regarded as close approximations of reality and are effective in addressing alternate conceptions (Windschitl, 1998; Zietsman, 1986). A computer simulation representing velocity concepts was shown to determine and remediate alternate conceptions among high school students (Zietsman, 1986). Windschitl and Andre (1998) found that a constructivist learning environment created through the use of computer simulations on the human circulatory system resulted in significantly greater conceptual change for their undergraduate participants. However, Carlsen and Andre (1992) determined that the addition of a computer simulation to the use of a conceptual change oriented text did not increase the incidence of conceptual change regarding electrical circuits versus the use of the text alone. Likewise, Sanger (2000) investigated the effects of adding computer animations to a conceptual change instructional intervention on electron flow in aqueous solutions and found that the addition of the animations did not have an affect on students' responses to conceptual questions. The investigator suggested the computer animations may have been a distracting factor instead of a constructive one (Sanger, 2000).

Others have approached conceptual change teaching by addressing students' prior knowledge in unique ways. Rivet and Krajcik (2008) purposefully contextualized the concepts of motion, velocity, acceleration, and force onto everyday experiences encountered by eighth-grade students. Analysis of pre and post-test assessments and student generated artifacts showed a strong positive correlation between the effects of contextualized instruction and an increase in the support of learning (Rivet & Krajcik, 2008). Bryce and MacMillan (2005) reported positive effects of using analogies to bridge prior conceptions and new topic information to develop an understanding of action-reaction forces in physics. For some of their high school participants, the use of bridging analogies was more effective in fostering conceptual change over traditional teaching methods (Bryce, 2005). Changing the role of the teacher by placing the learner in charge of determining the conceptions they hold, providing them with the appropriate conceptions, and allowing them to consciously make any necessary adjustments has been shown to be effective among elementary students learning about force and motion (Beeth, 1998).

As shown by these many studies determining, assessing, and remediating a learner's prior knowledge, alternate conceptions, and misconceptions have been a focus. Analyzing relationships between factors that influence conceptual change learning and the occurrence of specific prior knowledge has been understudied. Typical studies in the research literature involve identifying a learner's conceptions or prior knowledge of a science concept and then employing a teaching strategy to affect a change in their conceptions. However, the majority of the investigators of these studies make no analysis of specific factors that have been shown to influence the conceptual change of science concepts. These factors include the status given to a concept, controversial or non-controversial, and their intentions toward learning the concept. Furthermore, the relationship between a learner's thinking disposition, utilization of prior knowledge, and whether they learn a concept has not been investigated. This study attempts to assess an individual's prior knowledge before and after an instructional intervention and to analyze how an individual's prior knowledge and thinking disposition affects their learning.

Prior Knowledge and Reasoning Ability

An individual's prior knowledge plays an important role in determining the process and outcome of learning a particular science concept. The function of prior knowledge and conceptions is to: 1) offer a means and mechanisms to integrate new concepts, 2) exchange old concepts for new and appropriate ones, 3) allow for the differentiation between plausible conceptions and those that no longer have utility, 4) and to establish bridges or connections between abstract scientific conceptions and meaningful common knowledge. Other components that have been identified as functioning in tandem with a learner's prior knowledge are reasoning ability and thinking disposition. An individual's thinking disposition has been found to be related to how one chooses to reason during certain learning tasks (Stanovich & West, 1997, 2007).

Reasoning ability is divided into formal reasoning patterns and informal reasoning patterns. Formal reasoning includes the ability for the learner to recognize the logic behind the evidence that is given to support a scientific conception, and how such evidence contradicts naïve prior knowledge constructs (Lawson & Thompson, 1988; Posner, 1982). Furthermore, formal reasoning patterns are involved during the evaluation of alternative conceptions in a logical hypothetico-deductive way that allows the learner to overcome prior misconceptions and ultimately choose the more scientifically accurate conceptions (Lawson & Thompson, 1988).

Lawson and Thompson (1988) describe how misconceptions are not the results of a misunderstanding regarding a science concept or simply a case of the learner forgetting any previous knowledge about the concept, but they are strongly embedded alternative conceptual frameworks used for the interpretation of natural phenomena. With this perspective in mind, Lawson and Thompson (1988) suggested four attributes about a learner that gives the learner the ability to resolve their misconceptions. These four attributes are formal reasoning ability, mental capacity (working memory), verbal intelligence, and cognitive style. Working with seventh-grade students as they were introduced to various genetics topics and their relationship to natural selection, Lawson and Thompson (1988) found that out of the four attributes only formal reasoning ability was significantly related to the number of misconceptions held by the seventh-graders. When considering the effect of the students' prior knowledge, the researchers contend it is an entity to be modified or rejected, and is dependent upon whether the learner has developed into a formal operational thinker from a concrete operational one. Thus, concrete operational learners are less likely to reject their naïve prior knowledge because they do not have the requisite skills to allow them to reason effectively, but a formal operational learner would possess the right skills and reject their naïve prior conceptions for the correct scientific one (Lawson & Thompson, 1988). Lawson and Weser (1990) followed up with a study involving college students' reasoning ability concerning several scientific conceptions covered in a non-majors biology course. Reasoning was categorized as intuitive or reflective, with intuitive being regarded as less-skilled and synonymous with concrete operational, while reflective was aligned with formal operational. From this study, the investigators concluded that students less skilled in reasoning held on to their nonscientific beliefs (prior knowledge) even after instruction. Sungur and Tekkaya (2003) came to similar conclusions to those of Lawson and Thompson (1988) and

Lawson and Weser (1990) when they investigated tenth-graders' achievement of human circulatory system concepts. In their study, Sungur and Tekkaya (2003) found satisfactory achievement of the concepts to be significantly related to the level of reasoning ability (concrete or formal) of the student.

However, these studies only focused on the relationships between reasoning ability and whether the learner changed their prior conception after instruction; reminiscent of conceptual exchange as described by Hewson and Hewson (1983). Moreover, these studies failed to determine the effect of any influence by prior knowledge on the remediation of naïve or inappropriate prior conceptions. Staver and Jacks (1988) evaluated eighty-three high school chemistry students' cognitive reasoning level, cognitive restructuring ability, disembedding ability, working memory capacity, and prior knowledge before and after an instructional intervention focusing on balancing chemical equations. The authors determined that prior knowledge had a significant effect on the students' understanding of balancing chemical equations, whereas reasoning ability failed to show any significance in their hierarchical regression analysis (Staver & Jacks, 1988). Using syllogistic reasoning and explanation to foster a change in prior conceptions, Park and Han (2002) showed that middle school students learning about force and motion rejected the scientific conception because the conclusion drawn out during the reasoning task contradicted their prior conceptions. Park and Han's evidence revealed that logical thinking could be effective in helping a student change their prior conceptions regarding force, but there are four factors that would constrain a student's deductive reasoning. Included in their four factors is the necessity for a learner to draw conclusions based on the given syllogistic premise and not from any of their prior knowledge, beliefs, or expectations (Park, 2002). This assertion illustrates a connection between prior knowledge and reasoning ability.

Furthermore, recommending a disconnect between a learner's prior knowledge and the content of the premise while implementing a conceptual change intervention using syllogisms is contradictory to Staver and Jacks (1988) findings regarding the significance of prior knowledge on conceptual learning and reasoning. While introducing their study of the effects of reasoning skill, prior knowledge, prior belief, and religious commitment on the rejection of a belief in Special Creation, Lawson and Worsnop (1992) describe the view held by several researchers "…that prior declarative knowledge is the most important consideration in determining what a student will or will not learn." In addition, the authors provide David Ausubel's (1978) often quoted passage that includes the statement "The most important single factor influencing learning is what the learner already knows." However, Lawson and Worsnop offer information from a personal communication from Ausubel where he warns not to interpret the word "knows" too narrowly, that it not only can be interpreted to include content specific declarative knowledge but procedural knowledge, including deductive reasoning ability. Results from their study (Lawson & Worsnop, 1992) indicated that the best predictors of post-instruction knowledge was the learner's reflective reasoning ability (formal operational) and prior knowledge. Furthermore, the authors (Lawson & Worsnop, 1992) contend "that knowledge, once acquired, then determines what one believes." These findings support the importance of prior knowledge as a major contributor to the nature and character of science conceptions subsequently learned, regardless of when the learner obtained the prior knowledge relative to the learning of any new conceptions.

Informal patterns of reasoning come into play during the negotiation of complex problems that are rooted in socioscientific issues, open-ended, ill-structured, and are often contentious (Sadler, 2004; Sadler & Zeidler, 2005c). Informal reasoning underlies a learner's opinions and attitudes toward scientific concepts and involves ill-structured problems that do not have a definite solution, and therefore often involves inductive reasoning instead of deductive reasoning patterns (Zohar & Nemet, 2002). Much like formal reasoning, an individual's informal reasoning ability is supported by an adequate understanding of the issue in question (Sadler & Zeidler, 2005c). Keselman, Kaufman, Kramer, and Patel (2007) point out that reasoning undertaken within a social context is critical reasoning, but it has some differences as compared to scientific reasoning that occurs during research and experimentation.

Socioscientific issues are regarded as the venues for eliciting informal reasoning. These issues comprise scientific and technological knowledge that run tangent to the broader understanding and beliefs of a society. The science and social factors are interdependent and both play central roles in the negotiation of the issue (Sadler, 2004). Since they involve the products and processes of science and create social debate and controversy, socioscientific issues are often regarded as controversial issues and call upon multiple perspectives during evaluation and discussion (Sadler, 2004; Sadler & Zeidler, 2005b). Topics that fall under this umbrella include cloning, stem cell research, global warming, alternative fuels, HIV and AIDS, and evolution (Sadler, 2004; Sadler & Zeidler, 2005b, 2005c; Wu & Tsai, 2007; Zohar & Nemet, 2002).

Through their work involving informal reasoning and socioscientific issues, Sadler and Zeidler (2004) determined that individuals display three distinctive patterns, 1) rationalistic, 2) emotive, and 3) intuitive, during decision making. Rationalistic informal reasoning is characterized by reason-based processes, emotive patterns involve emotions and care regarding an issue, and intuitive patterns involve immediate reactions involving the context related to the issue. During the resolution of a socioscientific issue, individuals typically rely on a combination of all three of the patterns (Sadler & Zeidler, 2005b, 2005c). Sadler and Zeidler assert (2004) that:

> "Just as scientists employ informal reasoning to gain insights on the natural world, ordinary citizens rely on informal reasoning to bring clarity to the controversial decisions they face."

For example, thirty college students participated in a study (Sadler & Zeidler, 2005b) designed to explore their informal reasoning patterns involving genetic engineering. The students displayed evidence of rationalistic, emotive, and intuitive forms of reasoning and relied on a combination of the three patterns as they established decisions regarding the genetic engineering issues. The authors describe how the students' reasoning incorporated both cognitive processes and affective elements, with the cognitive informal reasoning supported by logic and reason (Sadler & Zeidler, 2005b). In an additional example, Sadler and Zeidler (2005c) conducted a study of the significance of content knowledge in improving informal reasoning by college students in undergraduate natural science and non-natural science courses. The participants utilized all three patterns of informal reasoning when resolving the genetics issues. Moreover, the data revealed that variations in the quality of informal reasoning were directly related to the level of content knowledge related to the issue. Likewise, Wu and Tsai (2007) found that a student's level of scientific knowledge could be viewed as an important factor in generating better informal reasoning among tenth-grade students posed with an issue involving nuclear energy. Furthermore, students who made rational evidence-based decisions were more inclined to change their positions after being exposed to additional relevant information. Wu and Tsai's findings support those of Sadler and Zeidler regarding a relationship between content knowledge and informal reasoning, but Wu and Tsai explain that the tenth-graders in their study provided arguments that lacked scientifically supported information, even though the students had previously been exposed to instruction regarding nuclear energy. This would indicate, at least, a disconnection from knowledge of the concept and the quality of the argument developed during informal reasoning. Kolstoe (2001) argued that a student's knowledge obtained during learning about a science concept can be used effectively for informal reasoning and decision making regarding controversial issues. However, Sadler and Zeidler (2005c) assert it is intuitive to think that a direct relationship between content knowledge and informal reasoning ability exists, but research findings do not offer any convincing support for this position. Furthermore, there has not been any investigation into the direct effects of prior knowledge on rationalistic, emotive, and intuitive informal reasoning patterns.

While informal reasoning is rooted in intuitive and emotive actions that may or may not be rational in nature or supported by any amount of content knowledge, formal reasoning on the other hand is based on rational, logical, deductive processes stemming from a wealth of content knowledge on the issue. As Wu and Tsai (2007) pointed out, formal reasoning and informal reasoning appear to be opposite forms of reasoning based on any literal interpretation, and there are indeed some particular distinctions. However, similarities and interconnections among informal reasoning patterns and formal reasoning patterns are found and can be made. Formal and informal reasoning are both recognized as rational processes (Kuhn, 1993; Sadler & Zeidler, 2005b, 2005c; Wu & Tsai, 2007). Tweney (1991) insists that even though the information provided by scientific endeavors may be presented in a formal reasoning format, the actual results were obtained through informal reasoning. In addition, for both formal and informal reasoning, a degree of knowledge regarding the problem or issue is beneficial for the development of informed decisions. Such informed decisions are the result of changes in conceptual understanding through conceptual change mechanisms as a result of the process of reasoning (Duncan & Reiser, 2007).

It has been established that prior knowledge is a key indicator in the quality and ability to reason formally. However, less is known about the role of prior knowledge and conceptions in informal reasoning as compared to formal reasoning. Investigators of informal reasoning contend this is due to the nature of the content and the problems and issues it generates. Issues (science content) taken up during formal reasoning are well-defined, explicit, clear, and have clear-cut solutions, where issues tackled from an informal perspective are ill-defined, ill-structured and possess logical reasons that both support and refute their foundation, thus rending the content controversial and open to analysis from multiple perspectives (Wu & Tsai, 2007). Multiple-perspective analysis by a learner involves a variety of elements, one of which is prior knowledge. Investigators have shown that prior knowledge or knowledge gained prior to reasoning and learning about a science conception affects both the reasoning process and the outcome of learning (Lawson & Thompson, 1988; Lawson & Weser, 1990; Lawson & Worsnop, 1992; Park, 2002; Sadler & Zeidler, 2005c; Staver & Jacks, 1988; Sungur & Tekkaya, 2003; Wu & Tsai, 2007). Moreover, several authors of formal and informal reasoning studies either theoretically founded their work or based the discussions of their findings, or both, on conceptual change and conceptual change learning theory (Duncan & Reiser, 2007; Georghiades, 2006; Lawson & Thompson, 1988; Lawson & Weser, 1990; Lawson & Worsnop, 1992; Oliva, 2003; Park, 2002). The question that has not been answered fully focuses on what direct effect prior knowledge has on reasoning and thus conceptual change. To try to elucidate some points of the direct effects of prior knowledge, several researchers from the discipline of cognitive science have looked into reasoning by learners independently of prior knowledge. In doing so, the researchers have analyzed what is referred to as a learner's cognitive disposition (Baron, 2008; Sa, Kelley, Ho, & Stanovich, 2005; Stanovich, 1999; Stanovich & West, 2007).

Thinking Disposition

Cognitive disposition, otherwise known as thinking disposition, is an attribute of an individual that dictates how they view information from the perspective of critical thinking and reasoning. Stanovich (1999) offered other ways of describing and assessing thinking disposition through the use of other terms found in the research literature; such as intellectual style, cognitive emotions, inferential propensities, epistemic motivations, and habits of mind. Moshman (1994) and Stanovich (1999) describe how these terms are used similarly to refer to psychological mechanisms and strategies that remain stable over time, tend to generate characteristic behavioral tendencies and tactics, and are derived from dispositions that lie at the interface of cognition and affect, motivation, social relations, and cultural context.

Thinking disposition reveals how a learner addresses their prior knowledge and prior understanding of an issue, a situation, or content information as they reason, make judgments, and come to conclusions through formal and informal processes (Sa, et al., 2005; Stanovich & West, 1997). Thinking dispositions are mediators of the production of rational or irrational decisions, and they are related to a learner's belief formation, belief identification, and decision making that involves weighing new evidence strongly or lightly against a belief, or to weigh the opinions of others strongly or lightly in forming a belief of their own. This propensity is directly related to the notion of open-mindedness. The character of an individual's thinking disposition is an indicator of their openness to new ideas, or their tendency to consider all ideas, opinions, and information in a decision making situation, including the decision to learn a science concept (Stanovich & West, 1997, 2007). Therefore, an individual that possesses a disposition toward more open-minded thinking would exhibit a tendency to learn science concepts that do not align with their existing beliefs, views, and prior knowledge (Sinatra, et al., 2003). Moreover, these tendencies are not domain general but are applied over a learner's spectrum of knowledge, and thus have a fair degree of domain specificity. While studying the relationship between natural my-side bias and cognitive ability among college students, Stanovich and West (2007) concluded that there is no domain generality regarding the influences of thinking dispositions. If a person shows a high degree of belief bias in one domain, it does not imply they will exhibit a high degree of bias within another domain (Stanovich & West, 2007). Sinatra, et al (2003) studied the relationships between undergraduate college students' understanding and acceptance of evolution (a controversial science topic) as opposed to photosynthesis (a non-controversial topic) and their cognitive (thinking) disposition. The researchers determined that participants who displayed a more open-minded disposition were more likely to accept human evolution, but there was no relationship between a student's level of open-mindedness and their acceptance of photosynthesis. In addition, it was found that no relationship existed between a student's knowledge and acceptance of evolution, yet a significant relationship existed between a student's knowledge and acceptance of photosynthesis. These findings speak to domain generality and domain specificity differences regarding how students negotiate science content. As the authors noted, this stands in contrast to Lawson and Worsnop's (1992) assertions that it is merely a deficiency in one's content knowledge of an issue that constrains a learner's ability to reason appropriately and experience a conceptual change. Furthermore, Sinatra, et al (2003) argue their findings highlight the importance of thinking disposition during the learning of controversial science topics. The focus of this study is on thinking disposition and its relationship to learning a controversial science topic.

Open-minded thinking, sometimes referred to as reasoning independently of prior knowledge and beliefs, is regarded as the greatest degree of critical thinking since it allows the learner to view evidence, data, and arguments objectively (Stanovich & West, 1997). There is ample research evidence from cognitive science that shows prior knowledge and beliefs can bias reasoning (Stanovich & West, 1997). Within science education, there is no conclusive evidence on the full nature of prior knowledge's effects on reasoning and conceptual learning. However, it has been stressed that an accounting of a learner's existing knowledge and conceptions must be achieved in order to implement an effective intervention designed to address conceptions that are not correct or not appropriate. Unfortunately, the research on thinking disposition and its relationship to prior knowledge and learning science concepts is minimal. However, it has been concluded that habits of mind, such as open-minded thinking, are key elements in developing an acceptable level of scientific literacy (Coll, Taylor, & Lay, 2009).

Scientific habits of mind are beneficial to people regardless of their background (AAAS, 1990). These habits can aide people when dealing with content and issues that involve evidence, logical arguments, uncertainty, and can include characteristics such as open-mindedness, skepticism, rationality, objectivity, suspension of disbelief, and curiosity necessary for rationalizing, formal and informal reasoning, constructing arguments, and learning science concepts, including controversial ones (AAAS, 1990; Coll, et al., 2009). Scientific habits of mind lend to a flexibility of thinking that is essential for critical reasoning. Flexible thinking is directly related to actively open-minded consideration of information. Open-minded thinking involves an engagement in reflection, processing information that disconfirms one's beliefs, and willingly changing one's beliefs when presented with contradicting information that is strongly supported by evidence (Baron, 1985, 2008). Therefore, open-mindedness and thinking disposition operate in parallel and intersect with prior knowledge to influence reasoning and affect conceptual learning (Figure 1).

From the cognitive sciences, research into the effects of prior beliefs on reasoning has shown that an individual's thinking disposition and degree of open-mindedness can predict how they will evaluate the quality of an argument (Sa, West, & Stanovich, 1999; Stanovich & West, 1997). Macpherson and Stanovich (2007) conducted a study to evaluate college students' thinking dispositions as a predictor of critical thinking. The investigators found that thinking disposition was a significant predictor of the ability to overcome any belief bias regarding the reasoning task presented during the study.

In science education, research on the relationships of thinking dispositions, open-mindedness, and prior knowledge is limited. Coll, Taylor, and Lay (2009) analyzed the habits of mind of twenty practicing scientists across the physical and life-sciences through open-ended interviews. Coll, et al (2009) determined that among their scientist participants, their habits of mind varied greatly and were the products of prior knowledge and beliefs. Personal beliefs and scientific training both influenced the way the scientists formulated their thoughts regarding controversial topics. Moreover, the scientists explained how they are aware of the impact of a significant cultural element on their thinking (Coll, et al., 2009; Coll & Taylor, 2004). Sinatra, et al (Sinatra, et al., 2003) assessed the thinking disposition of their college student participants, and looked for any relationships between their disposition and the learning or acceptance of either a controversial science topic or a non-controversial science topic. However, Sinatra, et al (2003) did not evaluate any form of prior knowledge possessed by their participants regarding the topics. Therefore, no conclusion can be made, nor was one offered, regarding the influence of prior knowledge and conceptions. In light of limited work, there are still unexplored aspects surrounding the interplay of thinking disposition and prior knowledge.

Controversial Science Topics and Geologic Time

Topics in science are regarded as controversial due to conflicting, sometimes mutually exclusive, viewpoints held by individuals and groups that comprise our society (Dawson, 2001). The range of conflicting viewpoints offered regarding controversial topics are often based on alternative values upheld by significant groups that make up a society (Oulton, 2004). Issues that are considered controversial include a broad range of topics including genetic cloning, stem cell research, global warming, alternative fuels, HIV and AIDS, vaccines, evolution, waste disposal, energy conservation, and cell phone safety (Levinson, 2006; Sadler, 2004; Sadler & Zeidler, 2005b, 2005c; Wu & Tsai, 2007; Zohar & Nemet, 2002). Differing viewpoints on the gamut of controversial topics are derived from our social and cultural experiences with the natural world. These viewpoints provide the framework which we use to interpret the world around us (Oulton, 2004). Therefore, Kolsto (2001) explains that it is a significant aspect of democratic societies for lay-people to be involved, and promote their views on controversial topics by presenting quality arguments through proper reasoning. To accomplish this, citizens need scientific knowledge of issues and the science behind any evidence regardless of the topic. It is important to involve scientists as well as the general public in the discussions of science-related social issues to produce a better informed public (Kolsto, 2001).

This study addresses the controversial concept of geologic time. Geologic time has connections across several scientific disciplines, for example both the biological and physical sciences (Libarkin, et al., 2007), and resonates across social groups due to its direct relationship to a variety of viewpoints, beliefs, understandings, and values (Anderson, 2007; Trend, 2000). Geologic time is problematic for learners, but what confounds learners the most is the aspect of deep time. Deep time concepts are difficult because of the temporal component of billions of years, which is difficult to visualize and not a part of anyone's direct experience. In addition, deep time concepts consist of information that runs counter to what learners believe about the creation and age of earth and the evolution of its inhabitants and physical features (R. D. Anderson, 2007; Trend, 2000, 2001).

Research concerning student's prior knowledge and alternate conceptions regarding geologic time, including deep time topics, has been minimal. Trend (2001) contends that almost no research exists regarding the teaching and learning of deep time. Moreover, Dove (1998) conducted a meta-analysis of the research into earth science alternative conceptions and concluded that no studies focused on deep time. Trend (1998, 2000, 2001) embarked on a series of studies to analyze deep time conceptions held by school- age students, pre-service teachers, and practicing teachers. From these studies, Trend determined that certain misconceptions were common across all three groups. Schoon and Boone (1998) and Trend (2001) contend that an analysis of alternate conceptions regarding deep time is important because deep time is a major geoscience concept that can become a critical barrier to learning additional geoscience concepts if students do not possess a rich understanding of its aspects (Schoon, 1998; Trend, 2001).

The majority of research concerning geologic time has focused on determining what conceptions a learner possesses regarding earth science and geologic time. Trend (1998) investigated ten and eleven year old students' understanding of geologic time and determined they lacked a clear understanding of the chronology of time and related geological events. Working with pre-service elementary teachers, Trend (2000) found they hold very similar views of geologic time to those of ten and eleven year olds. In addition, in-service elementary teachers' conceptions of geologic time are similar to those of pre-service teachers and elementary students (Trend, 2001). It was concluded from this series of studies that each geo-event concept categorized in the deep time scale should interact appropriately with a learner's prior conceptions in order to foster additional learning (Trend, 2001). Libarkin, Kurdziel, and Anderson (2007) implicitly revealed Trend's notion in a study conducted to determine college students' understanding of geologic time. The college students did not have any difficulty in understanding the biological events that took place during earth's history, but had difficulty in framing and comprehending the time span between events. The authors suggested that the timescale of evolution was the barrier to developing a complete understanding of deep time in this case, and that evolution should therefore be taught explicitly during the instruction (Libarkin, et al., 2007). However, in all of these studies, no specific focus was made on prior knowledge or prior conceptions and how the learners related their prior knowledge to the geologic time concepts. Moreover, no relationship or interaction of the learner's thinking disposition with geologic time concepts was explored.

Geologic time offers two imbedded concepts, the age of earth and evolution, which propels it forward as a socio-scientific issue. Evolution, as a science concept, spans across all disciplines of physical and life sciences. It is a major framework in the geosciences and earth system sciences and is a major contributing factor to the controversial nature of geologic time. The scientific accounts of these two integrated concepts run counter to the views held by most individuals in society. Due to world view positions, most students and the general population are skeptical of the theories of evolution put forth by scientists (Anderson, 2007). Therefore, from a conceptual change perspective, teaching evolution or any other socio-scientific issue should be carried out in the social and intellectual context appropriate to the learner (Anderson, 2007). Furthermore, an evaluation of a learner's prior knowledge and thinking disposition should be carried out before instruction of such a controversial concept. To date, an investigation in the relationships among prior knowledge of geologic time concepts and thinking disposition has not been concluded.

The minimal research involving geologic time offers very little evidence of the effects of prior knowledge and conceptions on the learning of geologic time and related topics. Trend (2001) explained the necessity of understanding a learner's alternate conceptions of geologic time in order to effectively teach the material. However, Trend (2001), as well as Libarkin, et al (2007), stopped short of actually analyzing the effects of a learner's prior knowledge when learning geologic time concepts. Even though in each case, the researchers framed their work within conceptual change theory and expressed the importance of understanding a student's alternate conceptions. Trend (2000) explained the necessity of understanding geologic time within the broader context of Earth Systems Education; a curriculum that highlights the interconnectedness of all aspects of the planet from biological, geological, atmospheric, physical, etc. If such an approach is the goal, then "other knowledge" contained in a learner's conceptual ecology as described by Posner, et al (1982) must be considered. Due to conflicting views about the age of earth, earth's genesis (big bang theory/special creation), and evolutionary processes that have shaped earth over the millennia, geologic time has all of the necessary qualifications for being a controversial science topic.

Summary

A rich conceptual understanding of a science concept requires the interplay of several cognitive factors that include, but are not limited to, a learner's existing knowledge and alternative conceptions. In order for learning to occur, the individual must first become dissatisfied with their existing knowledge and conceptions that relate to the information being presented to them. The establishment of dissatisfaction for an existing conception is seen as pivotal in furthering the process of conceptual change. If the learner does not see any error with their existing conception, no conceptual change will take place. Evidence of the pivotal role of dissatisfaction and creating disequilibrium with existing conceptions is well established (Canoplat, 2006; J. Dodick, Orion, N., 2003; Hilge, 2001; Planinic, et al., 2006; Posner, 1982; Trundle, et al., 2002).

Once dissatisfaction occurs, changes in a concept proceed in a way that involves an individual's prior knowledge and prior conceptions. An individual's prior knowledge related to a particular science concept can be viewed as knowledge frameworks, knowledge schema, framework theories, or naïve theories that the learner uses to render the new information intelligible and plausible. Further involvement results in prior knowledge being changed either directly or in its relationship to the learner's broader knowledge related to the science concept. Hewson and Hewson (1983) outlined four interactive mechanisms between existing conceptions and new concepts that can be employed by a learner as a result of the introduction of new information. An existing conception can become *integrated* with a new conception the learner is internalizing. A learner can use their existing conceptions to *differentiate* what of their prior knowledge is fruitful, what is not, and how the new conception can fit into their broader framework of knowledge. Sometimes an existing conception lies in complete conflict with a new conception, and thus the learner will choose to *exchange* the old for the new. The abstract or multifaceted character of some science concepts makes them difficult to easily position them against existing knowledge. In this situation, the learner must *build bridges* between the new concept and existing concepts by placing the two sets of concepts into a relatable context. The specific mechanism utilized by prior knowledge might be a function of the science information, the context of the information, or the classroom environment. Nonetheless, evidence of all four mechanisms, integration (Keselman, et al., 2007; Trundle, et al., 2007b), exchange (Ebenezer, et al., 2010; Edens & Potter, 2003), differentiation (Strommen, 1995; Trundle, et al., 2006), and bridging (Bryce, 2005; Rivet & Krajcik, 2008) has been documented.

The fundamental role that prior knowledge and conceptions fulfill is to direct how new conceptions are formed during learning. Prior knowledge and conceptions make new conceptions intelligible and plausible either by exposing inherent inconsistencies that need reconciling or by supporting major restructuring or replacement of an existing conception. Furthermore, the prior knowledge and conceptions that learners have are resistant to modification or change. Much of a learner's prior knowledge and conceptions remain intact after exposure to instruction designed to identify and address inadequate prior knowledge. A mutually inclusive association is evident between prior knowledge and conceptual change learning (Barnett, 2002; Posner, 1982; Sanger, 2000; Vosniadou & Brewer, 1987). A great deal of research exists that has exposed the many alternate and misconceptions individuals possess regarding the full range of science content taught in public schools, colleges, and universities. Moreover, the research undertaken to reveal existing conceptions has been conducted in tandem with the evaluation of conceptual change teaching strategies and interventions designed to remediate misconceptions and assess the persistence of inappropriate prior knowledge frameworks (M. E. Beeth, 1999; Hewson & Hewson, 1983; She, 2004; Trundle, et al, 2002).

A learner's reasoning ability is regarded as an essential skill for the evaluation and the understanding of scientific information. Reasoning occurs formally or informally, with formal reasoning being based on rational thought, logic, evidence, and objective decision-making, while informal reasoning is regarded as being based on emotions, values, feelings, and subjective decision-making (Lawson & Worsnop, 1992; Park, 2002; Sadler, 2004). Research has shown that prior knowledge influences both forms of reasoning and that the learner employs both when learning science. In addition, studies have shown how difficult it is to reason independently of ones prior knowledge (Sa, et al., 2005; Stanovich & West, 1997).

Reasoning ability has been directly linked to the thinking disposition of a learner. A learner's thinking disposition describes the degree of openness to new ideas or open-mindedness (Moshman, 1994; Sa, et al., 2005; Stanovich, 1999; Stanovich & West, 1997). It is well supported that open-mindedness is a quality that allows for proper evaluation of newly presented science information, and that it is an important habit of mind for all consumers of the enterprise of science (AAAS, 1990; Coll, et al., 2009; Coll & Taylor, 2004). However, the research on the relationships among prior knowledge, thinking disposition and learning science content is minimal. Sinatra, et al (2003) provided evidence that supports the notion that thinking disposition can be a predictor of science learning. In addition, Sinatra, et al's (2003) study revealed that the character of the science content, controversial or non-controversial, can be a determining factor on the interaction of thinking disposition and science learning.

Controversial science topics are ones that intersect and cross social and scientific boundaries and are often regarded as socio-scientific issues (Dawson, 2001; Sadler, 2004).

These topics can come from any science discipline, as well as being integral parts of major concepts among the separate science areas. Controversial topics elicit both formal and informal reasoning patterns that are influenced by prior knowledge and negotiated relative to a learner's thinking disposition (Keselman, et al., 2007; Sadler, 2004; Sadler & Zeidler, 2005c; Sinatra, et al., 2003; Stanovich & West, 1997). The focus of this study is geologic time, a controversial science topic that as a part of an Earth Systems Science approach includes the disciplines of earth science, geology, physical science, and the life sciences. When dealing with geologic time concepts, it not only requires the learner to utilize their prior knowledge of earth science, geology, and biology, but the learner must consider prior knowledge derived from social institutions in relation to worldview positions (Trend, 2000). Research on prior knowledge and its relationship to learning geologic time is limited (Trend, 2001). Trend (1998, 2000, 2001) conducted three studies based on how prior knowledge is related to learning geologic time from the perspective of the learners' understanding of deep time and its connection with relative and absolute time. Libarkin, et al (2007) studied students' conceptions of geologic events and the scale of geologic time. However, none of these studies delved into reasoning or thinking dispositions, nor did these studies focus on geologic time as a controversial topic with a multiplicity of perspectives. Furthermore, research on the interaction of prior knowledge, thinking disposition, and learning controversial geologic time concepts has yet to be investigated. This study analyzes the relationship and patterns between an individual's prior knowledge regarding geologic time, their thinking disposition (open-mindedness), and their knowledge gain of new geologic time concepts.

CHAPTER III

METHODOLOGY

Rationale

Science education's greatest purpose is to prepare people to lead fulfilling and responsible lives by helping them develop an appropriate understanding of science concepts (AAAS, 1990). However, science topics exist that are fundamentally difficult for individuals to conceptualize due to being very abstract, complex, incongruent to one's beliefs, or a combination of all three. In addition, most science topics are open to interpretation from multiple perspectives. Whenever a science topic has multiple perspectives, no definite solution, and involves rich discussion from many viewpoints, it is termed "controversial". Controversial science topics are comprised of scientifically derived information and knowledge that has conceptual and technological connections with prevailing social institutions. In this sense, these topics can be regarded as socio-scientific issues (Sadler, 2004). Often, these topics are laden with emotion and deeply imbedded within social contexts (Sinatra & Mason, 2008).

Many controversial socio-scientific topics have been addressed through research in science education, including geologic time and its related topics. However, little research has been conducted on the effects of the relationships between a learner's prior knowledge, thinking disposition, and their content knowledge acquisition of geologic time (Sinatra, et al, 2001). A view into a learner's existing conceptions, and how they think about new information in relation to their existing conceptions is paramount in fostering conceptual understanding and change of a scientific conception (Posner, 1982). Furthermore, information pertaining to processes involved in prior knowledge and conceptual change learning of controversial science topics can be addressed (Sinatra, 2002).

Since one focus of this study was prior knowledge, assessment of the teachers' knowledge related to geologic time before attending was essential. In order to determine if a relationship existed between thinking disposition and learning, it was important to determine what teachers knew before instruction. By understanding what the teachers knew before instruction, a post assessment could be used to determine if any actual change occurred in the teachers' knowledge of geologic time as a result of the program. Pre and post assessments have been conducted on the conceptual learning on a variety of science topics (Trundle, et al., 2007a). The Geoscience Concept Inventory (GCI) used in this study was developed and used to assess geoscience conceptions held by learners using a pre and post testing format (Libarkin & Anderson, 2005b).

A second focus of this study was to analyze how science teachers made use of their existing knowledge and conceptions when learning geologic time concepts. Semi-structured interviews were conducted to obtain their personal perspectives of how they juxtapose their existing knowledge with the new information. The interviews were semi-structured to provide a focused initial prompt, but designed to allow the teachers to expand on their thoughts by moving the interview in a direction that would give them the freedom of full reflection. Hatch (2002) describes semi-structured interviews as the type where the researcher provides guiding questions, but the researcher is open to follow any leads the participant takes during their interaction together. Ultimately, interviews are a tool used for uncovering a participant's experiences and revealing their meaning when organizing and making sense of their worlds (Hatch, 2002). Semi-structured interviews have been used extensively in conceptual change studies to uncover a learner's existing conceptions and to determine what a student knows prior to instruction, after instruction, as well as to clarify the meanings behind the responses (Trundle, et al., 2002).

A third focus of this study was to capture the teachers' openness to new ideas through an analysis of their thinking disposition and its relationship to learning geologic time concepts. Patterns of reasoning involved with learning and decision making have been found to be related to an individual's open-mindedness (Stanovich, 1999; Stanovich & West, 1997). Furthermore, the character of the science topic being considered (controversial or non-controversial) will influence a learner's reasoning patterns. Prior content knowledge, thinking disposition, and a reasoning task are factors which have been implicated in affecting learning and acceptance of controversial topics. Sinatra, et al (2003) found differences in the relationships between college students' thinking disposition and their learning and acceptance of evolution, a controversial science topic, and photosynthesis, a non-controversial science topic, but they did not offer any information regarding the students' prior conceptions. Few studies have been undertaken to assess a learner's thinking disposition in relation to their prior concepts and level of knowledge gained regarding geologic time (Sinatra, et al, 2001; Trend, 2000, 2001).

Research Questions

The following research questions guided this study:

1. How do elementary and secondary science teachers appropriate their existing conceptions regarding geologic time when learning about concepts that are inconsistent with their existing knowledge and conceptions?
2. How is thinking disposition related to the learning of geologic time concepts?

3. What relationships are evident among the teachers' appropriation of prior conceptions, thinking disposition, and learning about geologic time?

Research Context

TENNMAPS MSP (Clark, et al., 2007) was a three-year professional development program whose primary component took place over ten consecutive days during the summer for a total of 60 contact hours and four follow-up days of six contact hours each for a total of 24 additional contact hours, two in the fall and two in the spring. For attending the program, each participant received about $1,000 in equipment, a stipend, graduate credit upon request, and on-site and electronic support of content and instructional materials throughout the school year.

TENNMAPS is the Tennessee-specific expansion of SE MAPS, a highly successful National Science Foundation-sponsored interdisciplinary educational product developed for eight states. TENNMAPS differs from the SE MAPS program in that the earth and environmental science program engages participants in exploration of landscape and cultural relationships through precisely aligned activities with local science standards (Audet & Jordan, 2003). For TENNMAPS, science content instruction preceded the study of map features, aerial photography, and remote-sensing imagery. The TENNMAPS professional development program was designed to provide grades 2-12 teachers of science with Earth Systems science content, coupled with demonstrations and hands-on activities that could be easily translated to the classroom since the examples were literally "out the teachers back door". The professional development instruction was designed to visualize environmental earth-science relationships (e.g., effects of geologic processes, topography, drainage, vegetation, effects of interaction with human activity), and then to use these to investigate thought-provoking open-ended problems by studying visible manifestations of cultural activities on maps and imagery (e.g., strip mining, pumped hydroelectric storage, agriculture, and urbanization). For science content covered during the programs**,** refer to Appendix A.

The TENNMAPS partnership included sixteen school districts, the Northeast Professional Development Center in the state, scientists from three Universities, and science educators. Teachers (grades 2-12) who taught science at least one period a day attended the professional development in groups encouraged by their principals, who were part of the partnership. School districts provided release time and substitutes for the teachers to attend the fall and spring post-program follow-up days that occurred during the school year. All of the professional development activities were offered in the geographic region where the teachers worked and lived except for one special event, the Earth Science Fair, which took place on one of the participating University's campus.

After the first year of the program it was identified, through evaluations by the partnership, that more reflection modeling and learning through peers was needed to achieve the goals of the program. In the second year of the program a component was added in which two experienced master teachers, identified by their school districts, modeled activities related to the specified earth science content. The two master teachers were from the same region as the participants. One was an elementary (2-6) science teacher, and the other was a secondary (7-12) science teacher. When participating in instruction modeling, the participants split into two groups, elementary and secondary, and selected the group relevant to their grade level. The master teachers employed a combination of content instruction integrated with teaching activities, along with a demonstration and explanation of the implementation of the activity. The master teachers self identified these activities based on the science content and the associated state standards. In this way the master teachers became classroom teachers of science and science pedagogy, and the participants of the institute became their students. To increase reflection and ongoing feedback, participants were encouraged to reflect in their notebooks and to ask questions each day based on their reflections. These questions were addressed each morning and each afternoon in large and small groups for each day of the professional development. Therefore, the modifications implemented in the second year included such components as asking participants to reflect on their learning, an emphasis on providing emotional support and encouragement, and modeling and learning through simulated classroom modeling experiences. Hanley, et al (2008) and others had previously identified these characteristics as having a positive effect on self-efficacy beliefs and experience. See Appendix B for a summary of the types of activities during summer, fall, and spring sessions.

The researcher was an integral part of the program from the design of each day's agenda. This included presenting information to the teachers regarding general pedagogy related to teaching science and national science teaching reform efforts. More importantly, the researcher served as a facilitator for overall implementation of daily activities for the ten-day component and the four follow-up days. In this role, researcher provided assistance and support to the instructional staff and master teachers. In addition, the researcher acted as an ombudsman and liaison between the teachers participating in the workshop and the instructional and administrative staff. In this multi-faceted role, the researcher developed a unique relationship with the teachers over the course of the program. The teachers regarded the researcher as a friend and a confidant. Most of the teachers felt relaxed and comfortable when interacting with the researcher, more so than when interacting with the workshop presenters and master teachers.

The increased comfort level felt among the participants and shared with the researcher offered the participants an opportunity to speak freely with the researcher formally as well as informally.

Participants

A different cohort of teacher participants attended each year of the program. However, there were seven teachers that attended all three consecutive years. The participants in this study were selected from year two (2008 – 2009) of the program. A total of forty-five teachers attended, with thirty-three of them being regular, full-time, grades 2-12 science teachers. From the pool of thirty-three teachers, fifteen were randomly selected for interviewing using the random number generator function in the Excel spreadsheet software (Microsoft Corporation, v. 2007) (Table 1). Each teacher had been sorted alphabetically and assigned a number just prior to running the random number generator. Random numbers were matched with the teachers' assigned number in the order the generator produced them. Next, each teacher was approached by the researcher and asked if they would be willing to take part in an interview related to learning Earth Systems science concepts. The teachers had the option to agree to take part or to decline to take part in the study. This process continued until the study participants were selected. During the random selection process, two teachers declined to take part in the study. All forty-five teachers attending the program signed an IRB-approved consent form and thus were aware of their option to take part in the interviews. The fifteen interview participants represented 45% of the total thirty-three science teachers that attended the program. The decision to draw a sample of fifteen instead of interviewing the total group was based upon

Table 1

Teacher-Participant Demographics

Teacher*	Gender	Years Teaching	Grades Taught	Undergraduate Degree	Graduate Degree
Angela	F	24	5	Performing Arts	Education
Ben	M	2	5	Elementary Education	-
Beth	F	30	3 - 4	*Did not report*	Education
Carrie	F	34	7	Biology	Education
Cindy	F	16	1	Education	Education
David	M	13	9 - 12	Health & Physical Ed	-
Hallie	F	13	9 - 12	Biology	Education
Jack	M	32	8	Biology	Education
Kathy	F	6	6	Education	Education
Kim	F	26	8	*Did not report*	Education
Laura	F	5	7	Elementary Education	-
Lois	F	1	7	Biology	-
Rena	F	12	K - 5	Biology	-
Sonya	F	15	2	Criminology	Education
Will	M	7	7	Biology	Education

*Pseudonym

logistics. Meeting with each of the thirty-three teachers would not have been feasible within the time-frame of the project due to the traveling distances between them.

Of the fifteen participants, eleven were female and four were male, with fourteen of them being Caucasian and one Asian-American. Teaching experience ranged from one year to thirty-four years. Seven of the teachers taught in the elementary grades (2-6), and eight of them taught in the secondary grades (7-12). Six of the teachers had an undergraduate degree in a science discipline, five of them had an undergraduate degree in education, two had an undergraduate degree in an area other than education or science, and two did not report. The two teachers with an undergraduate degree other than science or education had a master's degree in education. In all, nine had graduate degrees in education (Table 1). All of the participants lived and taught in the northeast region of state where the study and the program took place.

Research Methodology

This study utilized a mixed-methods design, with both qualitative and quantitative approaches to data collection and analysis. Data collection was conducted concurrently, where both the qualitative and quantitative data were gathered essentially at the same time. Therefore, this study can be categorized as a "concurrent triangulation design". According to Creswell (2009), this type of design affords comparison of data to determine any convergence or divergence related to associated theories. The use of separate qualitative and quantitative methods in this type of design is used to strengthen any weaknesses inherent in either method. In a concurrent triangulation design, the results of the separate methods are integrated during interpretation to strengthen claims (Tashakkori & Teddlie, 2003).

The qualitative data came from interviews conducted with the teachers. The interviews were initially open-coded and analyzed for patterns and themes. Next, they were coded through with a set of codes from the research literature. The coding scheme described the mechanism by which the teachers reconciled any conflict between their existing conceptions and the geologic time concepts (Hewson & Hewson, 1983). The logical and appropriate mechanism is an exchange of the old existing conception for the new correct one. This coding scheme provided a way to categorize the teachers' view of the interaction of prior knowledge and conceptions with new conceptions during conceptual change learning.

Quantitative data for the study was collected from the Actively Open-minded Thinking Scale (AOT) and the Geoscience Content Inventory (GCI). The AOT (Appendix C) is a psychometric measure that provided a snapshot of each teacher's thinking disposition. Thinking disposition is directly related to an individual's openness to new ideas and open-minded thinking. The AOT generated a quantifiable value for each participant's level of open-mindedness to be cross-verified with the description of their open-mindedness from the interviews. The GCI (Appendix D) measured the teachers' level of content knowledge that included geologic time. The data from the GCI was used to evaluate any changes in the teachers' level of geologic time content knowledge. The GCI results were juxtaposed with the AOT data and interview analysis data to determine the existence of any relationships regarding open-mindedness, prior knowledge and new concept interaction, in relation to learning outcomes.

Triangulation can be seen as having different but related functions. Glesne (2006) describes triangulation as the use of more than one data collection method to contribute to the trustworthiness of data. Hatch (2002) refers to triangulation as the comparison of data from differing sources, i.e. interview and observation data. For studies with a concurrent triangulation design, triangulation aims to compare and contrast quantitative results with qualitative findings (Tashakkori & Teddlie, 2003). The efforts of triangulation in this study were to reveal how the overlap of different facets of prior conceptions, thinking disposition, and learning specific science content might emerge, and add scope, depth, and breadth to the study through the integration of the qualitative and quantitative data (Creswell, 1994; Tashakkori & Teddlie, 2003). In addition, results from the coding and analysis of the interviews were compared to the descriptive analysis and results from both of the quantitative measures. For example, some of the interview questions were designed to reveal the teachers' perspectives on learning difficult (controversial) science concepts in a way that prompted them to reflect on their existing conceptions during the process. This allowed the researcher to capture their openness to new ideas. The interview results were compared to the teachers' results on the AOT in an effort to identify any congruence or incongruence between the two.

In addition, this study consisted of methods and methodology that are consistent with an exploratory design. An objective was to investigate aspects of a theory and to explore a phenomenon more closely (Creswell & Plano-Clark, 2007). This study focused on thinking disposition, an intentional-level cognitive construct, which has been investigated very little in science education. This includes the phenomenon involving prior knowledge's unique role in directing conceptual learning of geologic time concepts. Exploratory investigations similar to this current study use qualitative data to explore a phenomenon, and then use the interpretation of the qualitative data to connect to the quantitative data (Creswell & Plano-Clark, 2007). Furthermore, the study was exploratory in design due to research questions directing the investigation instead of the confirmation or disconfirmation of a hypothesis. Table 2 outlines the data sources, when the data was collected, how the data was analyzed, and alignment with the research questions.

Table 2

Data Sources

Data Source	Administered/Collected	Research Question	Analysis
Interviews	Pre/Post	1, 2, 3	QDA Miner-Coding & Reviewing
GCI	Pre/Post/Post-Post	2, 3	SPSS-Descriptive Stats & t-Test
AOT	Pre/Post	2, 3	SPSS-Descriptive Stats & t-Test

Data Sources

This section outlines and describes the physical methods used in this study to collect the data. The sources of the data, the time the data were collected, and how the data were analyzed are summarized and presented in Table 2.

Interviews

Fifteen participants were randomly selected by arbitrarily assigning a number to each participant and then generating random numbers using the Excel spreadsheet software. A semi-structured format was chosen for the interview protocol. The interview protocol consisted of ten prompting questions that allowed a participant to answer them as openly and candidly as they desired. Appendix E lists the guiding questions used for the interview. A semi-structured format was chosen to give the teachers full opportunity to describe their thoughts and experiences. Semi-structured interviews proceed through the researcher providing guiding questions, but the researcher is open to follow any leads the participant takes during their interaction together (Hatch, 2002). In addition, the interviewing mode taken up by the researcher had phenomenological characteristics. Phenomenological interviews are used to extract the description of an experience as told by the participant. They are regarded as conversations where the participants are encouraged to share their experience (Valle & Halling, 1989).

The goal of the interviews was to obtain a description of how each teacher internalized controversial socio-scientific information. Phenomenological interviews are often theme-based as well (Valle & Halling, 1989). The theme that grounded the interviews of this study was conceptual change learning as influenced by open-mindedness. The process used for the interviews was framed in a semi-structured format to ensure adherence to the topic, but was open and fluid as well. Valle and Halling (1989) explain that even though each interaction in phenomenological interviewing is individualized, the researcher must stay disciplined and focused on the research objectives. Hatch (2002) supports this view and states that a phenomenological interview can be formally structured by the researcher providing the same opening question each time to get their participants talking. For example from my study, each participant was prompted by asking a variation on the question "What parts of Earth science are more difficult for you to understand?" The movement of the interview as directed by the participant's responses dictated how I would structure a variant of this question, as well as all questions. One variant example was "…what parts, theories, ideas, concepts have been the most difficult for you to understand?" Responding to this prompt, a teacher would typically identify some concept related to Earth science or science in general. This would be followed up by a question asking the participant to expand on the parameters around this concept. For instance, during one interview, a participant referred to “time” in the course of responding to the initial question. The follow-up question by the interviewer was, “Does time give you a problem?” The conversation then proceeded from that point.

The interviews were designed to provide information to address the first and third research questions. Interview questions 4 through 9 prompted the participants to reflect and talk about how they position controversial science information. Their responses revealed how they negotiated controversial science information with what they already knew about the concept along with other knowledge they possessed that was directly or indirectly related to it.

Initial interviews were conducted during the ten-day summer sessions. The interviews took place individually in a quiet, private area during non-activity times. Each interview was audio-recorded and lasted between fifteen and forty minutes. Follow-up member-checking interviews with the teachers occurred throughout program. The follow-up interviews were conducted during planning, break, or free periods in the teachers’ classrooms, and were used as member checking opportunities by the researcher to clarify aspects of the pre-interview, or to have the teacher expand more on a theme. A total of 375 minutes of interview time were recorded for an average of 25 minutes per teacher. The follow-up interviews consisted of a more open format since questions directed at clarification and elaboration were employed instead of specifically following the pre-interview script. However, occasionally a teacher would request for an original interview question to be repeated to re-establish the context.

Geoscience Concept Inventory

The teachers' level of content knowledge of earth science, pre and post-program, including geologic time concepts, was determined using the Geoscience Concept Inventory (GCI) (Appendix D). The GCI developed by Libarkin and Anderson (2005a) is a multiple-choice instrument designed to determine the level of conceptual understanding of several main concepts in physical geology. This widely used multiple-choice assessment instrument has been adopted by college faculty and high school teachers for entry-level earth science courses. The test is based on common misconceptions and was developed and validated through a unique mixed-methods approach that required an extensive and iterative methodology to ensure that the test items were reliable and valid. Seventy-three items have been validated through test item analysis using item response theory and Rasch analysis.

From the seventy-three validated questions, a subset of forty questions was chosen that aligned with the state science curriculum standards and TENNMAPS program content. The questions were evenly distributed along the Rasch difficulty scale. The GCI administered to the teacher participants was a second iteration of the forty-question subset. The test had been reanalyzed and better realigned with program and state standards content to produce a measure that more accurately reflected content selected for the program.

The GCI was administered a total of three times during the program. First in the morning on the first day of the summer sessions and the beginning of the program, after announcements and introductions, next on the afternoon of the last day of the two week summer session, and finally in the afternoon of the last follow-up session held in the spring. Among other things, the pre and post scores from the GCI from the summer session were used to plan instructional activities for the follow-up sessions during the fall and spring.

Actively Open-minded Thinking Scale

The Actively Open-minded Thinking scale (AOT) (Appendix C) is a Likert-style measure designed to assess an individual's cognitive or thinking dispositions. Thinking disposition is an intentional-level cognitive construct as opposed to an algorithmic cognitive process. Thinking disposition is regarded as a stable psychological mechanism that generates characteristic behaviors and tendencies within an individual (Stanovich, 1999). Thinking disposition can be regarded as a person's tendencies toward thinking and learning, and thus gives a description of how a learner uses their knowledge and beliefs to affect learning outcomes (Baron, 2008; Sinatra, et al., 2003; Stanovich, 1999).

The AOT is a composite scale derived from several measures empirically designed to analyze the nature and structure of an individual's thinking disposition reflected as actively open-mined thinking. Stanovich and West (1997) developed the first AOT scale composed of the Flexible Thinking Scale (Stanovich & West, 1997), the Belief Identification Scale (Sa, et al., 1999), the Absolutism subscale from the Scale of Intellectual Development (Erwin, 1981, 1983), the short-form field version of the Dogmatism Scale (Troldahl & Powell, 1965), the Categorical Thinking subscale of the Constructive Thinking Inventory (Epstein & Meier, 1989), a Superstitious Thinking Scale (Stanovich & West, 1997), the Need for Cognition Scale (Cacioppo, Petty, Feinstein, & Jarvis, 1996), and the Social Desirability Response Bias Scale (Paulhus & Reid, 1991). Returns from the original scale were separated into the corresponding subscales and subsequently analyzed. The AOT was later revised as a composite measure which included the flexible thinking, belief identification, absolutism, dogmatism, and categorical thinking subscales consisting of forty-one questions (Stanovich & West, 2007). Others have assembled and administered different composite AOT scales (Sa, et al., 2005; Sa, et al., 1999), some with up to sixty-six question items (Sinatra, et al., 2003). Stanovich and West have conducted reliability tests on all of the available question items that can be used to assess cognitive disposition. In their latest analyses, for their 41 question item measure, the split-half reliability was found to be 0.75, and the Cronbach's alpha was 0.83 (Stanovich & West, 2007). Scales constructed from these sources can be either analyzed as a composite or disarticulated into their component subscales for analysis. However, Stanovich and West (2007) no longer calculate subscale statistics for the AOT, due to the high correlation of the subscales.

The AOT used for this study was constructed by assembling twenty-seven question items spread across the sub-scales of flexible thinking, belief identification, absolutism, dogmatism, categorical thinking, and need for cognition. The answer selections for the items ranged from 1 (strongly disagree) to 6 (strongly agree). A composite score on the AOT for each teacher was derived by first reverse-scoring questions that were negatively oriented and then summing the values for all of the questions. The lowest score obtainable on the measure, 27, indicates a complete lack of open-mindedness. Therefore, as the summed score increases, the degree of open-mindedness of an individual increases to a maximum value of 162, indicating a great deal of open-mindedness.

The pre-program administration of the AOT took place in the morning of the first day of the ten-day summer session, and was a paper form. Post-program administration of the measure occurred the week just prior to the final spring follow-up session. The post AOT was administered online with the MR-Interview software package by SPSS. Teachers were sent a link with instructions for completing the survey. All of the teachers completed the survey prior to attending the final spring session.

Data Analysis

Three research questions established the foundation of this study. The following descriptions detail the analysis of each data source. The first three sections detail the analysis of data from each source and how it corresponds to each research question. The fourth section describes how the data from all of the sources were analyzed to address the third research question (Table 2).

Interviews

Research question 1 focused on how the teachers used or appropriated their existing conceptions, and question 3 focused on the connections between the use of the teachers' existing conceptions, open-mindedness, and learning geologic time concepts. Both research questions 1 and 3 relied on the analysis of the appropriation of existing conceptions by the teachers. The interviews were coded using a set of codes adopted from Hewson and Hewson (1983). Four categories comprised the coding scheme. The categories described the interaction between the teachers' existing conceptions and geologic time concepts and indicated the teachers' appropriation mode regarding their existing conceptions. Following are the coding categories used for the study:

1. *Integration*. New concepts are integrated with the learners' existing conceptions. Modifications to existing conceptions, the new conceptions, or both take place during learning.

2. *Differentiation*. Existing conceptions and new conceptions are regarded as separate and independent of one another and become compartmentalized by the learners. However, they are related based on the problem both sets of conceptions are seeking to answer.
3. *Exchange*. The learner's existing conception is exchanged or replaced by the new conception.
4. *Bridging*. A link is established between the new conception and the learner's experience that creates meaning for the new concept and allows the learner to realize the concept is intelligible and plausible.

A typological approach was utilized for the coding and analysis of the interviews (Hatch, 2002). The four coding categories were regarded as typologies describing how the teachers appropriate their existing conceptions. Coding and analysis proceeded with the four typologies framing the analysis. The qualitative analysis software QDA Miner was used to code and analyze the interviews. Passages were read and labeled as integration, differentiation, exchange, or bridging using the highlighting function in the QDA Miner program. Once an interview was coded, an overall assessment was made regarding which appropriation mode was indicated by the responses. In addition, an assessment of the teachers' open-mindedness was determined via the analysis of the interview data and used to inform research question 3. A written summary for each analysis was generated to support the categorization for each teacher (Appendix F). Summaries included reflection and comments by the researcher and selected passages from the interview text.

Follow-up interviews with the teachers were conducted throughout the academic year. Follow-up interviews were used as an opportunity to engage in member checking with the teachers. The interpretation of a previous interview by the researcher was shared with the interviewee for clarification and elaboration on any pertinent point. The researcher and the interviewee would engage in a conversation regarding a particular point or passage until the researcher fully understood the meaning the interviewee intended by their statements.

Inter-rater Reliability

Inter-rater reliability was established between the researcher and three assistants that are teaching colleagues of the researcher. The assistants were familiar with the conceptual change model and its principles that served as the primary theoretical framework for this study. In addition, the assistants were trained on the coding scheme used for coding the interviews. Training involved providing the assistants with the background of the study, major aspects of the study's theoretical framework, the research questions for the study, how the codes and coding scheme were derived, and any additional information the assistants felt they needed.

Method. The directions given to the assistants were to code the provided interview using the coding scheme, determine the teacher's (interviewee) appropriation mode, and make an assessment of the teacher's level of open-mindedness. The assistants and the researcher coded an entire interview separately and made their assessments of appropriation mode and open-mindedness. The researcher and assistants came back together to share and discuss their results.

Coding of Passages. The four coded interviews were laid out side by side and reviewed for the number of passages coded and the code category assigned to each passage. Next the researcher and the assistants discussed each coded passage. A tally was taken for both the total number of passages and the number of passages coded for each of the four codes (integration, differentiation, exchange, and bridging). There was an 87% agreement among the total number of passages coded. Figure 2 provides data for the coding of specific passages for each code category. There was 79% to 100% agreement between the raters for the specific code category given to each passage (Figure 2). Discrepancies among the coded passages were discussed and reconciled among all four of the raters.

Appropriation Mode Determination. The researcher and the three assistants all independently coded and assessed the interview data for the teacher's appropriation mode. All four raters were in 100% agreement the teacher exhibit Integration appropriation of existing conceptions. The group discussed their opinions based on their coding of the interview for why they each selected integration appropriation. There was a 100% consensus among the rating group for their reasons for selecting integration appropriation.

Open-mindedness. The researcher and the three assistants all independently assessed the teacher to have a low level of open-mindedness. The group discussed their opinions regarding why they determined the teacher to have a low level of open-mindedness. There was 100% agreement and consensus in the passages selected by each rater used to provide evidence for their low-level rating.

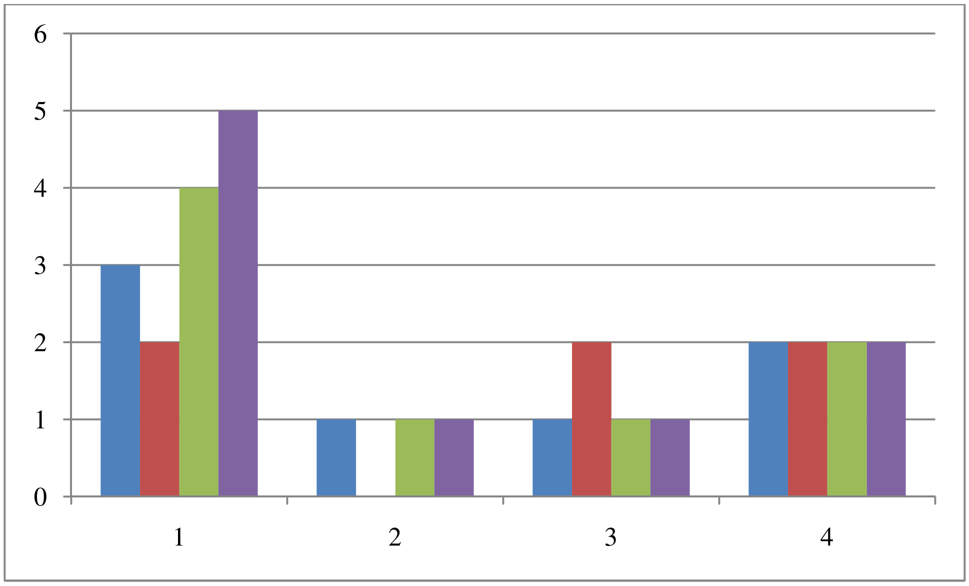

Figure 2. The occurrence of specific coded passages among the four raters for the determination of inter-rater reliability. Number 1 = Integration, 2 = Differentiation, 3 = Exchange, 4 = Bridging

Actively Open-minded Thinking Scale

Research questions 2 and 3 required the analysis of the teachers' thinking disposition. The AOT administered at the beginning of the ten-day summer session was used to analyze the teachers' thinking disposition. The statistical software SPSS 17.0 was used to generate all statistics for the AOT data. The data was first keyed into an Excel spreadsheet. All reflected data were reverse-scored to obtain the appropriate value. A composite score for each teacher was calculated by summing all the values for an individual teacher. Values for the separate sub-scales of the AOT were generated by selecting and summing the respective questions for each sub-scale. Next, the data were copied and pasted into an SPSS data spreadsheet. The data were arranged to facilitate analysis of a composite score as well as scores for the sub-scales. A set of descriptive statistics were generated by SPSS and tabulated. Pre and post scores for the AOT were analyzed. Repeated measures t-Tests were conducted to analyze any changes from pre to post program administration of the measure. Parameters for the t-Tests included two-tailed consideration and an alpha level equal to or less than .05. Effect size for statistically significant t-tests was determined by analyzing both the r^2 statistic and Cohen's *d*. Comparisons of the two sets of scores were made in order to identify if any changes were evident. Thinking dispositions are regarded as stable cognitive constructs that do not readily change over brief periods of time (Sinatra, et al., 2003; Stanovich, 1999; Stanovich & West, 1997).

Geoscience Concept Inventory

Research questions 2 and 3 required the analysis of the teachers' content knowledge. The pre-program, post-program, and post-post-program GCI's, administered on the first day (pre) and the last day (post) of the ten-day summer component and again after the fourth follow-up day (post-post), were used to analyze the teachers' geosciences content knowledge. The statistical software SPSS 17.0 was used to generate all statistics for GCI data. The GCI was hand graded by the researcher. Grading consisted of marking incorrect responses to each question. An Excel spreadsheet was built by first placing each teacher in a row and each question number on the GCI in a column. Next, the number 0 was assigned to any question answered incorrectly, and the number 1 was assigned to any answered correctly. Correct and incorrect responses were tabulated for each question for each teacher. Questions were grouped based on the primary geosciences conceptions they were designed to assess, singling out those specific to geologic time. The Excel spreadsheet was copied and pasted into SPSS. Descriptive statistics for both the composite results and results regarding geologic time were generated using SPSS. Descriptive statistics were run on the pre, post, and post-post GCI data. Repeated measures t-Tests were conducted to analyze any changes from pre to post and to post-post administration. Parameters for the t-Tests included two-tailed consideration and an alpha level equal to or less than .05. Effect size for statistically significant t-tests was determined by analyzing both the r^2 statistic and Cohen's *d*.

Relationship among Thinking disposition and Geologic Time Content Knowledge

Research question 2 specifically addressed the relationships between the teachers thinking disposition (open-mindedness) and geologic time knowledge prior to the program (pre), after the ten-day component of the program (post), and finally after the four follow-up days (post-post) of the program.

Pearson's correlations were conducted to determine the existence of any statistical relationships between the teachers' thinking disposition as determined by the AOT and their level of geologic time knowledge across the three administrations of the GCI. Prior to running the correlations, the statistical software package SPSS SamplePower 3 was used to determine if the study's sample of 15 would be an adequate sample size for conducting Pearson's correlations. For an Alpha level of $p = .05$, SamplePower 3 determined that a minimum sample size of 12 was needed to conduct a statistical procedure.

Relationships among Prior Conceptions, Thinking disposition, and Content Knowledge

Research question 3 focused on the apparent relationships among prior knowledge and conceptions, the teachers' thinking disposition, and their level of geologic time content knowledge prior to the program and post program activities. Since the sample size was relatively small, N = 15, and the research question required a more in depth and explanatory approach, individual and cross-case analysis was used. The results of the cross-case analysis specifically addressed the evidence of any relationships.

To analyze the relationships between prior conceptions, thinking disposition, and content knowledge, an Excel spreadsheet was built to create frequency distributions (Appendix F). Due to the qualitative interview data not being compatible with the continuous quantitative data from the GCI and the AOT, the interview data, AOT data, and GCI data were converted to ordinal numerical data to allow for the comparison of frequencies. The establishment of the ordinal categories provided a heuristic model to analyze and make sense of the data collected via the GCI, AOT, and interviews. The teachers were grouped according to their orientation, determined by the interview analysis, regarding the interaction of prior knowledge and geologic time conceptions; 1 = Integration, 2 = Differentiation, 3 = Exchange, 4 = Bridging. A level of open-mindedness, determined by the AOT, was assigned to each teacher. Table 13 lists the ranges of scores assigned to the degree of open-mindedness; low = 1, moderate = 2, high = 3. Performance on the GCI was used to determine pre and post levels of content knowledge of the all of the geology concepts covered, as well as geologic time concepts. Table 14 lists the ranges of scores assigned to the level of geologic time content knowledge; low = 1, high = 2.A teacher was assigned a three-digit number based on their observed levels. For example, a teacher could have been assigned a 1-3-2 number (Integration – High degree of open-mindedness – Moderate level of geologic time understanding). Only the frequencies of observed number combinations were tabulated.

Individual Case Construction and Analysis

Fifteen individual cases were constructed by juxtaposing interview data (summaries from coding and analysis), AOT data, and pre and post GCI data for each teacher (Appendix G). The interview data served as the primary source of data for writing each case. Specific textual components from the coded interviews were used to support the analysis and descriptions for each case. The AOT was used to compare differences between the teachers' returns on the measure, and their responses regarding how they view their existing knowledge in respects to the geologic time concepts that were taught. The GCI was used to compare changes in their level of content knowledge with their thinking disposition and appropriation of prior knowledge.

The interviews, interview summaries, and the Excel spreadsheet with the teachers three digit numerical information were placed side by side and reviewed for patterns, consistencies, and inconsistencies. Triangulation was achieved by the side by side comparison of the three sources of data. All three data sources reflected some aspect of conceptual change learning. A summary for each case was created that compiled the pertinent and major themes identified through the analysis and triangulation of interviews, AOT, and GCI (Appendix H).

Member checking during the year long program served to clarify and elaborate the themes, patterns, and points derived from the interview analysis.

Cross-case Construction and Analysis

Analysis across the cases was conducted by comparing the summaries constructed for each individual case. Merriam (1988) provided instruction for effectively conducting a cross-case analysis. Case summaries were reviewed multiple times to identify any convergent themes as well as any divergent or contradictory instances. A meta-matrix (Merriam, 1988) was designed using an Excel spreadsheet to tally and organize data from the individual case summaries and the GCI and AOT. Comparable textual components from the cases were aligned with the matrix and used to support claims of convergence and note any divergence.

CHAPTER IV

RESULTS AND FINDINGS

Organization of the Chapter

This chapter describes the findings and results from all of the data collection instruments and methods. The chapter is divided into three main sections based on the research questions, with the main sections further divided into sections relative to the data collected that is pertinent to each of the research questions (Table 2).

The first section, *Appropriation of Prior Conceptions*, addresses research question number 1. This section is divided into *Individual Case Summary Paragraphs* and *Cross-case Summary*. The *Individual Cases* sub-section provides the results of the analysis of the interviews for each participant. The *Cross-case Analysis* sub-section outlines the results of the analysis across all fifteen of the individual cases.

Section two, *Relationship between Thinking Disposition and Learning Geologic Time Concepts*, describes the results generated by the participants on the Actively Open-minded Thinking scale and the Geologic Time content found within the Geoscience Concept Inventory and any apparent relationship between the participants' performance on the two measures. This section addresses research question number 2. Section 2 is subdivided into three sub-sections, *Actively Open-minded Thinking scale*, *Geologic Time*, and *Relationship among Open-mindedness and Learning Geologic Time Concepts*.

Section three, *Relationship between Prior Conception Appropriation, Thinking Disposition, and Learning Geologic Time*, presents evidence of the existence or non-existence of any relationship among the participants' prior knowledge, open-mindedness, and the effects on learning geologic time. Interview data and data from the AOT and GCI are juxtaposed and analyzed to address research question number 3.

The *Findings* are presented in the last section of this chapter. This section lists the findings in a concise ordinal fashion as derived from the information provided in the results sections of the chapter.

Appropriation of Prior Conceptions

For this study, the term *appropriate/appropriation* refers to the act of setting apart, authorizing, or assigning some specific purpose or use (Kardash & Scholes, 1996). From this perspective, the interview data was analyzed to determine the participants' purpose assigned to their prior conceptions or how they used their prior conceptions when learning geologic time concepts. This was accomplished using the integration, differentiation, exchange, and bridging codes (Hewson & Hewson, 1983) described in chapter 3. The codes were then used to assign a category or mode of appropriation for each participant.

Interview questions 4, 5, 7, 8, and 9 (Appendix E) were used to probe the participants for their appropriation of their prior conceptions. The responses for each question made by the participant were coded as one of the four coding categories. An assessment of the responses was made, and each participant was categorized into one of the coding categories. For example, a participant could have been determined to appropriate their prior conceptions through a "Bridging" process. For demographic and other information specific to each participant, refer to Table 1.

Each participant's interview was analyzed from a case-study perspective (Appendix G) to address research questions 1 and 3. Concise paragraphs describing each participant's appropriation of existing conceptions taken from their case summary, and a data table (Appendix H) providing textual data excerpts from the participants' respective interviews are provided to address research question 1. Findings for research question 3 will be addressed in the *Relationship between Prior Conception Appropriation, Thinking Disposition, and Learning Geologic Time* section of this chapter.

A cross-case analysis was completed to provide additional data and description for addressing research questions 1 and 3. A written analysis of the cross-case comparisons, a list of emergent themes, and a table of observed coding frequencies are provided to attend to research question 1.

Research Question 1: How do elementary and secondary science teachers appropriate their existing conceptions regarding geologic time when learning about concepts that are inconsistent with their existing knowledge?

Individual Case Summary Paragraphs

Angela was a fifth-grade teacher that had been teaching science in the elementary grades for twenty-four years. She has an undergraduate degree in performing arts and a master's degree in elementary education. Several times during informal conversations with the researcher she mentioned having a long-standing interest in science. While in college, Angela completed biology, geology, and earth science courses, a course in chemistry, and a course in physics for her degree in biology. She completed this well-rounded group of science courses even though she did not major in a science discipline.

Angela described learning concepts through a process involving the integration of new concepts with existing concepts (Appendix H1). She spoke of when new information is learned, adjustments have to be made to what is already known in order to deal with any conflicts between existing conceptions and the new concepts. The adjustments that are made allow for the new concepts to be integrated into her framework of existing conceptions. Angela is an integration appropriator and distributes this mode of appropriation onto her students as well. She made mention of her students integrating science conceptions when they learned science concepts.

Angela did not reveal much information in her interviews regarding her open-mindedness. She was very concise in her answers. However, Angela talked about adjusting prior conceptions when learning concepts such as geologic time. This adjustment, as she stated, would position the new information where it could be believed and accepted or not believed and not accepted. Therefore, the adjustments to prior or existing conceptions would be minimal and simply allow for the intertwining, according to Angela, of the new conceptions. This along with her description of how she feels that a person's existing conceptions and beliefs will have a definite impact on learning geologic time concepts revealed Angela's low-level of open-mindedness.

Ben had just completed his second year of teaching fifth-grade at the time of the start of the summer component of the TENNMAPS program. The academic year following the summer component, which included the four follow-up days for the program, was Ben's "tenure" year.

Ben taught in a self-contained classroom where he provided instruction for all subject areas to his students. Ben has an undergraduate degree in elementary education. He had completed the minimum number of required science courses to obtain a degree in elementary education. Ben had stated to the researcher several times during interviews and during informal conversations how he was also a Missionary Baptist minister.

Ben exhibited Differentiation appropriation through his expression of how existing concepts and new concepts should be kept separate from a belief or knowledge standpoint (Appendix H2). This is especially the case if the conceptions conflict with one another. He sees this as the preferred situation for himself and his students when learning concepts related to geologic time. He states that he works to keep concepts differentiated by not “intertwining a lot of things” when he learns them. Ben described how he does this when he teaches these concepts as well. Furthermore, Ben does not think that his fundamental knowledge and beliefs are corrupted by keeping different concepts for the same phenomenon that are contradictory to one another.

Ben talked about being open-minded and listening to other interpretations of content. He expressed a genuine interest in geologic time conceptions other than his existing ones, but when it came to internalizing concepts related to geologic time, his existing conceptions took precedence. Ben expressed how he “comes back” to what he really knows about geologic time conceptions. Due to the primacy he places on his existing conceptions and other factors, such as a rigid differentiation of geologic time conceptions, Ben does not exhibit an open-minded position.

Beth was a third and fourth-grade teacher that had been teaching in the elementary setting for thirty years. She taught in a self-contained classroom format as an elementary teacher. Beth did not provide any information regarding her undergraduate degree or any information regarding the college-level science courses she had completed. However, she did list that she held a master's degree in education. Beth retired from teaching at the end of the academic year that with the TENNMAPS program.

Beth exhibited Differentiation appropriation (Appendix H3). She prefers things, such as the geologic time concepts, to be "defined". She finds "comfort" in keeping her existing conceptions of geologic time concepts separate from her existing conceptions. Beth places the two sets of conceptions in well defined spaces that she can negotiate back and forth as needed depending on the situation. She states "I don't like to live in the muck", revealing her desire to keep the two sets of conceptions well defined and separate, as well as specifically saying "I keep them separate".

Beth exhibits a low level of open-mindedness. Interestingly, she made statements that could be construed as being open-minded. For example, Beth said that it was important to change what you know and believe when you learn more information about a particular concept. However, if the new information does not fit with what her existing conceptions she disregards it. In addition, she effectively differentiates the scientifically accepted geologic time conceptions from her existing ones in order to keep the new conceptions from clouding her existing conceptions. She states that she is "very strong in her beliefs" about issues on geologic time. Beth describes how she takes information from the new concepts being taught that is applicable and fits with her existing conceptions, but any information she deems to be not applicable or fails to conform to her existing conceptions does not become part of her knowledge.

Carrie has been teaching in the elementary/middle-grades for thirty-four years. During her tenure as a teacher, she has taught seventh and eighth-grade science. At the time of the TENNMAPS program she was teaching seventh-grade science and had been for several years. Carrie holds undergraduate degrees in both biology and geography, as well as a master's degree in education.

Carrie described an Integration appropriation when learning geologic time concepts (Appendix H4). She sees complementary patterns among her existing conceptions and the concepts she has learned regarding geologic time. The concepts "flow together" for her with little difficulty and conflict due to identical patterns within the concepts. As a result, she does not try to separate the conceptions. Instead, she brings them together to form a unified conception. They become and integrated set for Carrie that has multiple elements. The multiple elements together answer a variety of general geologic time questions for her while the individual component elements answer specific ones.

Carrie exhibited a high degree of open-mindedness. She described how people think about geologic time conceptions in different ways and they interpret them in different ways, but that it "…all falls into a pattern, and its really not all that hard to understand." In addition, Carrie made a profound statement when she said "…you have to be open-minded enough to think." She alluded to how close-mindedness can stifle thinking. Carrie expressed that you have to be willing to accept the fact mistakes are made when developing information about natural phenomenon, and to not "agonize" the point of possible mistakes.

Cindy originally began her teaching career as a health/physical education teacher at the K-5 level. After a few of years teaching health and P.E., she moved into the general education classroom where she taught science for kindergarten through fifth-grade. The year prior to entering the TENNMAPS program, she taught first-grade and moved up to fifth-grade the school year during the program. In total, she had sixteen years of teaching experience. Cindy has both a bachelor's degree in elementary education and a master's degree. Cindy completed several courses in biology while an undergraduate, but did not complete any courses in the other science disciplines. She made statements on more than one occasion regarding her lack of geosciences knowledge.

Cindy described a differentiation appropriation perspective to prior knowledge appropriation (Appendix H5). She differentiates her existing geologic time conceptions from any new conceptions to build two discrete sets of conceptions. Cindy states that in doing so, she can use the appropriate conception as needed. She reconciles any conflict between her existing conceptions and any new conception by altering how she perceives a phenomenon, such as the big bang. She accomplishes this via a bridging mechanism and gave the example of reassigning the big bang as a tool used [by God] to create the universe instead of the Big Bang being the "what" that created it. Cindy's use of bridging to allow her to reassign the status and category of the big bang theory is interpreted as a form of secondary appropriation. Therefore, by using the primary appropriation mode of differentiation and the secondary appropriation mode of bridging, Cindy was regarded as a bimodal appropriator.

Cindy exhibited a low level of open-mindedness. More than once, Cindy specifically stated that she did not believe in the scientifically accepted geologic time conceptions. She described how she compartmentalized, cognitively, the scientific conceptions in a totally separate compartment from where her existing conceptions reside. The only time she calls upon and utilizes the scientific geologic time conceptions is when she has to use them for teaching purposes. As she says, "I just teach this as a different theory…"

David has logged thirteen years as a high school science teacher. He has taught all high school grades (9^{th}, 10^{th}, 11^{th}, & 12^{th}), which included teaching courses in physical science, biology, health, and earth science. Other than teaching science, David serves as the head coach for his high school's track team and the assistant coach for the football teach. David holds a bachelor's degree in health and physical education and completed several college-level science courses. In addition, David spent several years in retail management prior to entering the classroom.

David exhibited an Integration appropriation of existing conceptions (Appendix H6). He expressed this integration perspective through the use of the Bridging metaphor of building a house. He stated that learning new conceptions like those of geologic time occurs by adding to a proper foundation. New conceptions are tied to existing conceptions that make up the foundation. David described how the pieces have to fit together. If the pieces do not fit together well, then existing conceptions might have to be "adjusted". David's use of his building a house metaphor as a bridge for him to understand how existing conceptions and new science concepts are integrated together is characteristic of bimodal appropriation. Bridging allows an individual to place information within certain contexts or to make connections that renders new information and conceptions plausible and intelligible. David described how when we learn science concepts, we use our existing conceptions like a foundation of a house and build up from there; adjusting our existing conceptions to permit the new conceptions to fit properly.

David exhibited a high level of open-mindedness. He described learning science conceptions as a process of making necessary adjustments to existing conceptions in order to build a proper knowledge framework. David did not regard existing conceptions as a rigid base that could not be modified, repaired, or improved upon. He expressed that "…sometimes things are off…we may have to tear down and build back." In addition, he talked about how he integrated different ways of knowing and viewing aspects of the natural world, along with other worldview perspectives, into his science teaching. For example, he gave an example of a lesson about the importance of water to livings things from both a physiological aspect as well as a social and religious perspective.

Hallie has taught high school science for thirteen years. Like most high school science teachers, she has taught all four grades contained within a high school and taught a range of courses that has included physical science, biology, and earth science. Hallie holds bachelor's degrees in biology and German. In addition, she holds a master's degree in education. Due to her undergraduate degree and certification in German, Hallie teaches German at the high school where she is employed.

Hallie described a Differentiation appropriation regarding her existing conceptions (Appendix H7). She differentiates new conceptions from her existing conceptions and evaluates the new information independently. Hallie holds the new conceptions separately while she determines if they are sensible, plausible, and intelligible. When she determines there is enough credible evidence to support the new conception, she will reevaluate her existing conceptions. Her reevaluation allows her to determine what needs to be replaced through the exchange of an existing conception for the new, more accurate conception. Since Hallie might eventually exchange her existing conception with a new more accurate one, she engages in a secondary appropriation mode after initially differentiating her existing conceptions from the new conceptions. Thus, Hallie is a bimodal appropriator.

Hallie has a high degree of open-mindedness. She stated that she does not let anything she already knows or any of her existing conceptions influence her when she is learning about new science concepts. She evaluates a conception and decides if the conception is supported with enough good data. If the conception is fully supported, she will add it to her knowledge framework and ultimately exchange it for the old conception.

Jack was a secondary science teacher in the eighth-grade classroom. He had been teaching science in the seventh and eighth-grade for thirty-two years. He completed a bachelor's degree in biology and a master's degree in education. During his undergraduate education, Jack completed several courses in biology, earth science, and chemistry, as well as a course in physics. Jack retired from teaching at the end of the academic year that encompassed the TENNMAPS program.

Jack is an Integration appropriator. He weaves new conceptions into his existing conceptions with little effort. He refers to "tying" new concepts into his existing conceptual framework without any conflict (Appendix H8). He expressed a process of "combining" his existing conceptions with new conceptions and "adjusting" and "modifying" his existing conceptions as needed. To resolve any conflicts he might have between his existing conceptions of geologic time and new conceptions, Jack undergoes bridging to place the new conceptions into a manageable context. Furthermore, Jack very seldom experiences a conflict due to the effectiveness of his bridging process. He stated that he "…never had any trouble tying in concepts in science…" Jack's bridging process enables him to integrate his existing conceptions with new geologic time conceptions relatively easily. Jack is a bimodal appropriator. He uses bridging secondarily to facilitate integration of existing conceptions with new conceptions.

Jack displayed a low level of open-mindedness. Two or three times Jack stated that he was an open-minded person. He talked about enjoying listening to new scientific information and the latest findings regarding geologic time. However, when talking about the negotiation of existing knowledge and conceptions, Jack would make prefacing statements about being "strong" in what he already knew and believed about geologic time. Jack talked about new geologic time information not "offending" him or his existing beliefs. The secondary bridging appropriation allowed Jack to reconcile new conceptions that were counter to his existing ones, but the new conceptions had to conform to his existing framework.

Kathy had taught sixth-grade science at a middle school for six years. She holds a bachelor's degree in elementary education and a master's degree in elementary education. While completing her undergraduate training, Kathy completed a minimum of science courses consisting of biology and earth science.

Kathy displayed Integration appropriation regarding geologic time concepts. She expressed how new concepts of geologic time can be "meshed" with existing conceptions (Appendix H9). To aide in meshing such conceptions, Kathy employs a bridging mechanism to tie concepts together to support one another. She sees this support as a means to corroborate and strengthen her existing geologic time conceptions. Kathy stated how new geologic time conceptions confirm what she already knows about how earth was created, how mountains are built, and the creation of the solar system. Furthermore, she teaches geologic time concepts from this same perspective. Kathy is a bimodal appropriator. Kathy's bridging mechanism is a secondary process that allows her to integrate new geologic time conceptions into her existing conception framework.

Kathy has a low level of open-mindedness. She regards her existing geologic time conceptions as part of her primary knowledge that all new conceptions have to fit into. Kathy juxtaposes everything against her existing primary conceptions. In addition, Kathy stated she didn't think that there was anything she could learn that would encourage or cause her to change any of her existing conceptions. When asked if new information regarding geologic time would cause her to change her core beliefs, Kathy stated "Probably nothing is going to change my belief, but I don't think it's going to discredit each other. I just firmly believe that it's not going to do that. It may change our mind…But, I think if you think on a different level that one day in God's eyes is not one day in what man sets…" Here Kathy is alluding to the debate in geologic time regarding the age of earth being 5000 years versus 4.5 billion.

Kim had taught eighth-grade science for twenty-six years prior to beginning the TENNMAPS program. She did not report nor did she tell the researcher any specifics of the undergraduate degree she had completed. However, she did report having a master's degree in education. In addition, Kim reported taking some biology and earth science courses while in college.

Kim expressed a Differentiation appropriation of geologic time concepts (Appendix H10). She has established two sets of conceptions for geologic time principles. When learning scientific conceptions of geologic time, Kim compartmentalizes them separately and gives them individual status. Kim negotiates any conflicts between her existing conceptions and new conceptions by making bridging connections to existing conceptions she determines to be related to the new concepts. Kim described how bridging certain conceptions with existing conceptions placed everything in a context that confirms her existing geologic time conceptions. The bridging helps Kim to interact with the scientifically held conceptions in certain situations without them affecting her existing geologic time conceptions. For example, when teaching certain geologic time concepts, Kim just offers the information for what it is. She stated "I still teach them [geologic time concepts] just from the reading and, you know, the info, but I don't ever teach it as fact." Having a primary differentiation appropriation mode and a secondary bridging appropriation mode classifies Kim as a bimodal appropriator.

The information Kim gave regarding her existing conception appropriation highlighted her low level of open-mindedness. Furthermore, Kim stated that she just does not think what the scientific community has put forth regarding geologic time is right. As she said, "…I don't see it, you know, it's not tangible."

Laura had been teaching seventh-grade science for five years prior to the TENNMAPS program. She holds a bachelor's degree in elementary education that included only a few science courses. For the two years prior to attending the TENNMAPS program, Laura had been teaching in a module based science classroom. Instruction in this classroom consisted of the students working at stations or "activity centers" focused on specific science content. The stations provided multimedia presentations and interactive experiments for each student to complete. Laura, as the teacher, would monitor each student's progress and assist with instruction as was needed. Laura had mixed feelings toward this form of instruction. The amount of time she was able to interact with the students was very minimal. She commented on how the limited interaction and the sense of being an overseer skewed her identity as a teacher.

Laura described a Differentiation appropriation perspective regarding learning geologic time concepts (Appendix H11). Laura has built two different conceptual frameworks for geologic time concepts and navigates between the two. Even though she contends that she works to keep the two frameworks separate, there are aspects that she tries to reconcile between the two through an integration process of making aspects of geologic time “fit” into her existing conceptions. However she reveals that it is a hard process to make the scientifically accepted concepts fit into her existing conceptions, and it just does not work most of the time.

Laura exhibited a low level of open-mindedness. She differentiates geologic time conceptions from her existing conceptions because she cannot fit them together, nor can she figure out a way they could fit together. Laura went so far as to state she does not regard scientifically accepted geologic time concepts, such as evolution or the big bang, to have theoretical status. Although when she teaches it, she presents it to her students as theories. Laura’s low level of open-mindedness does not allow her to give much consideration to geologic time conceptions, nor when she teaches them; “I just tell them it's a theory. I mean, really it's based on things that they think, you know, this is how it's happened, but that's not necessarily, you know, true. But, I try not to bring my personal thoughts into it even if they ask me. I just kind of move to something else.”

Lois had completed her first year of teaching seventh-grade science prior to starting the TENNMAPS program. She had recently completed a bachelor’s degree in biology and her certification to teach. Lois had completed several courses in both biology and chemistry while working on her undergraduate degree. Following the TENNMAPS program year, she was moving to the eighth-grade science classroom.

Lois views her existing conceptions of geologic time as completely incompatible with the scientific view of geologic time and thus maintains a Differentiation perspective (Appendix H12). She notes that she does not "buy into" current theories regarding geologic time and sees her conceptions and current accepted conceptions as wholly different, and she keeps them differentiated completely. She regards them as two plausible theories that explain the same set of phenomena. However, Lois feels her existing conceptions are more intelligible, sensible, and accurate.

Lois' description of her differentiation mode of existing conception appropriation highlights her low level of open-mindedness. She gives no regard or consideration to any of the scientifically accepted geologic time conceptions. Lois described how even thinking about geologic time and the age of earth is a problem for her. "…as far as like that whole time frame thing, that kinda hangs me up sometimes. I probably won't know that until the end, you know."

Rena had been teaching science for twelve years in the kindergarten through fifth-grade setting. She had completed a bachelor's degree in both biology and middle-grades education. In addition, Rena was the librarian at the elementary school where she taught. Prior to the TENNMAPS program and the year following, Rena predominantly aided in team-teaching science for all grades in her school.

Rena employed an Integration appropriation when learning about geologic time concepts. She negotiates new geologic time concepts through her existing geologic time framework (Appendix H13). She feels aspects of geologic time can "mesh" with her existing conceptions.

Rena is a bimodal appropriator. Rena brings new conceptions together with her existing conceptions by making bridging connections with specific elements of her existing geologic time conceptions. Rena reconciles conflicts between new geologic time information and her existing conceptions by placing the new information in a similar context as her existing conceptions. Once the context is established, then she can integrate it into her existing schema.

Rena's level of open-mindedness is on the low end. She gives some consideration to new geologic time concepts, but they either have to be able to integrate into her existing conceptions easily or be bridged to a similar context. Never the less, all new concepts have to be filtered through her existing conceptual framework through a comparison process. "That is the core that is the absolute truth to me. I do compare it, like evolution. That has been, I mean of course we have evolved, we don't look the same as we did at the beginning, but… you know, yeah I do compare everything to that…"

Sonya had been teaching seventh-grade in a self-contained format for fifteen years prior to the start of the TENNMAPS program. Interestingly, the year after the TENNMAPS program Sonya began teaching in a self-contained second-grade classroom. Sonya holds a bachelor's degree in criminology and a master's degree in education.

Sonya exhibited Integration appropriation of her existing geologic time concepts (Appendix H14). She described how she filters new information through her existing conceptual framework. She states that she "always tests it" through her existing conceptions. She integrates what she can integrate and "discards" what does not fit. This is an easy process for Sonya as she makes the point that she never has any problem negotiating the union of her existing conceptions with new, scientifically accepted conceptions. There are never any major conflicts between her existing conceptions and new concepts because what does not seem to fit into her existing framework is no longer of any importance.

Sonya has a low level of open-mindedness. She is only amenable to conceptions that fit easily into her existing conceptual framework. Sonya says that “I know that I know that I know” and seeks a fit for any new geologic time conceptions. Any of the new information that does not fit is disregarded and not added to the framework. In addition, Sonya feels some conceptions are not worth considering or thinking about after they have been assessed with regards to her existing conceptions. “I'll test it through that to see if it's something I want to think about or something I can add to my belief system or something that I just discard.”

Will had been a seventh-grade science teacher for seven years prior to the start of the TENNMAPS program. In addition, Will was active in attending professional development activities for science and had been each year since the beginning of his teaching career. He holds a bachelor’s degree in biology and a master’s degree in education.

Will displayed Differentiation appropriation regarding learning geologic time concepts (Appendix H15). He expressed that you can learn new conceptions without compromising your existing conceptions. They can be separated into different spaces cognitively without one set influencing the other set. He expressed this situation for himself and reassures his students that it is alright for them to handle the concepts in this manner as well.

Will has a high level of open-mindedness. He repeatedly described how you can work with two sets of conceptions for a scientific phenomenon, or work with your existing conceptions and new conceptions without compromising one or the other. He specifically stated he does not use his existing conceptions to alter new conceptions. “They don’t influence it at all". This revealed Will's high level of openness to new ideas. An additional example of Will's open-mindedness involves how he interacts with his students during teaching of geologic time concepts. When his students have difficulty with this situation, he reassures them that it is okay and proper to keep the two separate conceptions and think about them by saying "…you can separate both, and I try to explain it to kids, you can believe in the science and you can have both. It's not either or."

Cross-case Analysis

The cross-case analysis and summary was compiled to address research question 1 and research question 3. This section reports on the analysis and findings regarding the teachers' appropriation of their existing conceptions as they negotiated and learned geologic time concepts. Five major themes related to the appropriation of existing conceptions were identified, and one regarding open-mindedness, through the coding and analysis of the teachers' interviews. Table 4 provides a concise organization of the emergent themes derived from the individual case analyses regarding existing conception appropriation and open-mindedness.

Mode of Appropriation. Integration and differentiation were found to be the predominant modes of existing conception appropriation (Table 4). However, descriptive remarks were made by the teachers in total that referred to all four modes of appropriation (Appendix H). Eight of the participants described a differentiation appropriation mode, while seven of the fifteen teachers exhibited an integration mode. Of the seven teachers that described an integration perspective, four were elementary teachers, and three were secondary. Of the eight teachers that described a differentiation perspective, three were elementary teachers,

Table 3

Emergent Themes from the Cross-case Analysis

- Integration and Differentiation were the primary modes of existing conception appropriation described.
- Differentiation was described more often than Integration, with differentiation more prominent among teachers with an undergraduate degree in education.
- Appropriation of existing conceptions occurred through a monomodal or a bimodal process, with equal distribution regarding degree and elementary vs secondary.
- Bimodal appropriation involved bridging appropriation predominantly as the secondary modality.
- A distributive property of existing conception appropriation was evident among the majority (86%) of the teachers with an undergraduate education.
- Teaching methodology for geologic time concepts reflected the teachers' appropriation modes.
- Most (73%) of the teachers possessed a low-level of open-mindedness.

and five were secondary teachers (Table 4). There was a minor pattern evident regarding the teachers' undergraduate degree. Teachers with an education degree were more likely to appropriate their existing conceptions through differentiation than their colleagues with a science degree (Figure 3). In this instance, three coded as integrators, while five were coded as differentiators. However, teachers with a degree in science were nearly equally split among integration and differentiation appropriation with four coded as integrators and three coded as differentiators (Figure 3).

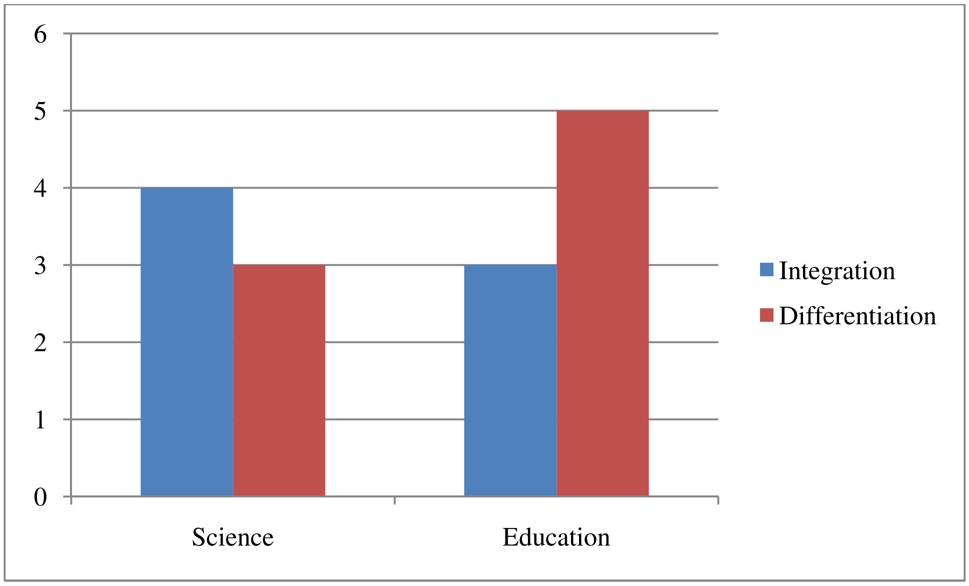

Figure 3. Coded Appropriation Mode by Undergraduate Degree

None of the teachers described exchange or bridging as a primary mode of prior conception appropriation. Exchange appropriation was described by two of the teachers, however it was viewed as a situation that was very unique or occurred under extreme circumstances. Bridging appropriation was described several times; however it was not described in a primary appropriation manner. Bridging was described as a facilitator to integration and differentiation appropriation. Description of bridging as a facilitator is described in the next section, and textual elements can be seen in Appendix H.

Modal Process of Appropriation. Seven of the participants described an appropriation process that consisted of the use of two modes of appropriation, referred to as bimodal appropriation. Bimodal appropriation consisted of the participant utilizing one mode as a primary appropriator and using a secondary mode to assist or facilitate appropriation by the primary mode. The secondary appropriation mode was used by the participants to resolve conflicts between existing conceptions and new conceptions or to provide a context for the new conception. Out of the seven bimodal appropriators, four of them prescribed to an integration mode when learning geologic time concepts, while three of them exhibited a differentiation mode of appropriation regarding geologic time concepts. Furthermore, the bimodal appropriators were evenly split between elementary and secondary teachers. However, there were slightly more monomodal appropriators than bimodal appropriators among the teachers with an undergraduate degree in education.

The other nine participants described a monomodal appropriation mode of prior conception appropriation (Table 4). Monomodal appropriation consisted of a teacher predominantly describing a single appropriation mode when learning geologic time concepts. In monomodal appropriation, a primary appropriation mode stood alone as the sole description of appropriation and was not assisted by a secondary mode in order to facilitate appropriation. However, there were instances where a monomodal appropriator would make reference to another mode. For example, Angela, a monomodal integrator, explained how she adjusts existing conceptions and new conceptions to allow learning, but if she eventually compiles enough information supporting the new conception she *might* change her position in a fashion reminiscent of exchange-appropriation (Appendix H1). Even though Angela made mention of exchange appropriation, it is not her primary mode. Angela will engage in exchange appropriation given special circumstances, but for typical learning situations she utilizes the integration mode of appropriation.

Secondary Modality. Seven of the participants were determined to be bimodal appropriators. Bimodal appropriation consisted of the use of a primary appropriation

Table 4

Appropriation Modality

Teacher*	Primary Appropriation†	Secondary Appropriation†	Distributor of Appropriation
Angela	1	0	X
Ben	2	0	X
Beth	2	0	
Carrie	1	0	
Cindy	2	4	X
David	1	4	
Hallie	2	3	
Jack	1	4	X
Kathy	1	4	X
Kim	2	4	X
Laura	2	0	X
Lois	2	0	
Rena	1	4	
Sonya	1	0	
Will	2	0	

†1=Integration, 2=Differentiation, 3=Exchange, 4=Bridging
*Pseudonym

mode (integration or differentiation) and a secondary mode to support and assist with the primary mode of appropriation. Among the bimodal appropriators, six of the teachers expressed the bridging mode of appropriation, while one described exchange. Thus, regardless of whether a teacher described the use of integration or differentiation as their primary mode of appropriation, they used bridging predominantly as their secondary appropriation mode. In their description of their bimodal appropriation, six of the teachers described how the learning of new information and new geologic time concepts supported and reinforced their existing conceptions. For example, Rena expressed when she learned new geologic time concepts she reflected them upon her existing conceptions related to those specific concepts. She then modified the concepts being learned in order for them to align with her existing conceptions. As a result, the new modified information would add more credence to her existing conceptions.

Distributive Appropriation & Teaching. All of the participants made reference to themselves regarding learning geologic time concepts and the appropriation of their existing conceptions. However, seven of the teachers not only spoke of the appropriation of their existing conceptions, but gave their interpretation of how their students appropriate existing conceptions. In these cases, the teachers viewed their students' mode of appropriation to be identical to their own mode. In some instances, the teacher would drift back and forth describing their appropriation and their students' appropriation. Jack talked about "tying in" geologic time concepts to his existing conceptions, and then describe how he would teach the concepts in a way that would let the student figure out how they could "work it around" their existing conceptions on their own. Others were not as direct. Angela described learning the geologic time concepts from a third person perspective, while making reference to how her students would appropriate their existing conceptions. The majority of the teachers who exhibited distributed appropriation had an undergraduate degree in education (86%), but it was nearly equally split between elementary and secondary teachers.

The other eight participants mentioned their students at some point, but it was not in relation to how they saw their students as appropriators. They spoke of how they might present the geologic time concepts during teaching as a function of their own appropriation mode. In addition, the seven teachers that exhibited the "distributive" characteristic described how they would teach the concepts as a function of their own appropriation mode as well. Laura described this situation of reflecting an appropriation mode as a teaching process. Being a differentiation appropriator, Laura keeps everything separate, so when talking about how she would teach how the universe was created, she stated that she would present the big bang as one theory and her original conception as another theory. From this, a student can engage their existing conceptions however they choose.

Open-mindedness. An aspect of this study was to determine the level of open-mindedness the teachers possessed. Other than the information provided by the AOT, the researcher made an assessment of the teachers' open-mindedness through the analysis of the interviews after coding and analyzing for the determination of the teachers' appropriation mode.

The majority of the teachers, 11 out of the 15 (73%), expressed the negotiation of geologic time conceptions in a manner that was indicative of a low level of open-mindedness. Even though several of the teachers made statements such as "…I am pretty open-minded…" their insistence of using their existing conceptions as guides, dictators, or filters when learning geologic time concepts negated their statements. However, Carrie, Hallie, David, and Will described learning, teaching, and interacting with geologic time conceptions with a greater degree of open-mindedness. These teachers described giving the new conceptions full consideration, and not quickly dismissing them or disregarding them.

Looking at the teachers' undergraduate degree, 100% of the teachers with an undergraduate degree in education and 43% of the teachers with an undergraduate degree in science were coded as having a low-level of open-mindedness. All of the elementary teachers were coded as having a low-level of open-mindedness, while the secondary teachers were equally divided between low and highly open-minded. The connection between 100% of the elementary teachers having a low-level of open-mindedness plus the fact none of them have a science degree might be due in part to elementary science teachers are not required to have an undergraduate degree in a science discipline. However, secondary science teachers are required to have an undergraduate degree in a science discipline.

Summary. It was determined that elementary and secondary science teachers appropriate their existing conceptions through either an Integration process or a Differentiation process (Figure 4 & Table 4). The number of integrators versus differentiators was almost evenly divided between the two categories. Likewise the incidences of integration and differentiation appropriation for elementary science teachers versus secondary science teachers were nearly equally divided between the two groups.

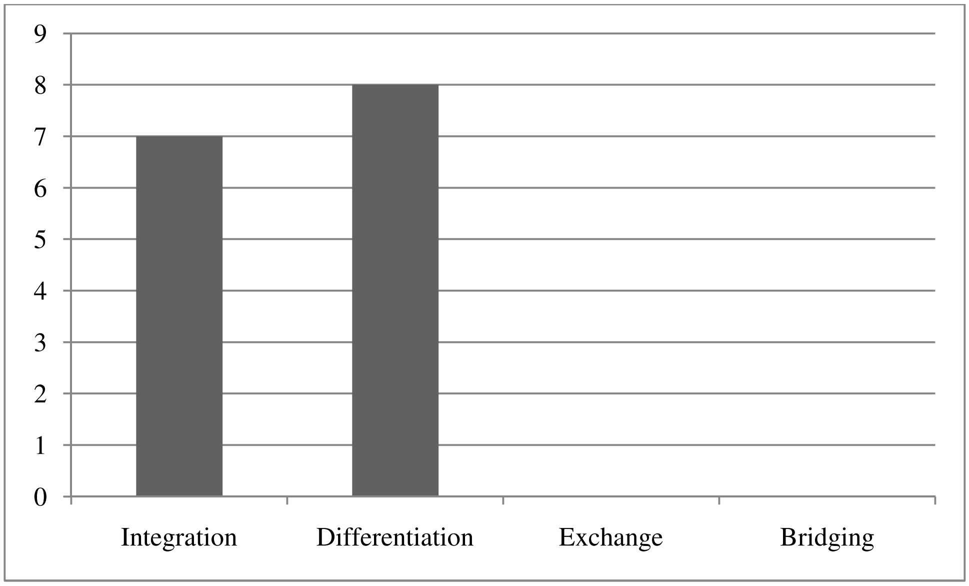

Figure 4. Frequency of primary appropriation mode

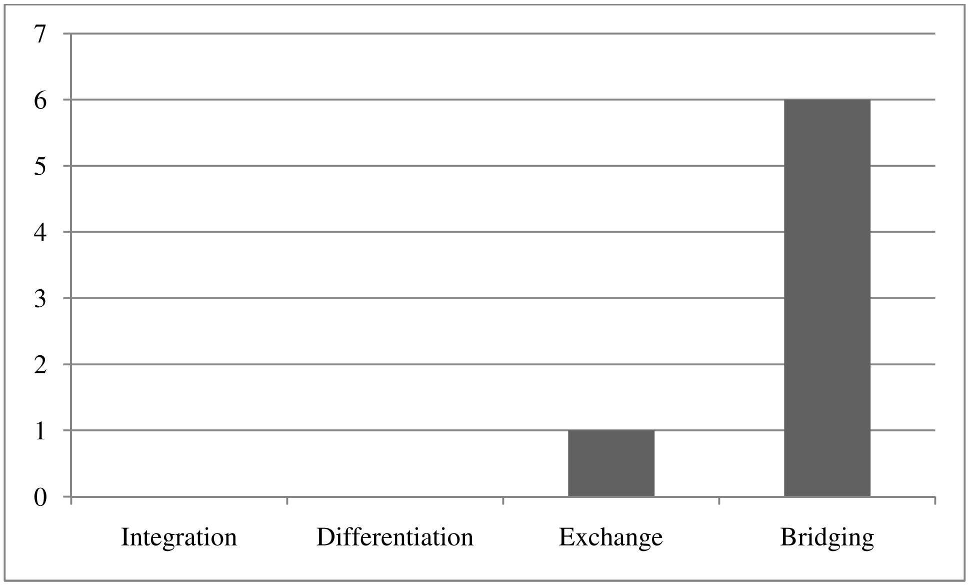

Figure 5. Frequency of secondary appropriation mode

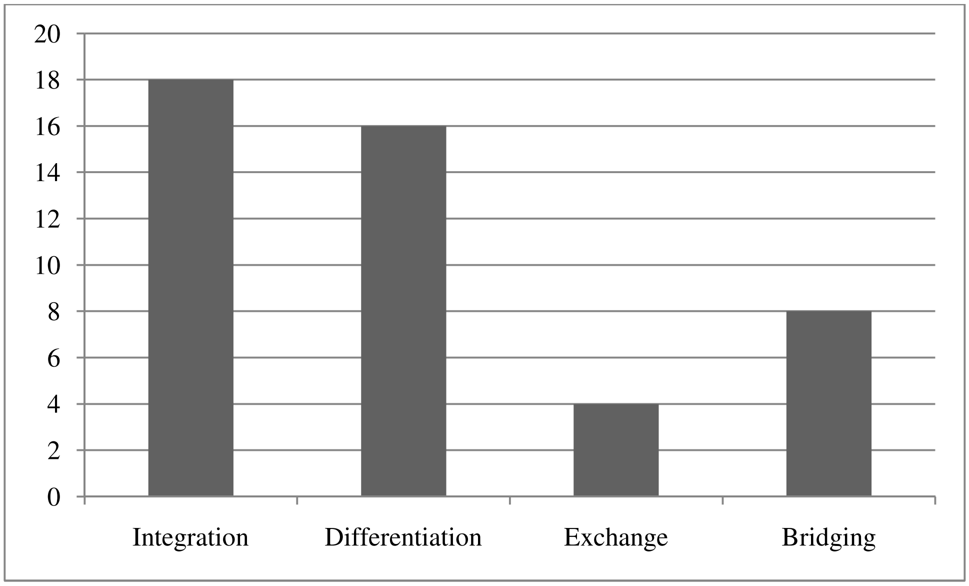

Figure 6. Frequency of appropriation mode described during the interviews

Elements of all four prior conception appropriation categories were found across the fifteen participants, but with differing degrees of emphasis. Counts of the frequency of each coding category found that integration was the most frequently described appropriation of prior conception, while Exchange was the least (Figure 6). However, eight of the teachers were coded as differentiators versus seven as integrators. Seven of the nine teachers exhibited a bi-modal process of existing conception appropriation where they described a primary mode of appropriation that was assisted by a secondary mode. In all cases of bimodal appropriation but one, Bridging was displayed as the secondary mode of appropriation (Figure 5). The one bimodal appropriation exception involved exchange as the secondary appropriation mode.

Seven of the teachers perceived their students appropriated their existing conceptions the same way as they appropriated them. This phenomenon was equally likely among the elementary science teachers as it was among the secondary teachers. In addition, a teacher's primary appropriation mode influenced how the teacher described how they negotiate and teach concepts such as geologic time to their students.

Eleven of the fifteen teachers expressed a low level of open-mindedness through their description of how they appropriated their existing conceptions when learning geologic time concepts. Some of these teachers even made specific statements attesting to their high level of open-mindedness, but followed through with descriptive evidence of the contrary. In addition, the eleven teachers' descriptions of their methods used during the teaching of geologic time concepts provided further supporting evidence of their low degree of open-mindedness.

Relationship between Thinking Disposition and Learning Geologic Time Concepts

Research question 2 required the analysis of the teachers' performance regarding the Geologic Time questions within the Geoscience Concept Inventory (GCI) and the determination of their thinking disposition through their results on the Actively Open-minded Thinking scale (AOT). The GCI assessed the teachers' knowledge of certain geology and geosciences concepts, including geologic time. The AOT provided an indication of the teachers' thinking disposition based on their open-mindedness or openness to new ideas.

Learning controversial concepts, such as geologic time, involves the intersection of influences that may affect the outcome of the learning (Figure 1) (Lawson & Thompson, 1988; Sadler, 2005; Sadler & Zeidler, 2005a, 2005b; Stanovich & West, 1997, 2007). In order to gain more information regarding the influence of thinking disposition on learning geologic time, an analysis was conducted to determine the existence of a relationship between the two. Prior to conducting the analysis of a relationship, the assessment of the teachers' thinking disposition, and the results of their learning of geologic time concepts was carried out.

Research Question 2: How is thinking disposition related to the learning of geologic time concepts?

Geologic Time

The GCI was used to assess the teachers' knowledge of geology and geoscience concepts that included rock formation and the rock cycle, weathering, erosion, tectonic activity, volcanism, and ***geologic time***. The GCI was administered to the teachers prior to the beginning of the program, immediately after the initial ten-day session and once again after the four follow-up sessions. The administrations are referred to as "Pre", "Post", and "Post-Post" respectively. The questions on the GCI that specifically pertained to geologic time were analyzed and the results are presented in this section. The cumulative GCI was analyzed prior to parsing out the geologic time questions, and the results are presented in Appendix J.

The GCI contained 11 questions that specifically addressed geologic time concepts (Appendix I). The average number of geologic time questions answered correctly was 5, 5, and 4 for the pre, post, and post-post administrations respectively (Table 5). In addition, there was no statistically significant difference as determined by a repeated-measures t-Test between the average number of geologic time questions answered correctly over the course of all three administrations of the GCI (Table 6). Similar to the complete GCI measure, there was a reduction in the number of geologic time questions answered correctly from the post ten-day evaluation to the post-post program evaluation after the follow-up days (Appendix J).

Table 5

Number of Geologic Time Questions Answered Correctly

Teacher†	Pre-Program	Post Program	Post-Post Program	Average*,+
Angela	7	6	3	5
Ben	4	4	2	3
Beth	3	4	1	3
Carrie	3	3	6	4
Cindy	0	2	3	2
David	4	4	1	3
Hallie	8	7	8	8
Jack	8	7	7	7
Kathy	5	5	-	3
Kim	5	3	2	3
Laura	4	2	1	2
Lois	8	5	6	6
Rena	7	8	6	7
Sonya	4	3	4	4
Will	8	8	8	8
Average+	5	5	4	5

*11 questions total
†Pseudonym
+Rounded Value

Table 6

Paired Samples t-Test for Correctly Answered Geologic Time Questions

Pair	Mean	Std. Deviation	t	df	Sig. (2-tailed)*
Pre-Program To Post Program	0.467	1.302	1.388	14	0.187
Pre-Program To Post-Post Program	1.071	2.129	1.883	13	0.082
Post Program To Post-Post Program	0.571	1.869	1.144	13	0.273

*p < .05

The teachers began the TENNMAPS program with less than a 50% understanding of geologic time concepts (Table 5). Over the course of the program, their understanding did not improve. It declined from the pre-administration of the GCI to the post-post period, even though geologic time concepts were a focus throughout the program from beginning to end. From a percentage basis, the teachers answered fewer geologic time questions correctly than the percentage of questions for the cumulative measure; 45% (Table 5) versus 53% (Appendix J) respectively. In addition, the fact that there was a statistical difference between the pre and post-administration of the full GCI and no difference between any of the three points for the geologic time concepts reveals the difficulties of teaching and learning these concepts. It has been noted that learning geologic time concepts involves a unique challenge for a variety of reasons. The abstract and problematic nature of deep-time and the consideration of geologic time concepts as being controversial are two of the primary root causes given for challenges related to learning geologic time (Libarkin, et al., 2007; Trend, 2000, 2001).

Actively Open-minded Thinking Scale (AOT)

The AOT was designed to measure an individual's open-mindedness. It is composed of six sub-measures that assess established thinking dispositions. When taken collectively, the thinking disposition sub-measures provide a measure of an individual's openness to new ideas or their open-mindedness (Stanovich, 1999; Stanovich & West, 1998). Increasing open-mindedness is revealed by an increase in the score returned on the measure. The measure had a range from 27 to 162. Therefore, an individual with a score of 162 would be considered to be far more open-minded than someone with a score of 27. The AOT was divided into two intervals labeled "low" and "high" (Table 8)

The range of scores returned for the pre-program administration of this study was 97 to 130, and the post-program range was 95 to 136. The average score returned by the teachers pre-program was 116 and the post-program range was 114 (Table 7). The average scores for both the pre and post-program fell into the "high" open-minded range. Of the fifteen teacher participants, all scored in the "high" range of open-mindedness.

A repeated measures t-Test on the average scores of the AOT showed no significantly statistical difference between pre-program to post-program administrations of the measure. This was to be expected. Thinking dispositions that collectively give rise to open-minded thinking are regarded as being stable cognitive constructs that do not change over short periods of time (Stanovich, 1999; Stanovich & West, 1997, 2007). The TENNMAPS program transpired over a ten-month period. These data, showing no change from pre to post, corroborates the findings of others (Sinatra, et al., 2003; Stanovich & West, 1997, 2007).

Table 7

Actively Open-Minded Thinking Scale Category Labels & Descriptions

	Category	
Category Description	Low	High
Range*	27 - 94	95 – 162
Category Number	1	2

*Full Range of Measure = 27 – 162

Table 8

Actively Open-minded Thinking Scale (AOT) Results

Teacher*	Pre – AOT	Post – AOT	Average
Angela	122	123	123
Ben	112	111	112
Beth	109	111	110
Carrie	127	126	127
Cindy	97	95	96
David	111	110	111
Hallie	122	119	121
Jack	114	114	114
Kathy	118	106	112
Kim	101	103	102
Laura	123	112	118
Lois	115	113	114
Rena	114	112	113
Sonya	123	119	121
Will	130	136	133
Average	116	114	115

*Pseudonym

Thinking Disposition and Learning Geologic Time Concepts

Analysis of the results for the AOT provided a degree of open-mindedness for each teacher. The analysis of data for the GCI resulted in information regarding the teachers' learning of geologic time concepts. A comparison of the data from these two measures was utilized to determine if any relationship or trends were evident between the two measures.

A Pearson's correlation was conducted using SPSS to investigate the existence of any relationships. The analysis revealed no relationship between the teachers' open-mindedness as determined by the AOT and their learning of geologic time concepts. This included the cases for correctly answered pre, post, and post-post geologic time questions and the average AOT scores for the teachers. Initially, the Chi-squared statistical test was considered as a nonparametric alternative to the Pearson's correlation the category frequencies for open-mindedness and geologic time knowledge. However, after tabulating frequencies, there were several "cells" with values less than five.

Further analysis supported the finding of no correlation among the AOT results and the number of geologic time questions answered correctly. For the additional analysis, the teachers were categorized as being highly open-minded or low open-minded (Table 7) based on their scores on the AOT (Table 8), as well as being categorized based on the number of geologic time questions answered correctly. Answering six or more of the geologic time questions correctly was labeled as a "high" level of knowledge, while answering five or fewer was labeled as "low" (Table 9). Analysis of the GCI revealed 11 of the 15 teachers to have a low-level of geologic time knowledge, and four teachers to have a high-level of knowledge. The number of AOT and geologic time category combinations was tallied and assessed. From this tally, it was determined that no pattern existed regarding a teacher's level of open-mindedness and their level of geologic time knowledge other than the clustering of teachers in the low-level of geologic time knowledge. When the frequencies were analyzed reflected on the grade-level taught, it was evident more elementary teachers possessed a low-level of geologic time knowledge than the secondary teachers (Table 10). The analysis of frequencies reflected against the teachers' undergraduate education revealed the education majors all possessed a low-level of geologic time knowledge, while the majority of the science majors possessed a high level of geologic time knowledge (Table 11).

Table 9

Geologic Time Category Label & Descriptions

	Category	
Category Description	Low Level	High Level
Range*	0 - 5	6 - 11
Category Number	1	2

*Range of Correct Responses

Table 10

Geologic Time and Thinking Disposition Matrix Reflected by Grade level Taught

		TD Category†		
		1	**2**	
Grade Level*	**E**	-	6	**1**
		-	1	**2**
	S	-	5	**1**
		-	3	**2**
				GT Category^{+}

*Grade Level: E = elementary, S = secondary
†TD Category: 1 = low, 2 = high
$^{+}$GT Category: 1 = low, 2 = high

Table 11

Geologic Time and Thinking Disposition Matrix Reflected by Degree Area

		TD Category†			
		1	**2**		
Degree Area*	**S**	-	2	**1**	**GT Category^{+}**
		-	4	**2**	
	Ed	-	9	**1**	
		-	-	**2**	

*Degree Area: S = science, Ed = education
†TD Category: 1 = low, 2 = high
$^{+}$GT Category: 1 = low, 2 = high

Relationship between Prior Conception Appropriation, Thinking Disposition, and Learning Geologic Time

Research question 3 was addressed through the analysis of the teachers' prior conception appropriation determined via the interview coding and analysis, examination of their thinking disposition derived from the AOT, and a review of their learning of geologic time conceptions evidenced by their performance on the GCI. The primary focus of research question 3 fell upon what relationships or patterns were evident among the three parameters (prior conception appropriation, thinking disposition/open-mindedness, and geologic time). The influence and interaction of a learner's thinking disposition and their prior conceptions as they learn a controversial science topic is not well understood (Figure 1). Attending to research question 3 through this analysis offered information toward any influence on learning geologic time concepts.

Descriptive data and statistics for the three parameters have been presented earlier in this chapter. An analysis of appropriation, thinking disposition, and geologic time was made through the development of matrix tables composed of the frequency of the category classifications for the teachers on the three parameters as described in the methods chapter. The parameters were reflected against one another in pairs in individual matrices and then against all three in one matrix and are presented in this section. These matrices allowed for the juxtaposition of the appropriation, thinking disposition, and geologic time parameters and afforded the ability to identify any relationships or trends upon review of the tables. Patterns and relationships were determined based on the review of the statistical mode of the category classifications.

Research Question 3: What relationships are evident among the teachers' appropriation of prior conceptions, thinking disposition, and learning about geologic time?

Prior Conception Appropriation and Thinking Disposition

Each teacher's prior conception appropriation was determined through coding and analysis of the interviews. A numerical value was given to the primary appropriation category or modality determined for each teacher (Table 4). Analysis of each teacher's returns for the Actively Open-minded Thinking Scale (AOT) provided information regarding their thinking disposition relative to their open-mindedness. A numerical value was given to each teacher to represent their degree of open-mindedness or, in other words, their thinking disposition as a function of their openness to new ideas. Table 7 provides a description of each category label, while Table 22 lists each teacher's categorization.

Review of the matrix for prior conception appropriation and thinking disposition revealed that no relationship existed between a teacher's mode of appropriating prior conceptions and their thinking disposition/open-mindedness. Earlier analysis indicated the teachers to appropriate their existing conceptions through integration or differentiation. However, it did not matter which appropriation mode was adopted by the teacher, they were equally as likely to have a high level of open-mindedness (Table 12). Likewise, there was no pattern between the level of open-mindedness of a teacher and which of the appropriation modes they adopted and utilized other than all of them scoring in the highly open-minded range.

Table 12

Prior Conception Appropriation and Thinking Disposition Matrix

		TD Category†	
		1	**2**
PC Category*	**1**	0	7
	2	0	8

*Prior Conception Appropriation: 1 = Integration, 2 = Differentiation
†Thinking Disposition: 1 = Low Open-minded, 2 = High Open-minded

Prior Conception Appropriation and Geologic Time

Grading and analysis of the questions that pertained to geologic time from the Geoscience Concept Inventory (GCI) provided data relevant to each teacher's level of geologic time knowledge. Due to there being no statistical difference between any of the number of geologic time questions answered correctly across the three assessments, the average was used for analysis (Table 5). Each teacher was categorized based on the number of geologic time questions they answered correctly on the GCI (Table 9). Prior conception appropriation analysis and categorization was discussed in the previous section.

Analysis of the prior conception appropriation and geologic time matrix did not reveal any relationships between a teacher's mode of prior knowledge appropriation and learning geologic time (Table 13). The equal distribution of teachers among the two prior conception appropriation modes is evident in the Table 13 matrix.

Table 13

Prior Conception Appropriation and Geologic Time Matrix

		GT Category*	
		1	**2**
PC Category†	**1**	5	2
	2	6	2

†Prior Conception Appropriation: 1 = Integration, 2 = Differentiation
*Geologic Time: 1 = Low, 2 = High

Thinking Disposition and Geologic Time

A matrix was constructed from the teachers' category levels of thinking disposition, and their level of geologic time knowledge. Upon analysis of the matrix, no relationships were determined regarding the teachers' thinking disposition and their learning of geologic time concepts (Table 14). However, the clustering of all of the participants in the high range of open-mindedness and low range of geologic time knowledge is evident (Table 14).

Table 14

Thinking Disposition and Geologic Time Matrix

		TD Category†	
		1	**2**
GT Category*	**1**	0	11
	2	0	4

*Geologic Time: 1 = Low, 2 = High
†Thinking Disposition: 1 = Low Open-minded, 2 = High Open-minded

Prior Conception Appropriation, Thinking Disposition, and Learning Geologic Time

The category values for the three parameters, prior conception appropriation, thinking disposition, and geologic time, were organized into a matrix that produced the possible three-digit classification combinations. Given the number of levels of each of the parameters, sixteen different classification combinations could have been observed among the teachers (Table 15).

Table 15

Possible Three-Digit Classifications

		TD Category†			
		1	2		
PC Category*	1	1-1-1	1-2-1	1	GT Category+
		1-1-2	1-2-2	2	
	2	2-1-1	2-2-1	1	
		2-1-2	2-2-2	2	
	3	3-1-1	3-2-1	1	
		3-1-2	3-2-2	2	
	4	4-1-1	4-2-1	1	
		4-1-2	4-2-2	2	

*Prior conception appropriation: 1 = Integration, 2 = Differentiation, 3 = Exchange, 4 = Bridgin
†Thinking disposition: 1 = Low Open-minded, 2 = High Open-minded
+Geologic time: 1 = Low, 2 = High

After tabulating the three-digit classifications and entering the information into a matrix that was setup for the three parameters, only four of the possible sixteen classification combinations were actually observed among the teachers (Table 22). The maximum number of observed three-digit classifications possible was fifteen due to the study sample consisting of only fifteen participant teachers. As stated in the methods chapter, only the observed three-digit classification combinations were placed in a separate matrix table and analyzed for any relationships or trends (Table 16).

Examination of the matrix containing the number of observed classification combinations revealed no patterns or relationships regarding prior conception appropriation, thinking disposition, and geologic time knowledge. The teachers were close to equally divided among the two prior conception appropriation categories observed, 47% for integration and 53% for differentiation (Table 16). All of the teachers were clustered in the highly open-minded category as determined by the AOT, and the majority of the teachers were clustered in the low level of geologic time (Table 16). Two three-digit classifications encompassed 73% of the teachers; *Integration appropriation – Highly open-minded – Low geologic time knowledge* (1-2-1), and *Differentiator – Highly open-minded – Low geologic time knowledge* (2-2-1).

Table 16

Number of Observed Three-digit Classifications

		TD Category†			
		1	2		
PC Category*	1	-	5	1	GT Category+
		-	2	2	
	2	-	6	1	
		-	2	2	
	3	-	-	1	
		-	-	2	
	4	-	-	1	
		-	-	2	

*Prior conception appropriation: 1 = Integration, 2 = Differentiation, 3 = Exchange, 4 = Bridgin
†Thinking disposition: 1 = Low Open-minded, 2 = High Open-minded
+Geologic time: 1 = Low, 2 = High

When the teachers' level of open-mindedness, determined by the interview analysis, was used in place of the AOT results in the matrix, a difference was observed in the classifications and frequency distributions. Due to the majority of the teachers being coded as having a low level of open-mindedness from the interviews, the modes/frequencies shifted from the high level of open-mindedness to the low level (Table 17). However closer inspection showed the highest percentage, 54%, of the teachers were grouped into the *differentiation appropriation – low level of open-mindedness – low level of geologic time knowledge*, 2-1-1 (Table 17).

Re-categorizing the teachers based on their undergraduate degree and the grade level taught provided some observed pattern differences when considering the teachers' level of open-mindedness determined via the interviews. All of the teachers with an undergraduate education major except one moved from being categorized as highly open-minded to being low open-minded, but only 50% of the teachers with an undergraduate degree in science shifted to low (Tables 18 & 19). In this situation, the one teacher that did not change categories was the only secondary science teacher among the teachers with an undergraduate degree in education. In addition, all of the elementary teachers shifted from highly open-minded to low, but only half of the secondary teachers shifted to low (Tables 20 & 21).

Table 17

Observed Three-digit Classifications per Interview "TD Category"

		TD Category from Interview†			
		1	2		
PC Category*	1	3	2	1	GT Category+
		2	-	2	
	2	6	-	1	
		-	2	2	
	3	-	-	1	
		-	-	2	
	4	-	-	1	
		-	-	2	

*Prior conception appropriation: 1 = Integration, 2 = Differentiation, 3 = Exchange, 4 = Bridging
†Thinking disposition: 1 = Low Open-minded, 2 = High Open-minded
+Geologic time: 1 = Low, 2 = High

Table 18

Undergraduate Degree in Education – Interview TD

		TD Category†			
		1	2		
PC Category*	1	3	1	1	GT Category+
		-	-	2	
	2	5	-	1	
		-	-	2	
	3	-	-	1	
		-	-	2	
	4	-	-	1	
		-	-	2	

*Prior conception appropriation: 1 = Integration, 2 = Differentiation, 3 = Exchange, 4 = Bridging
†Thinking disposition: 1 = Low Open-minded, 2 = High Open-minded
+Geologic time: 1 = Low, 2 = High

Table 19

Undergraduate Degree in Science – Interview TD

		TD Category†			
		1	2		
PC Category*	1	-	1	1	GT Category+
		2	-	2	
	2	1	-	1	
		-	2	2	
	3	-	-	1	
		-	-	2	
	4	-	-	1	
		-	-	2	

*Prior conception appropriation: 1 = Integration, 2 = Differentiation, 3 = Exchange, 4 = Bridging
†Thinking disposition: 1 = Low Open-minded, 2 = High Open-minded
+Geologic time: 1 = Low, 2 = High

Table 20

Elementary Science Teacher – Interview TD

	TD Category†		
PC Category*	1	2	GT Category+
1	3	-	1
	1	-	2
2	3	-	1
	-	-	2
3	-	-	1
	-	-	2
4	-	-	1
	-	-	2

*Prior conception appropriation: 1 = Integration, 2 = Differentiation, 3 = Exchange, 4 = Bridging
†Thinking disposition: 1 = Low Open-minded, 2 = High Open-minded
+Geologic time: 1 = Low, 2 = High

Table 21

Secondary Science Teacher – Interview TD

	TD Category†		
PC Category*	1	2	GT Category+
1	-	2	1
	1	-	2
2	3	-	1
	-	2	2
3	-	-	1
	-	-	2
4	-	-	1
	-	-	2

*Prior conception appropriation: 1 = Integration, 2 = Differentiation, 3 = Exchange, 4 = Bridging
†Thinking disposition: 1 = Low Open-minded, 2 = High Open-minded
+Geologic time: 1 = Low, 2 = High

Summary of Results

1. From the interviews, it was determined that only 2 of the 4 modes of prior conception appropriation were evident among the teachers. However, all four modes were described to some extent, but not by each teacher. Some teachers talked exclusively about one type of appropriation mode, while others described two modes.
    - Integration and differentiation were the two primary prior conception appropriation modes exhibited by the teachers.
    - 53% of the teachers exhibited a differentiation mode.
    - 47% of the teachers exhibited an integration mode.
2. Prior conception appropriation was described in a monomodal or a bimodal fashion.
    - 53% of the teachers exhibited monomodal appropriation.
    - 47% of the teachers exhibited a bimodal appropriation.
    - 57% of bimodal appropriators were integration appropriators, while 43% were differentiation appropriators.
    - 86% of the time, bridging appropriation was used as the secondary mode of appropriation for bimodal appropriators (6 out of the 7 teachers).
    - Exchange appropriation was the only other secondary mode described.
3. Seven of the fifteen teachers (47%) distributed their mode of prior conception appropriation onto their students as the mode their students used to appropriate their prior conceptions when learning geologic time concepts.
4. All of the teachers described teaching practices for geologic time concepts that complimented their prior conception appropriation mode.

5. The majority (73%) of the teachers exhibited a low level of open-mindedness when they described how they appropriated their existing conceptions when learning and interacting with geologic time concepts.

Table 22

Three-Digit Category Classifications for Each Teacher

Teacher*	Prior Conception Category	Thinking Disposition Category(AOT)	Geologic Time Knowledge Category
Angela	1	2	1
Ben	2	2	1
Beth	2	2	1
Carrie	1	2	1
Cindy	2	2	1
David	1	2	1
Hallie	2	2	2
Jack	1	2	2
Kathy	1	2	1
Kim	2	2	1
Laura	2	2	1
Lois	2	2	2
Rena	1	2	2
Sonya	1	2	1
Will	2	2	2

*Pseudonym

6. On average, the teachers possessed a low level of geologic time knowledge.
    - The teachers answered an average of 45% of the geologic time questions correctly for all three administrations of the measure.
    - There was no statistically significant change in the number of correctly answered geologic time questions from pre to post to post-post program administration of the GCI.
7. The teachers ranged within the highly open-minded category as determined by the AOT. No teacher scored in the low category for open-mindedness.
    - 100% of the teachers scored as highly open-minded.
    - There was no difference in the teachers' average scores for the AOT from pre to post-post-program administration.
8. No relationship was found between a teacher's open-mindedness and the outcome of their learning geologic time concepts.
    - Pearson's correlation showed no statistically significant correlation among the teachers' scores on the AOT and the average number of geologic time questions answered correctly.
    - Analysis of frequency data for thinking disposition and level of geologic time knowledge supported the absence of any trend or relationship between these two parameters. This supported the results from the Pearson's correlations.
    - No relationships or major patterns were evident between thinking disposition and geologic time knowledge when the teachers' grade level was taken into account.
    - When the teachers' undergraduate degree area was considered, it revealed that all of the teachers with a bachelor's in education fell within the low level of geologic

time knowledge. This was not the case for those with a bachelor's degree in science where 67% of secondary science teachers were categorized in the high level of geologic time knowledge. However, there were no patterns evident between their knowledge and thinking disposition as determined by the AOT for either group.

9. There were no relationships or trends observed among the teachers as a whole group between their prior conception appropriation and their thinking disposition/open-mindedness.
10. There were no major relationships or trends determined among the teacher's prior conception appropriation and their level of geologic time knowledge.
11. The matrix data for analyzing relationships and trends among prior conception appropriation, thinking disposition, and learning geologic time showed the majority of the teachers (73%) fell into 2 of the 4 observed classifications (*Integration – Highly open-minded – Low geologic time knowledge* and *Differentiation – Highly open-minded – Low geologic time knowledge*), with both of the classifications consisting of a low level of geologic time knowledge. The remaining teachers (27%) were distributed among the other 2 observed classifications, both consisting of high geologic time knowledge.
12. Using the teachers' level of open-mindedness determined via the coded interviews, 73% of the teachers shifted from a high level of open-mindedness to a low level. When the relationships were analyzed from the perspective of the teachers' undergraduate degree area, there were no major patterns observed. However, the matrix analysis involving open-mindedness as determined from the interviews showed 100% of the elementary teachers but only 50% of the secondary teachers to have a low level of open-mindedness.

The data for this study revealed the teachers as integration appropriators or differentiation appropriators of their prior conceptions. The majority of the teachers described using bridging appropriation to facilitate integration or differentiation in a secondary aspect. There were no patterns or relationships between the teachers' thinking disposition and their learning geologic time concepts, nor were there any patterns or relationships determined among the teachers' prior conception appropriation, thinking disposition, and learning geologic time concepts.

The AOT revealed all of the teachers had a high degree of open-mindedness. However, interview data contradicted the AOT findings for the majority of the teachers. Moreover, the elementary teachers were all categorized as having a low degree of open-mindedness based on their interviews. There were no patterns evident based on the teachers undergraduate degree; science (biology) versus education.

CHAPTER V

CONCLUSIONS, IMPLICATIONS, AND RECOMMENDATIONS

Organization of the Chapter

This chapter contains the study's conclusions, implications, and recommendations for future research. The chapter begins with a summary of the study that includes the purpose of the study and a review of the methodology. The conclusions are presented in alignment with the primary focus of each of the three research questions. The implications section describes pertinent information for the teaching and learning of controversial science content that was gleaned from the results and findings of the study. The recommendation section outlines avenues of future study that could be pursued in regards to controversial science content, thinking disposition, and open-mindedness.

Summary of Study

Purpose

The purpose of this study was to conduct and present an analysis of elementary and secondary science teacher's use of prior conceptions regarding geologic time when learning about geologic time concepts as a function of their open-mindedness. Learning science concepts involves the interaction of several cognitive factors. The interaction of a learner's open-mindedness as determined by their thinking disposition has been suggested to affect the conceptual learning of certain science concepts (Lawson & Thompson, 1988). In addition, the way a learner negotiates their prior conceptions when learning new science information has been found to affect conceptual learning.

This study was directed by three research questions formulated by the researcher:

1. How do elementary and secondary science teachers appropriate their existing conceptions regarding geologic time when learning about concepts that are inconsistent with their existing knowledge?
2. How is thinking disposition related to the learning of geologic time concepts?
3. What relationships are evident among the teachers' appropriation of prior conceptions, thinking disposition, and learning about geologic time?

Review of Methodology

This study used a mixed-method research design described in Chapter 2 to address the three proposed research questions. Fifteen science teachers, seven elementary and eight secondary, were randomly selected from a group of 33 teachers that attended a professional development program that provided geosciences content instruction including demonstrations on how to teach the geosciences content. Three different points of data were collected to inform the research questions. One point consisted of qualitative data derived from interviews conducted by the researcher with the teachers. A second point of data was quantitative and was taken from the Geoscience Concept Inventory (GCI) content knowledge test. The third point of data was quantitative and involved the Actively Open-minded Thinking (AOT) scale to assess the teachers' open-mindedness.

The interview data was coded by the researcher, analyzed, and used to produce case summaries of the teachers' prior conception appropriation mode. Inter-rater reliability was established by comparing the coding results between the researcher and three colleagues that were familiar with the study and trained on the codes. The inter-rater reliability was presented as percent agreement between the raters. The qualitative data from the interview analysis was converted to a numerical value for subsequent analysis. The quantitative data from the GCI and the AOT were analyzed through repeated measures t-Tests and correlation analysis. Next a 3-digit numerical classification was given to each teacher based on the category of their appropriation mode, level of open-mindedness, and level of geologic time knowledge. Matrices were developed from the three sets of numerical data and 3-digit numerical classifications to analyze for relationships and trends among the teachers' prior conception appropriation, thinking disposition, and learning geologic time.

Conclusions

Introduction

This study was designed to investigate how elementary and secondary science teachers used their existing conceptions when learning controversial science concepts in relation to their level of open-mindedness. Studies have been conducted that have analyzed the relationships between students' open-mindedness and their learning of controversial science content (Sinatra et al., 2003), or the relationship of their reasoning, learning, and open-mindedness with regards to controversial science issues (Keselman, et al., 2007; Stanovich & West, 1997). In these studies, only quantitative measures were given to assess the students' open-mindedness, reasoning and learning. The difference between previous studies and this current study is two-fold. First, this study introduced qualitative investigation into the methods, and second, this study specifically assessed the learners' position and use of their existing conceptions when learning a controversial science topic. The conclusions presented here are focused around the study's three research questions. The following sections address the primary focus of each research question.

Prior Conception Appropriation

Research question number 1 required the researcher to obtain an assessment of how the teachers used or appropriated their existing conceptions when learning geologic time concepts and principles. Hewson and Hewson (1983) organized the research on the function of prior knowledge and conceptions into the four categories (modes) and labeled them Integration, Differentiation, Exchange, and Bridging. All four of the modes of appropriation described by Hewson and Hewson's (1983) are relevant to conceptual change learning in science and have been addressed through research (Cook, Carter, & Wiebe, 2008; Ebenezer, et al., 2010; Eshach & Schwartz, 2006; Rivet & Krajcik, 2008). The participants for this study were categorized based on the four modes of appropriation through the information provided in interviews.

The teachers in this study described either integration or differentiation as their primary mode of existing conception appropriation when learning geologic time concepts. Integration appropriation was determined through the teachers' use of terms and metaphors that described how they would "integrate", "incorporate", "mesh", "mix", or "intertwine" new information with their existing conceptions. Differentiation appropriation was determined through the teachers' descriptions of "keeping new information separate" from their existing conceptions, or describing how they purposefully compartmentalized the new information and the information that made up their existing knowledge frameworks in separate compartments.

Integration and differentiation modes of appropriation have been associated with assimilation processes in conceptual change learning and can result in weakly structured knowledge frameworks (Carey, 1985; DiSessa & Sherin, 1998; Posner, 1982; Scott, et al., 2007; Vosniadou, 1994; Vosniadou & Brewer, 1987). Assimilation processes are viewed as the initial steps in conceptual change learning. These first steps set the stage for the development of more robust and permanent conceptions through some form of accommodation (Carey, 1985; DiSessa & Sherin, 1998; Posner, 1982; Scott, et al., 2007; Vosniadou, 1994; Vosniadou & Brewer, 1987). Therefore, it makes sense for the science teachers in this study to describe or exhibit either integration or differentiation of their existing conceptions, especially in the early stages of learning a science conception such as geologic time. However, none of the teachers described moving to the next step of conceptual change learning where their existing inappropriate and naïve conceptions were replaced, radically restructured, or pushed aside for the new scientifically accepted conception. Moreover, this is evident among the results of the GCI. The teachers showed no change in their level of knowledge regarding geologic time concepts from the beginning of the program to the end of the program. An explanation for this situation can be offered through a sociocultural perspective of conceptual change learning involving conceptual addition. Conceptual addition by a learner involves adding conceptual information by using a "toolkit" of language and information derived socially and involving specific contexts (Scott, et al., 2007; Wertsch, 1991). Therefore, new conceptions are added to existing conceptions rather than replacing them. Geologic time is a controversial science concept, is regarded as being socioscientific, and would potentially be negotiated through conceptual addition processes. In addition, conceptual addition would favor integration and differentiation modes of existing conception appropriation and vice-versa.

Seven out of the fifteen science teachers described a bimodal process of existing conception appropriation where a secondary appropriation mode was employed to assist the primary modes of integration or differentiation. For the bimodal appropriation, bridging was described as the preferred secondary mode. Bridging is seen as a means to connect existing conceptions with new conceptions through establishing appropriate contexts (Bloom, 1992; Bryce, 2005; Georghiades, 2006). Placing conceptions within contexts allows the learner to assess plausibility and intelligibility of a conception. Therefore, bridging can be seen as a means for a learner to move from assimilation to accommodation of a science concept as that concept becomes a permanent part of the existing knowledge frameworks. Bridging was described predominantly as a secondary modality by the bimodal teachers when learning geologic time concepts. Even though bridging can aide in the process of building permanent and stable structures, this did not affect the bimodal teachers' learning of the geologic time information. Cindy, Jack, Kathy, Kim, and Rena described bridging mechanisms to help them integrate or differentiate new geologic time conceptions and their existing conceptions. However, they all stopped short of fully accommodating the new conceptions by maintaining a priority with their existing conceptions. Furthermore, their geologic time knowledge changed very little throughout the course of the TENNMAPS program.

Employing differentiation or integration processes would better suit some individuals when learning controversial science content like geologic time. Since controversial science concepts are ill-defined and do not have straightforward explanations (Sadler, 2004; Sadler & Zeidler, 2005c), complete exchange of an existing conception with a new one would potentially be problematic. Differentiation or integration appropriation would be less stressful and less difficult to manage. Likewise, using bridging in a bimodal process, as described by several of the teachers, would further mitigate the difficulties with controversial science concepts. Bridging would allow the teacher to make necessary connections with the controversial information and their existing conceptions that would facilitate integration, or highlight obvious differences and allow them to establish boundaries to differentiate the two sets of conceptions.

Nearly half of the teachers distributed or projected their preferred mode of appropriation onto their students. In these instances, a teacher would describe how they appropriated their existing conceptions and then describe the same process for how their students should or would negotiate the controversial content when learning it. This situation may not be too out of line from what these teachers deem is appropriate when learning geologic time concepts. From the teacher's perspective, if they have determined that a certain appropriation mode is effective, it would be regarded as the best course for their students to take as well. These approaches would fall in line with sociocultural aspects of conceptual change learning and conceptual addition.

All of the teachers described using teaching practices to teach controversial geologic time concepts that were congruent with their primary appropriation mode. Cindy, Kim, and Laura described how they differentiated the geologic time concepts when learning them by keeping them separate. When teaching geologic time concepts, these teachers described presenting the information in two completely different sets; one aligned with their existing conceptions, and the other aligned with the scientifically accepted conceptions. Presenting the information in this fashion could potentially facilitate the student to favor differentiation of their existing conceptions from the scientifically accepted conceptions. This phenomenon would seem logical from the teacher's perspective for the same reasons half of the teachers distributed or projected their appropriation mode onto their students. The teachers have established appropriation modes that they feel are effective when learning controversial geologic time content. Therefore, a teacher would potentially perceive teaching methods that privilege their appropriation modality to be the most effective.

Learning Geologic Time Concepts and Thinking Disposition

Overall, the teachers had a low level of geologic time knowledge from the beginning of the TENNMAPS program to the end of the program. However, Hallie, Jack, Rena and Will consistently answered over 70% of the geologic time questions correctly. In addition, Hallie and Will correctly answered 75% of the questions on the GCI, but Rena and Jack did not perform as well on the complete GCI measure. The low level of geologic time knowledge, as well as geosciences knowledge, can be attributed to several factors. The majority of the teachers have had very little exposure to geology and earth science. Jack and Angela were the only teachers to have several college level earth science courses, with the remaining thirteen teachers having fewer than two courses. Hallie, Jack, Rena, and Will scored the highest on both the complete GCI and for the geologic time questions. An explanation for Hallie, Rena, and Will's higher performance, even though they have had a minimum of earth science instruction, can be due to the three having undergraduate degrees in biology. Several concepts in biology, such as evolution, have a direct relationship with geologic time, and they possess overlapping content (Trend, 1998, 2000, 2001).

Furthermore, the low level of geoscience and geologic time knowledge among the majority of the teachers in this study is not an isolated situation, nor is it unique to these teachers. The amount of geology and earth science courses an elementary teacher takes in their teacher preparation program is minimal. Secondary science teachers major or minor in the specific content they are planning to teach, thus minimizing exposure to other science content including the geosciences. The teachers in this study focused predominantly on biology and the life sciences for their science concentration during their education, with six of the fifteen teachers having an undergraduate major in biology (Table 1). Five of the teachers reported having no coursework in geology or earth science, while seven reported having only one course during their undergraduate education. Moreover, David and Lois reported never having a course in earth science or geology. All of the teachers but David and Lois had at least one earth science course in middle school, high school, or college. Adding to this situation, geologic time is regarded as one of the most difficult concepts in geology, geosciences, and earth science to comprehend and accept (Libarkin, et al., 2007; Trend, 1998, 2000, 2001). The low level of knowledge of geologic time among the teachers is to be expected given the teacher's low level of overall geosciences knowledge including geologic time's problematic nature.

Geologic time's controversial character compounds the difficulty in learning its inherent concepts. Learning geologic time required the teachers in this study to employ both formal and informal reasoning patterns. Controversial concepts permit a learner to favor informal reasoning over formal reasoning in some situations (Sadler, 2004; Sadler & Zeidler, 2005c). Furthermore, patterns of informal reasoning can be directly related to a person's thinking disposition and open-mindedness (Stanovich & West, 1997, 2007). The teachers' AOT scores suggested they were all relatively open-minded. Open-mindedness is more closely aligned with formal reasoning patterns (Lawson & Thompson, 1988; Lawson & Weser, 1990; Stanovich & West, 1997, 2007). Formal reasoning is more closely aligned with effective conceptual change processes. When the teachers' level of open-mindedness was analyzed along with their performance regarding geologic time knowledge, no relationships were determined. This supports earlier findings regarding biological science concepts related to geologic time (Sinatra, et al., 2003).

Examination of the geologic time data and interview data exposed a different pattern. The teachers' interviews provided information regarding their open-mindedness that was contrary to what they returned for the AOT. While the teachers were determined to be relatively open-minded by the AOT, analysis of their interview transcript revealed the teachers predominantly described a low level of open-mindedness. When this information was juxtaposed with the geologic time knowledge data, the trend of low-level of open-mindedness and low-level of geologic time knowledge was observed among eleven of the fifteen teachers. This is a trend that would be expected given geologic time's controversial nature (Lawson & Thompson, 1988; Lawson & Weser, 1990; Sadler, 2004; Sadler & Zeidler, 2005c).

The remaining four of the fifteen teachers, Carrie, David, Hallie, and Will, returned a relatively high degree of open-mindedness on the AOT and from their interviews. Furthermore, Hallie and Will both rated highly open-minded on the AOT, were coded as open-minded from their interviews, and answered the most geologic time questions correctly. The common factor for the four teachers is they are all secondary science teachers. In addition, Carrie, Hallie, and Will have undergraduate degrees in biology. Carrie and David's low score on geologic time knowledge further supports the existence of no relationship between open-mindedness and learning geologic time concepts. To change a learner's conceptions takes a combination of effective conceptual change teaching strategies and a protracted amount of time (Chi, 2005; Trundle, et al., 2007b; Vosniadou & Brewer, 1987). The TENNMAPS program employed effective teaching strategies, but was not sufficient enough in time to potentially affect major changes in the majority of the teachers' conceptions regarding the controversial geologic time topic. Hallie and Will both scored high on the pre-program, post-program, and post-post-program assessment for geologic time. However, their scores were the same for all three assessments. David's scores remained the same across all three assessments, while Carrie experienced an increase in her post-post-assessment over the pre and post. This would lend credence to time being a factor of importance in conceptual change science learning and not necessarily a learner's degree of open-mindedness.

Prior Conception Appropriation, Thinking Disposition, and Learning Geologic Time Concepts

There were no relationships or patterns observed between prior conception appropriation, thinking disposition, and geologic time among the sample of elementary and secondary science teachers. Analysis of the data for this study showed the teachers to have a relatively low level of geologic time knowledge as evidenced by their performance on the Geoscience Concept Inventory. Furthermore, the data provided by the GCI, the AOT, and the interviews did not provide evidence of any relationships or patterns involving learning about geologic time as a function of the teachers' open-mindedness or the appropriation of their existing knowledge and conceptions. Analysis of all three of the parameters showed that more than half of the teachers fell into two groups. These two groups were *integrator – highly open-minded – low geologic time knowledge*, and *differentiator – highly open-minded – low geologic time knowledge*. The patterns evident by this data revealed the teachers to be split equally between integration appropriation and differentiation appropriation, and the majority of the teachers possessed a low level of geologic time knowledge.

The interview data provided open-mindedness information that was contradictory to the open-minded data provided by the AOT. Analysis of patterns using the open-mindedness data from the interviews provided expected results on the learning of a controversial science topic like geologic time. When the teachers were regrouped based on their undergraduate degree and the grade level they taught, two patterns emerged. First, all of the teachers with an undergraduate degree in education possessed a low level of open-mindedness, while only half of the science majors possessed a low level. Second, all of the elementary science majors possessed a low level of open-mindedness, while only half of the science majors possessed a low level. The dichotomy observed in open-mindedness between the teachers with science backgrounds and those without is not a surprising phenomenon. Sadler (2005) and Sadler and Zeidler (2005b) witnessed a similar dichotomy related to misconceptions of evolutionary theory and informal reasoning among undergraduate biology majors and non-science majors.

The striking pattern to emerge from the analysis in this study involved the low level of geologic time knowledge and the low level of open-mindedness among the elementary teachers and the teachers with an undergraduate degree in education. In this study, the elementary teachers and the teachers with an undergraduate degree in education were a mutually inclusive group. The teachers' undergraduate degree and the grades they taught were factors that provided a description of the context surrounding the teachers and the outcome of their learning geologic time. Contextualizing factors can have an impact on conceptual learning of any science content (Dole & Sinatra, 1998; Gorodetsky & Keiny, 2002; Hallden, Haglund, & Stromdahl, 2007; Sinatra, 2002). The teachers in this study possessed several characteristics that shaped the context of this study and imparted contextual aspects that shaped their conceptual understanding of geologic time. Some examples of contextual influence in this study included:

1. All of the teachers came from underperforming schools.
2. The majority of the teachers possessed a minimal background of science information.

3. The teachers lived and taught in rural communities.
4. The teachers lived and taught in the region of the United States often referred to as the "Bible belt".

In this study the social context involving the "Bible belt" had the greatest potential influence on the teachers' existing conception appropriation and their learning of geologic time concepts. Even though all of the elementary teachers possessed a low level of geologic time knowledge and a low level of open-mindedness, so did half of the secondary teachers and teachers with degrees in science. Moreover, no data were collected in this study to address aspects of teaching in underperforming schools or that the teachers taught in rural locales. However, social contexts surrounding the development of prior conceptions regarding geologic time, such as living in the "Bible belt", could potentially influence the appropriation of those existing conceptions during learning. Evidence supports the influence of prior conceptions on a variety of factors associated with learning (Afra, et al., 2009; Banet & Ayuso, 2003; Hewson & Hewson, 1983; Posner, 1982). The Bible belt is regarded as an area of the United States that encompasses the southern states, extending from Texas to the eastern coast line. The Bible belt is steeped in predominantly Protestant influenced notions, values, and beliefs (Heyrman, 1997; Vazsonyi & Jenkins, 2010). The majority of the teachers were aware of the implications of teaching science in this region. Carrie specifically spoke of the "Bible belt" and the challenges of teaching certain science topics as a result. Jack, David, Ben, Laura, and Angela made implied comments of the beliefs and existing conceptions they and their students possessed regarding geologic time and other science concepts.

Geologic time is often closely aligned with evolutionary concepts in biology due to mutually inclusive concepts (Trend, 2000, 2001). In this study, the teachers aligned geologic time with evolution and the big bang theory. Jack, Kim, Laura, Carrie, Beth, Cindy, Ben, Sonya, Kathy, Will, Lois, and Rena specifically mentioned evolution and/or the big bang theory during their interviews. The TENNMAPS program included lessons and discussion on deep geologic time, the fossil record, and evolution. Likewise, the GCI included questions specific to deep geologic time, the fossil record, and evolution. Van Dijk and Reydon (2010) assert a problem with learning evolutionary theory lies with the existing conceptions a learner holds prior to exposure to instruction on evolution. In their review of the misconceptions regarding evolutionary theory, van Dijk and Reydon (2010) determined the majority of students hold a teleological perspective of evolutionary theory. As was mentioned, the teachers in this study were raised, received their college education, lived, and taught in the “Bible belt” region of the United States. The possession of teleological conceptions by the teachers regarding geologic time and evolution would therefore be expected (Heyrman, 1997; Vazsonyi & Jenkins, 2010). In fact, Cindy, Jack, Ben, Kim, Sonya, Kathy, Rena, Laura, and Lois talked specifically about God and the Bible, and how the two influenced the way they viewed geologic time, evolution, and the big bang theory. Angela, David, and Beth made reference to religious beliefs, convictions, and supernatural powers.

Thinking disposition or open-mindedness could be considered a factor in the teachers’ low level of geologic time knowledge due to the teachers’ robust, teleological prior conceptions. Evidence suggests that existing conceptions are robust and deeply rooted. As a result, existing conceptions are difficult to alter or change (Carey, 1985; DiSessa & Sherin, 1998; Hewson & Hewson, 1983; Posner, 1982). However, open-mindedness was not found to be related to prior conception appropriation or learning geologic time concepts. This supports previous findings regarding biological evolution (Sinatra, et al., 2003). Even though the teachers talked about being fairly open-minded individuals, they gave indications of the opposite when they discussed learning new geologic time concepts. When the new concepts were being considered to be included in their knowledge frameworks, the concepts had to ultimately conform to their existing conceptions. Otherwise, the new information would have to be modified prior to integration, as described by Jack, or compartmentalized to keep it separate and differentiated, as described by Ben. Kim, Laura, Sonya and Rena negotiated open-mindedness and the geologic time concepts similar to Jack and Ben. These four teachers stated how they would think about the information, but they knew what they knew and what they *knew* was all that mattered in the end. In some instances, parts of the new information could be selected and aligned with their existing conceptions, and the information that could not would be disregarded. On the contrary, Hallie and Will, who both scored highly open-minded on the AOT and coded highly open-minded from their interviews, gave insights into their open-mindedness that were more in line with what is accepted as being open-minded. Hallie and Will were both coded as differentiators due to how they compartmentalize new information, but the compartmentalization serves only as a place to contain the new information while they come to understand it and eventually internalize it. Hallie expressed how she keeps new information separate but active until she has accumulated enough credible evidence to accept the new conception as the correct one. In fact, Hallie was one of only two teachers that made mention to any form of exchange appropriation. In addition, both Hallie and Will had an undergraduate degree in biology and taught secondary science.

An explanation of this contradictory situation involving open-mindedness could be found within the interpretation of open-mindedness. Open-mindedness has the potential to be a "relative" term influenced by contextual factors (Coll & Taylor, 2004). Therefore, due to a relative character influenced by contextual inputs, open-mindedness could be subject to interpretation. During interviewing, several of the teachers in this study gave their view of their own open-mindedness when talking about geologic time principles. However, they were assessed not to be very open-minded. The categorization of the teachers as not open-minded could have been the result of an interpretation of open-mindedness influenced by the context of the study, the researcher, and certain presuppositions. Open-mindedness is a habit of mind related to aspects of the nature of science considered to be fundamental in the acquisition of scientific knowledge. Thus, scientists must possess a relatively high degree of open-mindedness. However, scientists express open-mindedness in varying degrees related to contextual factors involving a scientific concept or phenomenon (Coll & Taylor, 2004). Moreover, scientists do not have a monopoly on open-mindedness (Leahy & Laura, 1997; Settle, 1996). Individuals with a teleological foundation, such as those living in the Bible belt, can possess a relatively high degree of open-mindedness. Leahy and Laura (1997) contend that considering alternative interpretations and truth claims gives individuals the ability to consider other dimensions of reality than just the empirical dimension. Inquiry into other dimensions of learning and knowing fosters open-mindedness within the individual (Leahy & Laura, 1997). All of the teachers in this study described existing conception appropriation in a fashion that afforded consideration of more than one view of geologic time concepts. The differentiation appropriators internalized the multiple views but kept them in separate cognitive spaces. The integration appropriators internalized the multiple views through a mechanism of fitting the views together. Settle (1996) argues people with a teleological ground possess a greater degree of open-mindedness than most scientific institutions based on their willingness to consider and assimilate a plurality of views. As Settle (1996) states, “The most important upshot…is the emergence of the moral demand of humility in one’s opinions and a respect for the opinion of others. In short: open-mindedness.” Kathy provided information to support Settle’s (1996) claims:

> “I try to listen to it with an open mind and you know, I do a lot of investigating and research on my own, and sometimes I'll ask, you know, show me one on one. You know if somebody will explain that to me one on one and I think you just find a way. I kind of settle it for myself. I'll find something that helps me to understand it. And, I do believe that some people come in with their own agenda and their own way and, not truly to teach you science. And, unfortunately that is true in our collegiate area. There are some people that that is their agenda. It might not be they may not realize it is intentional, but I've had that encounter myself in college. And, you just have to realize those people have their own agenda and their not really trying to teach good science. They're trying to teach their own belief.”

Thus, open-mindedness can be open to interpretation that requires analysis of the new information being considered, contextual factors associated with the episode in which the information is being considered, and the existing conceptions the individual possesses to enable them to negotiate the information. Further investigation would be required to assess the factors that influence open-mindedness specifically or the interpretation of open-minded within the context of the investigation.

Implications for Learning Controversial Science Concepts

The findings for this study show that a discrepancy regarding learning scientific information exists between conceptual change researchers in science education and second through twelfth grade science teachers. The teachers in this study described learning geologic time concepts in a way that would favor the construction of incomplete, inappropriate, and weak knowledge frameworks. Conceptual change researchers recommend processes and actions that promote and support complete, robust, and strongly-built frameworks (Carey, 1985; diSessa, 2008; DiSessa & Sherin, 1998; Vosniadou & Brewer, 1987). The teachers' views of learning geologic time concepts involve minor changes to their existing conceptions, while the accepted mechanisms can often be major in character.

This study supports Duschl and Hamilton's (1992) assertions of teachers' potential lack of both the information regarding proper conceptual change learning processes and the procedural know-how by teachers to enact radical reconstruction of students' existing conceptions. It is not just important for a teacher to know the science content they teach, but to know how to teach it in a way that facilitates a student's learning and understanding. In addition, the National Science Teacher Education Standards state that science teachers need to be familiar with the nature of learning science and scientific concepts (NSTA, 2003).

The science teachers in this study were asked if they were familiar with conceptual change learning principles regarding science concepts. None of the teachers had heard of conceptual change learning prior to our discussion. In addition, a limitation the teachers expressed was their lack of pedagogical knowledge related to teaching geosciences and geologic time, as well as other science information related to these areas. This absence of understanding how proper knowledge frameworks are built when coupled with little to no pedagogical content knowledge by science teachers can have profound effects on students' learning and understanding of science concepts, including geologic time (Duschl & Hamilton, 1992). The distributed appropriation phenomenon described by half of the teachers lends credence to the potential effects of these absences.

Table 23

Category Classifications Including Open-minded Classification from the Interviews

Teacher*	Prior Conception Appropriation Category	Thinking Disposition Category	Geologic Time Knowledge Category	Open-mindedness† (Interview)
Angela	1	3	1	1
Ben	2	2	1	1
Beth	2	2	1	1
Carrie	1	3	1	2
Cindy	2	2	1	1
David	1	2	1	2
Hallie	2	3	2	2
Jack	1	2	2	1
Kathy	1	3	1	1
Kim	2	2	1	1
Laura	2	3	1	1
Lois	2	2	2	1
Rena	1	2	2	1
Sonya	1	3	1	1
Will	2	3	2	2

*Pseudonym
†1=Low-level, 2=High-level

The teachers in this study described their prior and existing conception appropriation as either integration or differentiation. These two modes of appropriation, if utilized solely, are not sufficient to enable the construction or restructuring of knowledge frameworks that are complete and robust. Integration and differentiation are considered as initial steps in proper conceptual change learning, and the learner must then make further moves with their existing conceptions and the new conceptions through exchange or major restructuring (Hewson & Hewson, 1983; Hewson, 1992; Scott, et al., 2007). By thinking their students learn through the same mode of appropriation, the teachers are stopping short of providing their students with the necessary prompts to foster the development of proper knowledge frameworks. This could give rise to the degradation of the understanding of science concepts by students over time. Studies have shown that science knowledge does degrade over time, and the best defense against the loss of information is through effective conceptual change teaching methods (Trundle, et al., 2007b).

The use of integration and differentiation modalities for existing conception appropriation among these teachers could have been influenced by geologic time's controversial nature. Controversial science content offers unique challenges for teaching and learning. When negotiating controversial content, individuals call upon prior knowledge and existing conceptions differently than with non-controversial content. Dealing with controversial content forces learners to toggle between formal and informal reasoning patterns that can affect the decisions they make regarding the plausibility and intelligibility of the related concepts (Sadler & Zeidler, 2005a). Furthermore, controversial content places an emphasis on a learner's thinking disposition and open-mindedness toward the consideration and learning of the controversial content. Figure 1 outlines the connectedness of reasoning ability, existing knowledge, and thinking disposition with an emphasis on controversial science content.

Figure 1 could be viewed as a blueprint for how knowledge frameworks are built during conceptual change learning. It is possible a blueprint exists for each classification of science content. This would be similar to DiSessa (1985) and DiSessa and Sherin's (1998) descriptions of coordination classess. Coordination classes are established by the ontological classification of concepts by an individual and thus become part of a learner's existing conceptual framework that is called upon during subsequent learning. Since differences exist in reasoning patterns and thinking disposition that are related to the nature of the content (Stanovich & West, 1998), it could be argued that differences exist in the appropriation of existing conceptions for the same reasons. Thus the interplay of these three constructs would be different according to the status of the science content. Therefore, there could be multiple representations of Figure 1. Having this knowledge could equip a science teacher with powerful information that would allow them to select effective conceptual change teaching methods. Furthermore, a learner could utilize this information to make personal choices when learning controversial and non-controversial content that could have substantial and positive effects on the outcome.

Recommendations for Further Research

The research questions for this study were exploratory in nature and afforded the researcher the opportunity to investigate variables that have not been surveyed extensively. As a result of this study, it was determined that further research is required to elucidate the role of existing conception appropriation on the learning of controversial science content. Four recommendations have been proposed for future study.

1. Increase the sample size of the study. The sample for this study (n = 15) was a relatively small one and limited the types of statistical tests that could be employed. In addition, it would decrease the amount of sampling error. A larger sample would make it feasible to

conduct different statistical tests that have different analytical power. This differing power could have the potential to highlight unseen patterns and relationships that a small sample cannot afford.

2. Assess the participants for content knowledge on several science areas, especially those that are related to geologic time. Biology, chemistry, and geosciences have separate but specific content regarding geologic time, but they all possess aspects of geologic time content that are integrated among them. It may be that appropriation mode has a different effect or relationship on the level of geologic time knowledge attainable when approached from a geosciences perspective than it would when approached from another science discipline's perspective. The qualitative analysis of the effects of appropriation mode on the learning of biological or life science concepts and chemistry concepts related to geologic time needs to be investigated.
3. Conduct a study integrating the effects of broadening teachers' knowledge of geologic time, current evolutionary theory, and its historical development on teachers' overall understanding of geologic time. Many teachers are not knowledgeable of the historical aspects of the development of the science underlying geologic time and its related principles (van Dijk & Reydon, 2010). The development of the current evolutionary theories has transpired over nearly 300 years and involved several theory changes. Some of those theories were steeped in teleological aspects. Currently there is more than one theory circulating in the scientific community and the social milieu regarding the age of earth, evolution, and the origin of the universe.
4. Design a study involving reflexive analysis of existing conception appropriation, teaching practices, learning outcomes regarding both controversial and non-controversial topics by

the study participants, and their perceptions of what open-mindedness means to them. For example, analyze the participants' existing conception appropriation and their teaching practices along with the learning outcomes of their students on a particular set of science topics. This information would then be shared with the participants to give them insight into how they appropriate their existing conceptions and how this impacts their teaching methods and outcomes. Next have the participants implement conceptual change teaching strategies in absence of their appropriation modality and analyze their students' learning outcomes. As part of this process, the participants should reflect upon their innate actions and the established teaching strategies when teaching certain science topics, analyze the positive or negative impact of those actions, and make decisions regarding the teaching methods to change learning outcomes for their students. In addition, the researcher can learn what existing conception appropriation mode employed by the participants affects learning outcomes the greatest in relation to the science topic's controversial or non-controversial character.

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APPENDIX

Appendix A: Earth Science Content Covered in 2008 TENNMAPS Program

Mapping

Rocks and Minerals

Evolution of the Earth

Geologic Time

Fossils

Plate Tectonics

Earthquakes

Volcanoes

Water Cycle

Watersheds

Weathering and Erosion

Landslides

Soil

Energy

Sun, Moon, and Planets

Appendix B: 2008 TENNMAPS Daily Workshop Activities

****

Day 1 (Monday) Maps and Plate Tectonics

Welcome and Introductions
Intro to Geology
Info regarding the CD that accompanies the Textbook
Time/Geologic time
Nature of Science
Science Notebooks
Lunch
Time Activity?
Workshop Inventories (Geoscience concept inventory, etc.)
Plate tectonics
Seafloor spreading activities

****

Day 2 (Tuesday) Minerals and Rocks

Welcome and Intro for the day
Moon Rock
Science Literacy involving Rocks & Minerals (Intro to using a dichotomous key?)
Mineral Kit activity
Lunch
Mineral ID with Dichotomous Key
Rock Cycle video and Activity
Comparison of visual vs. dichotomous key identification

****

Day 3 (Wednesday) Rocks and Weathering

Welcome and Intro for the day
Igneous rocks
Identification of igneous rocks
Igneous rock video
Weathering
Weathering activity
Lunch
Sedimentary rocks
Metamorphic rocks
Dissolving limestone activity
What is my Subaru made of handout
Begin Crystal Making activity

****

Day 4 (Thursday) Earthquakes, Volcanoes, and Planetary Geology

Welcome and Intro for the day
Earthquakes
Rock and Earthquake activity
Slinky & Earthquake activity
Volcanoes
Volcano activity
Web cam presentation
Lunch
Planetary Geology
Astrobiology
Impact crater activity

****

Day 5 (Friday) Historical Geology & 4-H Camp Field Trip

Welcome and Intro for the day
Fossils
4-H Camp field trip
(1/2 of the group will go to the camp while the other ½ sits in for the lecture on fossils; after lunch they will swap activities.)

****

Day 6 (Monday) Fossils and Topo-mapping

Welcome and Intro for the day
Fossil Record
Timeline activity
Lunch
Topo-mapping
GPS (GIS) Activity

****

Day 7 (Tuesday) Field Trip

Welcome and Intro for the day
Field Trip

****

Day 8 (Wednesday) Water

Welcome and Intro for the day
Water woes
Water cycle video

Water cycle activity
Water Usage
Rivers
River video
Lunch
Groundwater map activity
Groundwater video
Glaciers
Water Pollution
Global warming/Climate change?

****

Day 9 (Thursday) Energy

Welcome and Intro for the day
Energy Activity
Fossil fuels
Alternative energy
Lunch
Coal/Strip-mining Issues
Renewable and Non-renewable Resources
Cookie Mining Activity
Allison’s Mining Activity

****

Day 10 (Friday) Beach and Shoreline

Welcome and Intro for the day
Beach and shoreline
Beach activities
Wave video
Tsunami book “The Wave”
Lunch
Lesson Plan activity
Post test inventories
Evaluation

Appendix C: Actively Open-minded Thinking Scale (AOT)

Adaptive Thinking Scale

Name:____

This questionnaire lists a series of statements about various topics. Please read each statement and decide whether you agree or disagree with each statement as follows by circling your response:

1 – Strongly Disagree 2 – Moderately Disagree 3 – Slightly Disagree 4 – Slightly Agree 5 – Moderately Agree 6 – Strongly Disagree

1. Of all the different philosophies which exist in the world, there is probably only one which is correct.
   1 2 3 4 5 6
2. It's really cool to figure out a new way to do something.

   1 2 3 4 5 6
3. A person should always consider new possibilities.

   1 2 3 4 5 6
4. I really hate some people because of the things they stand for.

   1 2 3 4 5 6
5. Feelings are the best guide to making decisions.

   1 2 3 4 5 6
6. There is one right way and lots of wrong ways to do most things.

   1 2 3 4 5 6
7. Changing your beliefs shows that you are a strong person.

   1 2 3 4 5 6
8. I believe we should look to higher authorities for decisions on important issues.

   1 2 3 4 5 6

9. I like jobs where I don have to think at all.

1 2 3 4 5 6

10. I never change what I believe in, even when someone shows me that my beliefs are wrong.

1 2 3 4 5 6

11. There are basically two kinds of people in this world, good and bad.

1 2 3 4 5 6

12. If I think longer about a problem, I will be more likely to solve it.

1 2 3 4 5 6

13. Nobody can change my mind if I know I am right.

1 2 3 4 5 6

14. Considering too many different opinions often leads to bad decisions.

1 2 3 4 5 6

15. It really makes me angry when someone can’t admit they are wrong.

1 2 3 4 5 6

16. It is better to simply believe in a religion than to be confused by doubts about it.

1 2 3 4 5 6

17. I like hard problems instead of easy ones.

1 2 3 4 5 6

18. I’m not interested in learning new ways to think.

1 2 3 4 5 6

19. Changing your mind is a sign of weakness.

1 2 3 4 5 6

20. Often, people who criticize me don’t know what they are talking about.

1 2 3 4 5 6

21. Right things and wrong things never change.

1 2 3 4 5 6

22. It’s okay to be undecided about some things.

1 2 3 4 5 6

23. It’s great when someone famous believes in the same things as me.

1 2 3 4 5 6

24. I try to avoid problems that I have to think about a lot.

1 2 3 4 5 6

25. I like jobs that make me think hard.

1 2 3 4 5 6

26. People should always consider evidence that goes against their beliefs.

1 2 3 4 5 6

27. It’s important to change what you believe after you learn new information.

1 2 3 4 5 6

Appendix D: Geoscience Concept Inventory (GCI)

DEMOGRAPHICS:
Please answer the following questions about your background.

Name____________________

Gender____ **College G.P.A._____**

Birthdate: Day_____ Month______ Year_______

College Major_______________ **Masters Degree___________**
Other Degrees______________

Racial Background: ___White ___Hispanic ___Asian
___African-American ___Pacific Islander
___American Indian ___Other________

In which high school grade did you take:

Physics	8	9	10	11	12	Never
Chemistry	8	9	10	11	12	Never
Biology	8	9	10	11	12	Never
Earth Science	8	9	10	11	12	Never

Which science courses have you taken in college?

Physics	8	9	10	11	12	Graduate
Chemistry	8	9	10	11	12	Graduate
Biology	8	9	10	11	12	Graduate
Earth Science	8	9	10	11	12	Graduate

Highest degree of:

Female Parent:	**Male Parent:**
___Elementary School	___Elementary School
___some High School	___some High School
___High School	___High School
___some College	___some College
___Bachelor's Degree	___Bachelor's Degree
___some Graduate School	___some Graduate School
___Master's Degree	___Master's Degree
___Doctoral Degree	___Doctoral Degree

Grade level you are currently teaching_________

How long have you been a full-time school teacher?_______ (Number of years completed)

Geosciences Concepts Inventory TEST QUESTIONS
Please answer the following questions to the best of your ability.

1. Some scientists claim that they can determine when the Earth first formed as a planet. Which technique(s) do scientists use today to determine when the Earth first formed? **Choose all that apply.**

(A) Comparison of fossils found in rocks
(B) Comparison of different layers of rock
(C) Analysis of uranium and lead in rock
(D) Analysis of carbon in rock
(E) Scientists cannot calculate the age of the Earth

2. Which of the following can greatly affect erosion rates? **Choose all that apply.**

(A) Rock type
(B) Earthquakes
(C) Time
(D) Climate

3. If the single continent in #40 did exist, how could scientists estimate the time needed for the single continent to break apart and form the arrangement of continents we see today?

(A) Scientists do not yet have a valid method for estimating the time needed to break continents apart.
(B) Through comparison of fossils found in rocks
(C) Through analysis of carbon in rock
(D) Through analysis of uranium and lead in rock
(E) Through comparison of different layers found in rocks

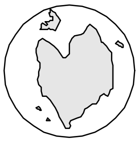
4. Which technique for determining when the Earth first formed as a planet is most accurate?

(A) Comparison of fossils found in rocks
(B) Comparison of different layers of rock
(C) Analysis of uranium and lead in rock
(D) Analysis of carbon in rock
(E) Scientists cannot calculate the age of the Earth

5. Which is the best definition of a tectonic plate?

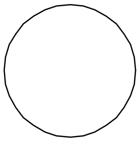
(A) All solid, rigid rock beneath the continents and above deeper, moving rock
(B) All solid, rigid rock beneath the continents and oceans and above deeper, moving rock
(C) All solid, rigid rock that lies beneath the layer of loose dirt at the Earth's surface and above deeper, moving rock
(D) All solid, rigid rock and loose dirt beneath the Earth's surface and above deeper, moving rock
(E) The rigid material of the outer core

6. What did the Earth's surface look like when it first formed?



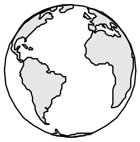
A

A. One large landmass surrounded by water



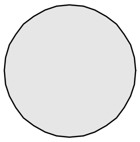
B

B. All water and no land



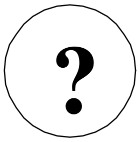
C

C. Similar to today



D

D. Mostly molten rock and no water



E

E. We have no way of knowing

7. Where do you think glaciers can be found today? **<u>Choose all that apply.</u>**

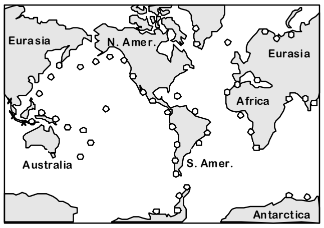
(A) In the mountains
(B) At sea level
(C) At the South pole
(D) Along the equator only
(E) Anywhere except along the equator

8. A student finds a dull black rock. She puts a magnet next to it, but it is not attracted to the rock. Which of the following statements best describes the rock?

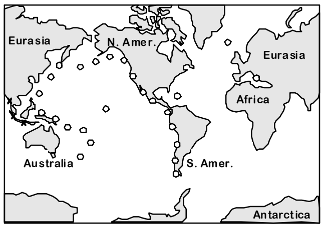
(A) Iron could be present in the rock because some black rocks contain iron
(B) Iron is definitely present in the rock because black rocks contain iron
(C) No metals are present in the rock because metals are magnetic
(D) Metals could be present in the rock, but not iron. Rocks that contain iron are red
(E) There are no metals present in the rock because rocks that contain metals are shiny, not dull

9. The following maps show the position of the Earth’s continents and oceans. The ‘s on each map mark the locations where volcanic eruptions occur on land. Which map do you think most closely represents the places where these volcanoes are typically observed?

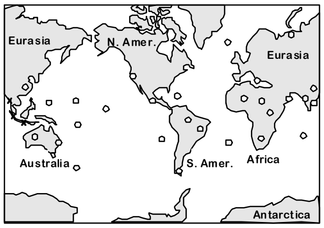
Circle one: **A** **B** **C** **D** **E**



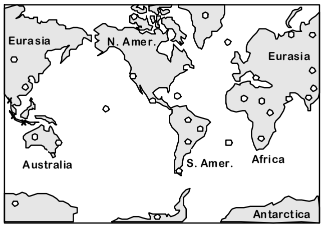
A. Mostly along the margins of the Pacific and Atlantic Oceans



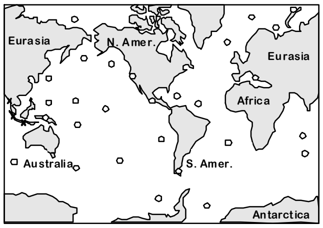
B. Mostly along the margins of the Pacific Ocean



C. Mostly in warm climates



D. Mostly on continents



E. Mostly on islands

10. Some people believe that they have evidence that can prove whether the very center of the Earth is a solid, liquid, or gas. Which of the following is an accurate statement about the innermost part of the Earth?

(A) The very center of the Earth is mostly made up of gases
(B) The very center of the Earth is mostly made up of liquids
(C) The very center of the Earth is mostly made up of solids
(D) Scientists don't have enough evidence yet to indicate whether gases, liquids, or solids make up most of the very center of the Earth

11. Which of the following are associated with events that cause large earthquakes? **Choose all that apply.**

(A) The construction and demolition of buildings
(B) Weather
(C) Bombs being dropped during a war
(D) Continents moving
(E) Changes in the Earth's core

12. Which of the following statements about the age of rocks is most likely true?

(A) Rocks found in the ocean are about the same age as rocks found on continents
(B) Rocks found on continents are generally older than rocks found in the ocean
(C) Rocks found in the ocean are generally older than rocks found on continents
(D) None of the above; we cannot figure out the age of rocks precisely enough to figure out which rocks are older

13. Rocks found in oceans can be _________. **Choose all that apply.**

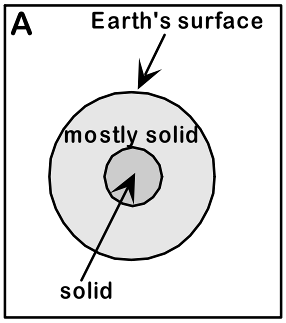
(A) Formed by animals
(B) Made up of pieces of continental rocks
(C) Formed by volcanic activity

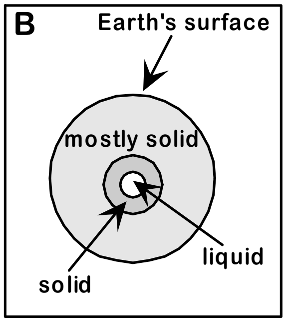
14. A large, ashy volcanic eruption occurs in Europe. Which effect would this eruption have on the air temperature near the Earth's surface one year later?

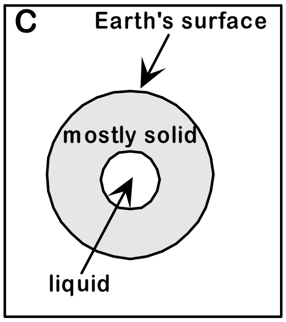
(A) Volcanic eruptions do not affect air temperature
(B) Only the air in Europe would be warmer
(C) Most of the Earth's air would be warmer
(D) Only the air in Europe would be colder
(E) Most of the Earth's air would be colder

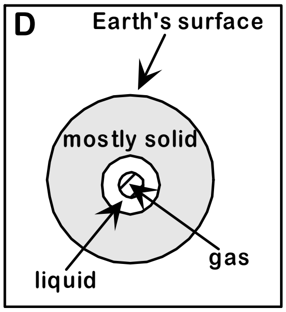
15. Which of the following figures do you believe is most closely related to what you might see if you could cut the Earth in half?

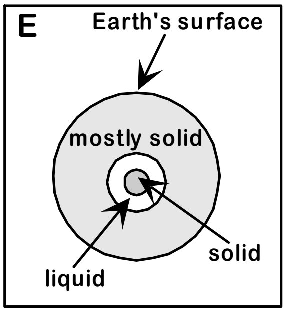
Circle one: **A** **B** **C** **D** **E**



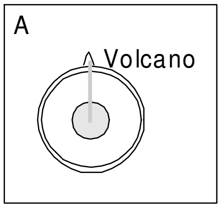




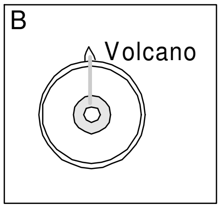




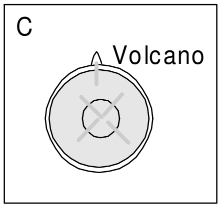
16. On continents, where does most volcanic material come from?



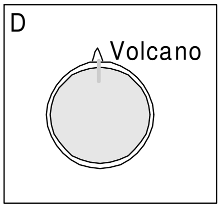
A. Material comes from the Earth's center, which is completely molten.



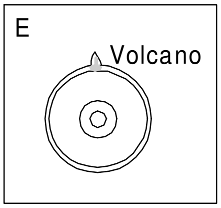
B. Material comes from a molten layer near the Earth's center



C. Material travels from the Earth's center to a molten layer just beneath the surface, mixes with this molten layer and then travels to the volcano.



D. Material comes from the molten layer beneath the Earth's surface

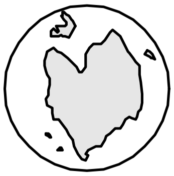


E. Material comes from pockets of molten material beneath the Earth's surface

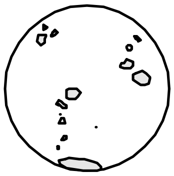
17. The figure below is a view of one-half of the Earth's surface as seen from space today. The gray areas represent land, and the white represents water. Which of the other figures do you think most closely represents this half of the Earth's surface when humans first appeared on Earth?

Circle one: **A** **B** **C** **D**

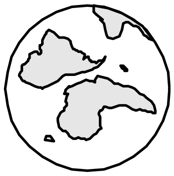
A



B



C



D

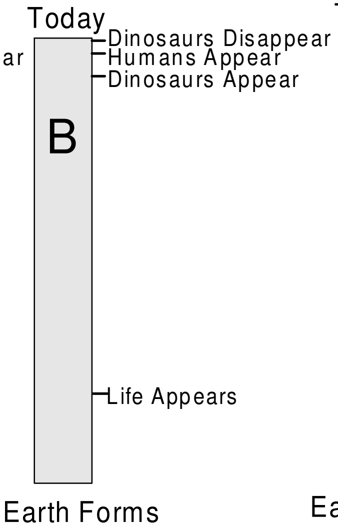
If you could travel back in time to when the Earth first formed as a planet:

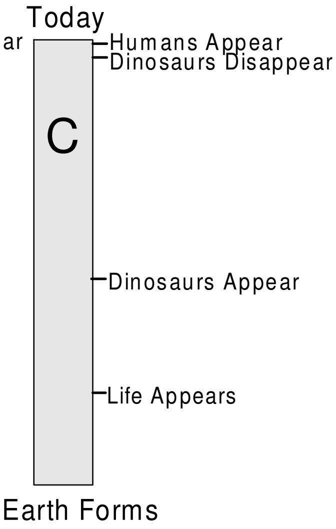
18. What type(s) of life do you think you might encounter?

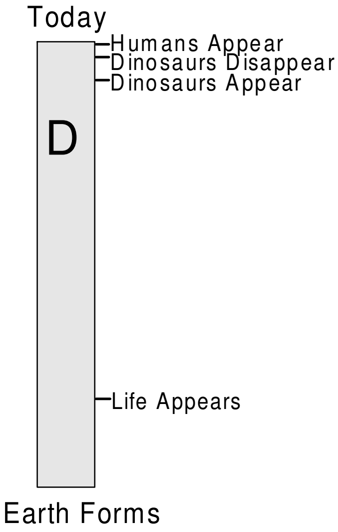
(A) There would be no life on Earth
(B) Simple, one-celled organisms
(C) Animal and plant life in water, but none on land
(D) All types of life in water and on land, except people
(E) All types of life in water and on land, including people

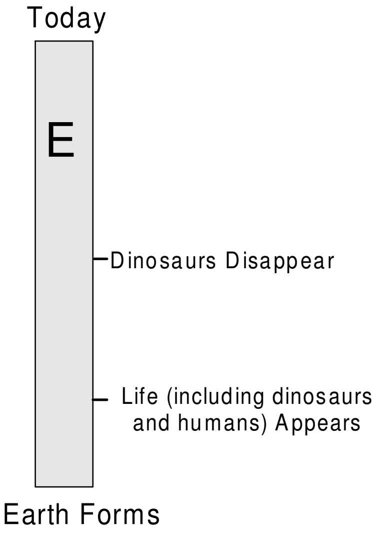
19. Which of the figures below do you think most closely represents changes in life on Earth over time?

Choose one: **A** **B** **C** **D** **E**









20. Which of the following best describes mountains? **<u>Choose all that apply.</u>**

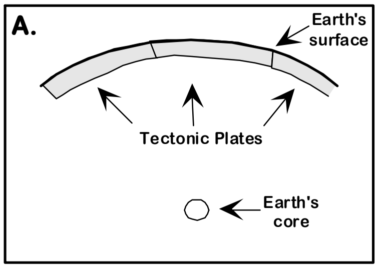
(A) Old mountains are generally taller because they have had more time to grow than young mountains
(B) Old mountains tend to have gentler slopes than young mountains because there is more time for rocks to get worn away
(C) Old mountains have more vegetation than young mountains because there is more time for plants to grow
(D) Old mountains tend to have rougher surfaces than young mountains because more time has passed and things crack as they get older
(E) All mountains are roughly the same age

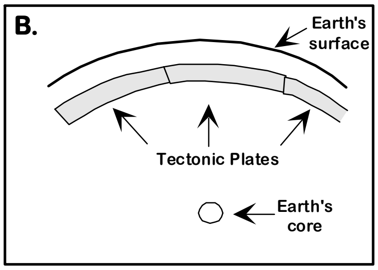
21. Where are most rocks formed?

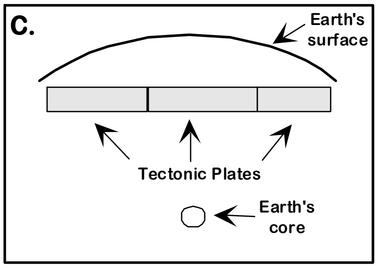
(A) Most rocks form underground and are pushed to the surface by magma.
(B) Most rocks form underground and are exposed when overlying rocks are removed.
(C) Most rocks form underground, but can never travel to the surface.
(D) Most rocks form at the Earth's surface.

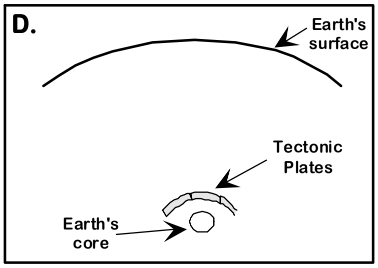
22 Scientists often talk about the Earth's tectonic plates and their role in mountain formation, volcanism, and earthquake occurrence. Which of the following figures most closely represents the location of the Earth's tectonic plates?

Circle one: **A** **B** **C** **D**









23. Which of the following statements do you think best describes the relationship between people and dinosaurs?

(A) People and dinosaurs co-existed for about five thousand years
(B) People and dinosaurs co-existed for about five hundred thousand years
(C) Dinosaurs died out about five thousand years before people appeared on Earth
(D) Dinosaurs died out about five hundred thousand years before people appeared on Earth
(E) Dinosaurs died out about 50 million years before people appeared on Earth

24. If the single continent in #40 did exist, how long did it take for the single continent to break apart and form the arrangement of continents we see today?

(A) Hundreds of years
(B) Thousands of years
(C) Millions of years
(D) Billions of years
(E) It is impossible to tell how long the break up would have taken

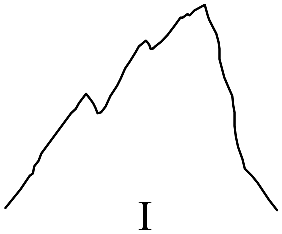
25. A scientist collects all of the fossils ever discovered into one room. This room now contains:

(A) Fossils of a few of the plants and animals that ever lived
(B) Fossils of most of the plants and animals that ever lived
(C) Fossils of most of the types of plants and animals that ever lived
(D) Fossils of all of the plants and animals that ever lived
(E) Fossils of all of the types of plants and animals that ever lived

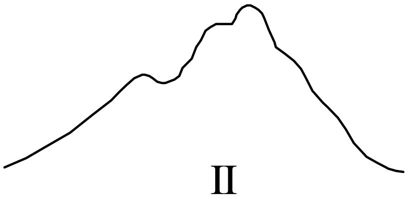
26. Fossils are studied by scientists interested in learning about the past. Which of the following can become fossils? **Circle all that apply.**

(A) Bones
(B) Plant material
(C) Marks left by plants
(D) Marks left by animals
(E) Animal material

27. During a recent trip to Canada, a traveler visited two mountains made up of the same type of rock. The sketches below represent the outlines of these two mountains. Which of the following reasons best explains the differences in the two drawings?



I



II

(A) Mountain I is older than Mountain II
(B) Mountain II is older than Mountain I
(C) Mountain I is on a continent that is moving faster than the continent Mountain II is on
(D) Mountain I is on a continent that is moving slower than the continent Mountain II is on
(E) Mountain I has experienced more erosion than Mountain II

28. Why is this rock hard?

(A) The Sun baked the material in the rock, causing the material to harden
(B) Water flowing over the material in the rock exerted pressure, causing the material to harden
(C) The material in the rock was buried, causing the material to harden
(D) Water mixed with the material in the rock, causing the material to harden

29. Which of the following can be caused by wind? **<u>Choose all that apply.</u>**

(A) Movement of tectonic plates
(B) Waves
(C) Earthquakes
(D) Mountain-building
(E) Erosion

30. Which of the following describes what scientists mean when they use the word “earthquake”. **<u>Choose all that apply.</u>**

(A) All earthquakes create visible cracks on the Earth's surface
(B) When an earthquake occurs, the earth shakes at least once every 10 seconds for a period of at least 1 minute
(C) All earthquakes damage man-made structures
(D) When an earthquake occurs, energy is released from inside the Earth
(E) When an earthquake occurs, the gravitational pull of the Earth increases

31. Which of the following are considered common mechanisms for weathering and erosion? **<u>Choose all that apply.</u>**

(A) Wind
(B) Rain
(C) Earthquakes
(D) Volcanoes
(E) Rivers

32. Which of the following responses best summarizes the relationship between volcanoes, large earthquakes, and tectonic plates?

(A) Volcanoes are typically found on islands and earthquakes typically occur in continents. Both volcanoes and large earthquakes occur near tectonic plates.
(B) Volcanoes and large earthquakes both typically occur along the edges of tectonic plates.
(C) Volcanoes mostly occur in the center of tectonic plates and large earthquakes typically occur along the edges of tectonic plates.
(D) Volcanoes and large earthquakes both typically occur in warm climates near tectonic plates.
(E) Volcanoes, large earthquakes, and tectonic plates are not related, and each can occur in different places.

33. Scientists have discovered fossils of four-legged creatures called dinosaurs. How much time passed between the appearance and extinction of these creatures?

(A) Hundreds of years
(B) Thousands of years
(C) Millions of years
(D) Billions of years
(E) Some of these creatures still exist

34. Where are volcanic rocks found?

(A) Mostly on islands or in the ocean
(B) Mostly near the equator
(C) Mostly on the edges of continents
(D) On islands, in the ocean, near the equator, or on the edges of continents only
(E) Almost anywhere

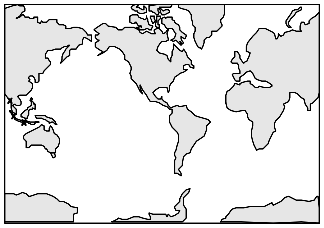
35. Why do tectonic plates move?

(A) The eruption of underwater volcanoes pushes the tectonic plates
(B) Currents in the ocean push against the tectonic plates
(C) Earthquakes push the tectonic plates
(D) Material is moving beneath the plates
(E) Magnetism moves the tectonic plates

36. Which one of the following is most closely related to events that cause large earthquakes?

(A) The construction and demolition of buildings
(B) Weather
(C) Bombs being dropped during a war
(D) Continents moving
(E) Changes in the Earth's core

37. The map below shows the position of the Earth's continents and oceans today. The gray areas represent land, and the white represents water. Which of the following best explains why the ocean basins look the way they do?



(A) Meteor impacts caused the ocean basins to form this way
(B) Ocean basins form as continents move
(C) The ocean basins formed in cracks that were created as the whole Earth cooled after its formation
(D) The ocean basins formed in cracks that were created as the whole Earth heated after its formation

38. Are rocks and minerals alive?

(A) Yes, rocks and minerals grow
(B) Yes, rocks are made up of minerals, and minerals are analogous to plant cells
(C) Yes, rocks and minerals are always changing
(D) No, rocks and minerals don't reproduce
(E) No, rocks and minerals are not made up of atoms

39. If you put a fist-sized rock in a room and left it alone for millions of years, what would happen to the rock?

(A) The rock would almost completely turn into dirt
(B) About half of the rock would turn into dirt
(C) The top few inches of the rock would turn into dirt
(D) The rock would be essentially unchanged

40. Some people believe there was once a single continent on Earth. Which of the following statements best describes what happened to this continent?

(A) Meteors hit the Earth causing the continent to break into smaller pieces
(B) The Earth lost heat over time and cracked, causing the continent to break into smaller pieces
(C) Material beneath the continent moved, causing the continent to break into smaller pieces
(D) The Earth gained heat over time and cracked, causing the continent to break into smaller pieces
(E) Only a small number of people believe there was once a single continent, and it is more likely that the continents have always been in roughly the same place as they are today

Appendix E: Interview Protocol

During the thirty minutes to an hour, I am going to ask you some general questions related to the TENNMAPS program and your learning and understanding of earth science. Please answer the questions as honestly and thoughtfully as possible. Your responses will be kept confidential. Unless you have an objection, the interview will be audio taped for the purpose of recording an accurate account of your responses. The audiotape will be secured in A404 Bailey Education Complex and destroyed after the transcription and analysis. Do you have any questions or concerns before we begin?

1. Do you consider yourself an earth scientist?
2. How important do you think it is for students to understand earth science concepts?
3. How confident overall do you feel in teaching earth science at this time?
4. What parts of earth science were easiest for you to understand? Why?
5. What parts of earth science were more difficult for you to understand? Why?
6. How often do earth science concepts change? Give examples.
7. How do you think your beliefs influence how you think about Earth Science?
8. Is it important to change what you believe after you learn more information?
9. When a science topic becomes difficult for you, what do you do?
10. Is there anything else that you would like to share with me?

Appendix F: Sample Interview Coding Sheet

Teacher: Jack (pseudonym) pg 1.

Line #	Integration	Differentiation	Exchange	Bridging	Textual Data
108	X				"As far as how you work that around your belief system is up to you"
152	X				"I've never had any trouble tying in concepts in science to my religious beliefs…"
156				X	"You see, any of these things I've learned in science information it just makes God a more dynamic and a more I guess, even a more powerful."
164-171				X	"So, I don't see why time should be a factor in Geology. I mean I don't understand why people have these problems with time limits, and you know, I can..there's very few parts of science that I have really studied that really conflicts or makes me doubt it because of my personal or religious convictions. I feel good about those and you know, especially when you look at DNA and things like that. You know, DNA, you know, if you share this huge percentage of DNA, I mean there's got to be a method in there. You know what I mean? So, I see it more as a method instead of dead ends and all this. Like a lot of people say I do believe this and I don't see why people have such a struggle with that."

Appropriation Mode: Integration

Open-mindedness: On the low end of open-minded overall…If the info can go along with his existing conceptions, then there really is no problem for him. If it conflicts too much he alters the new info until it conforms to his existing conceptions.

Teacher: Jack					pg 2.
Line #	Integration	Differentiation	Exchange	Bridging	Textual Data
173	X				"It all fits together to me and you know, I can combine all that together into my belief system."
200	X				"You know, because I have had instances where I've been convinced well maybe I'm a little bit wrong there, you know. And I need to adjust to that."
264-268	X				"If I construct something, I'm going to construct it a certain way and I'm going to make all the pieces fit. But, sometimes, you know, we put pieces in there that fit and we put it in there because they fit our theories. So, I like to go back and see if there's any alternatives and just sort of see where it goes."
Appropriation Mode:					
Open-mindedness:					

Notes/Summary

Teacher: Jack (pseudonym) pg 3.

Jack talks a lot about how he works new information that he is learning around what he already knows. He tries to fit the new pieces of information together with what he already knows about the content, or he fits it into a knowledge framework that is similar. He also states that nothing he has learned really conflicts with what he already knows and believes. This absence of conflict makes it easy for him to fit everything together. However, it there is some drastic differences or there seems to be some amount of conflict between his existing conceptions and the new information, he will alter either the new information or perhaps his existing knowledge. His insistence that he has no problem with new and potential information because it only reinforces what he already knows gives some insight into his low degree of open-mindedness. He talks about adjusting information to make the pieces fit together.

Jack specifically talks about geologic time. He says he doesn't see why people "have a problem with it." He says it highlights and reinforces patterns in the conceptions that he already has and will use his existing conceptions as a way to develop some type of understanding out of the new information. He describes this situation several times. The way he describes this situation in coordination with "fitting" new information in with his existing conceptions falls within a bridging appropriation pattern. As such Jack primarily integrates his existing conceptions with new information and using bridging help him do it. He uses bridging as a secondary mode of appropriation.

Appendix G: Case Summary Example

Cindy

Introduction. Cindy originally began her teaching career as a health/physical education teacher at the K-5 level. After a few of years teaching health and P.E., she moved into the general education classroom where she taught science for kindergarten through fifth-grade. Prior to the program, she taught first-grade. Cindy moved up to fifth-grade the school year when she was in the program. In total, she had sixteen years of teaching experience. Cindy has a bachelor's degree in elementary education and a master's degree in education. In addition, she attended all three years of the TENNMAPS programs.

Cindy's earth science and geology content exposure has been minimal. She reported that the only earth science course she has had other than the TENNMAPS workshops was a course in the 9th grade. She reported no earth science or geology coursework during her college education. However, she did complete four biology courses during her undergraduate training.

Appropriation of Prior Knowledge & Conceptions. Cindy describes a differentiation process as she negotiates controversial topics and her prior knowledge and conceptions. During our discussion about beliefs and knowledge and how these might affect one another during learning, Cindy began talking about the big bang theory and the creation of earth. She expressed she does not believe the current big bang theory is the correct description of how earth was created. Cindy offers her perspective on the big bang. She regards what she knows about the creation of earth as completely separate from what the current scientific theory states. She has differentiated her conceptions from those of the scientific community pertaining to the creation of earth. The evidence of differentiation can be seen when she describes how she teaches the big bang theory to her science students.

Researcher: “How do you think your beliefs influence how you think and understand…think about earth science?”

Cindy: “You mean like if I think the big bang theory and stuff like that?”

Researcher: “Sure.”

Cindy: “I don’t believe in that…I do when I teach it. I just teach this is a different theory and most of my kids believe that God created the heavens and the earth, and I see it and so, I’ve never had anybody say, well you know, that’s stupid. I just tell them it’s a different theory of how the earth was created.”

Researcher: “So, you presented in different…”

Cindy: “Yes…This is how I think it was created. I think that God created the heaven and earth, but this is a man’s theory of how they thought it came about.”

Researcher: “The big bang?”

Cindy: “Yes.”

Researcher: “So, you’ve got the two and you present them and you let them…”

Cindy: “Decide and form their own belief.”

Researcher: “Okay. So, you think that …Do you think that beliefs, though, influence the way you understand it?”

Cindy: “Probably. I think, well you know, I’ve always been taught that evolution’s a no-no, you know, and really I did...”

Researcher: “Okay.”

Cindy: "But again, I throw out that this is another theory of how heaven and earth is created other than the Biblical theory."

Cindy works to differentiate the two sets of competing conceptions. Differentiation allows her to set boundaries around each conceptual framework. By establishing boundaries, she can utilize the information in a specific way and at specific times that she sees as appropriate. For example, Cindy admits she believes the current theories about the big bang theory when it is necessary; "I don't believe in that [the big bang theory]…I do [believe in the big bang theory], when I do teach it…" Even though she maintains the two conceptions completely separate, she understands their basic premise and their relationship.

Cindy provided some information that made it appear she might be integrating new information into existing knowledge and conceptions, and this was seen when we discussed how someone's beliefs about a natural phenomenon might change as a result of learning new information. However, Cindy's integration is only circumstantial and merely appears as if it is happening. She ultimately keeps the two competing conceptions separate and calls upon them when necessary. Her "integration" attempt is actually a bridging effort.

Researcher: "…Is it important to change what you believe after you learn more information?"

Cindy: "Oh yeah. I mean, why teach something when you know there's a better way, you know?"

Researcher: "So, there's some facts that supported, and so this is…?"

Cindy: "Yes"

Researcher: “What about the way you believe? You mentioned things like creation and evolution, and so as they get more information about evolution…”

Cindy: “Well, it’s just like [program presenter] said, it’s not who created it, but how.”

Researcher: “But how?”

Cindy: “Yeah. These changes.”

Researcher: “Right, so you are looking at it’s just a system. You have to look at it from that perspective. Not a …in that case, not a who thing but a what thing?”

Cindy: “Yeah, and how.”

Knowledge or information integration for Cindy in this situation occurs by bringing her prior knowledge frameworks together with the new information. The new information then allows her to further refine her prior knowledge, but with no significant changes to her core knowledge. This will potentially allow her to answer new and old questions pertaining to the creation of earth and evolution through whatever theoretical process being applied and can apply that information at the right time and in the right venue.

Thinking Disposition/Open-mindedness. Cindy scored a 97 on the Actively Open-minded Thinking Scale (AOT). The composite score for the AOT gives an overall assessment of the open-mindedness of an individual. Cindy’s score of 97 indicates she is moderately open-minded. A moderately open-minded individual would have the disposition to possibly consider alternate ideas and new information but might not alter their existing conceptions in a way that indicates a strong conceptual change process. Cindy exhibited some open-minded tendencies, but for the most part tended to be relatively dogmatic regarding the primacy of her prior knowledge and conceptions regarding the big bang and evolution. These characteristics reveal a relatively low level of open-mindedness.

Information from Cindy's interview revealed her low level of open-mindedness. First, when considering the big bang theory, Cindy flatly dismisses it by expressing "I don't believe that." In addition, she discounts the theory further by stating that "I just teach this is a different theory…" However, it might be said that she does exhibit some moderately open-mindedness because she gives the big bang theory some consideration when teaching it to her students by providing it as an alternative theory for explaining the creation of earth. The only example of any potential moderate open-mindedness can be seen as she talks about changes in prior knowledge and beliefs as one learns new information.

Researcher: "…Is it important to change what you believe after you learn more information?"

Cindy: "Oh yeah. I mean, why teach something when you know there's a better way, you know?"

Researcher: "So, there's some facts that supported, and so this is…?"

Cindy: "Yes"

Researcher: "What about the way you believe? You mentioned things like creation and evolution, and so as they get more information about evolution…"

Cindy: "Well, it's just like [program presenter] said, it's not who created it, but how."

Researcher: "But how?"

Cindy: “Yeah. These changes.”

Researcher: “Right, so you are looking at it’s just a system. You have to look at it from that perspective. Not a …in that case, not a who thing but a what thing?”

Cindy: “Yeah, and how.”

In this situation, Cindy sees an opportunity to reconcile scientific information regarding the big bang theory and evolution with her existing conceptions of these processes. This situation presented itself in a presentation/discussion during the workshop about evolution and the fossil record. As a result, Cindy exhibited that she was open to new ideas about these concepts. However, she did not alter her core set of prior conceptions or beliefs about the origins of life and evolution. Instead, she worked to bridge the information about the mechanisms of creation and evolution into her existing knowledge frameworks. This is an example of bridging appropriation. For special circumstances Cindy will potentially use bridging appropriation to assist with her primary appropriation mode.

Geoscience Content Knowledge and Geologic Time. Cindy has a minimal amount of geoscience content knowledge as evidenced by her performance on the GCI. On the pre-assessment, she only answered six of the forty questions correctly. For the post-assessment, she answered twelve of the forty questions correctly. However, she did experience a 100% increase in the number of questions answered correctly from the pre to post administration of the assessment.

Regarding geologic time, Cindy’s level of content knowledge is severely deficient. She did not answer any questions correctly during the pre assessment, and only answered two questions correctly during the post-assessment. The two questions answered correctly on the post-assessment focused on two different aspects of geologic time. One pertains to how long certain geologic processes take to occur, and the other involves the relationship between how long different living things, including humans, have been on earth. Since the two questions did not assess the same concept within geologic time, and given the fact that the questions were multiple-choice, it can be speculated that Cindy simply guessed correctly for these two questions.

Summary. Cindy displays a Differentiation appropriation. She differentiates her existing geologic time conceptions from any new conceptions to build two discrete sets of conceptions. Cindy states that in doing so, she can use the appropriate conception as needed. She reconciles any conflict between her existing conceptions and any new conception by altering how she perceives a phenomenon, such as the Big Bang. She accomplishes this via a Bridging mechanism and gave the example of reassigning the Big Bang as a tool used [by God] to create the universe instead of the Big Bang being the “what” that created it. By using the primary appropriation mode of differentiation and the secondary appropriation mode of bridging, Cindy is a bimodal appropriator.

Appendix H: Interview Text Data Tables

Table H1

Angela Interview Text Data*

Appropriation Code	Text
Integration	"You know, if you learn new information that challenges what you believed all of these years and you're going to change your belief system or you're not going to accept it as these changes. You're going to adjust one way or the other."
Integration	"So, for instance whether you believe in creationism versus evolution or if you have a belief where intertwines both of them that's going to influence how you view concepts of Earth science."
Integration	"You're going to adjust one way or the other"

*Pseudonym

Table H2

Ben Interview Text Data*

Appropriation Code	Text
Differentiation	"…they can accept a concept as a concept and it contradicts what they believe or what they have been taught, they can separate [or] distinguish between that."
Differentiation	"I believe you have to, for me, I believe that you have to separate things. You know I just don't take hold of anything because there are so many different views out there. And I think that is what we have to do as far as keeping an open mind and spiritually…"
Differentiation	"But, at the same time, I feel like, you know, those two things are separate. And, those things in order and I actually not long ago read a quote, that I agreed with a 100%, didn't agree with everything that this in particular individual said, in their article, but I did agree with the point…that for in order for both of those things to flourish, they have to be separate for one or the other."
Differentiation	"I try not to intertwine a lot of things…"
Differentiation	"The major concepts that we all know, that's you know, evolution, theories of creation and things like that. I know those theories are out there, and you know I feel like personally that I benefit from knowing them. I don't feel that they have corrupted me."

*Pseudonym

Table H3

Beth Interview Text Data*

Appropriation Code	Text
Differentiation	“I’m the type of person that, you know, throw anything out at me and I’ll probably just go through and sometimes see what applies to me. So, I kind of keep them separate. It is more defined for me. That’s my comfort zone with it I guess. But, there's some myths, I guess, out there that we've all heard or seen or been taught. But, as far as my beliefs in science and religion it's very deep, you know. And, I think sometimes people get confused about things like that, so I kind of keep them separate.”
Differentiation	Beth: It's more defined for me. That's my comfort zone with it, I guess. *Researcher: “Keep these well defined boundaries around them…”* Beth: “Yes”
Differentiation	“Because, I don't like to live in the muck. I like to define it in some way. It's my personal decision about what I make about it. But, it's the one I have to live with. So, that's how I work with that.”

*Pseudonym

Table H4

Carrie Interview Text Data*

Appropriation Code	Text
Differentiation	"…you give each one of the theories equal time."
Integration	"It doesn't bother me to sit down and go through these things. But, it all falls into a pattern, and it's really not all that hard to understand."
Integration	"Well, over here we have the fossil record. It's here and in with the way I feel about it, I know that it was here and it's all part of maybe a mystery and things to be found and discovered. And different people think about it different ways and they interpret it different ways. But, it all falls into a pattern and it's really not all that hard to understand."
Integration	"I don't really separate the two. For me it's easy. I mean it kind of all flows together."

*Pseudonym

Table H5

Cindy Interview Text Data*

Appropriation Code	Text
Differentiation	"I don't believe in that [Big Bang Theory]. I do when I teach it. I just teach this is a different theory…it's a different theory of how the earth was created."
Differentiation	"This is how I think it was created. I think that God created the Heaven and Earth, but this is a man's theory of how they thought it came about."
Differentiation	"But, again, I throw out that this [Big Bang Theory] is another theory of how Heaven and Earth is created other than the Biblical theory."
Bridging	"Well, it's just like Mike said, it's not who created it, but how."

*Pseudonym

Table H6

David Interview Text Data*

Appropriation Code	Text
Integration/Bridging	"If you think about your science knowledge as a house…and the foundation has to be true or everything else up above it is not right, so you start out with a good fact-based foundation…but sometimes as you're building a house you find that something is off a little…sometimes we have to go back and adjust things."
Exchange/Bridging	"Sometimes some things [are] off, and for me to get this house of knowledge the way that we want it to be, we may have to tear down and build it back."

*Pseudonym

Table H7

Hallie Interview Text Data*

Appropriation Code	Text
Differentiation	"I want to just take the information for what it is and put it together."
Differentiation	"I try not to let any sorts of religious or superstitious or anything like that affect what I see. I see it and when and if I see it is true, it is true, and so a belief, as far as that goes, that would not affect my science at all."
Exchange	"I mean, if I'm convinced that something else, if I get enough facts of what I believed is incorrect, then sure, I'll change it."

*Pseudonym

Table H8

Jack Interview Text Data*

Appropriation Code	Text
Integration	“I’ve never had any trouble tying in concepts in science…”
Integration	“It all fits together to me, and you know, I can combine all that together…”
Integration	“I have had instances where I’ve been convinced well maybe I’m a little wrong there, you know, and I need to adjust to that…you got to be willing to modify the way you think about things…I’m going to make all the pieces fit.”
Bridging	“You see, any of these things I've learned in science information it just makes God a more dynamic and a more, I guess, even a more powerful. So, I don't see why time should be a factor in Geology. I mean I don't understand why people have these problems with time limits.”
Bridging	“In other words, I've never...the things we've been talking about up here during this two week, none of those offend my religious perspectives. I just say, you know, I think sometimes people will put God into a real small box, you know. So, I don't see why time should be a factor in Geology.”
Integration	“If I construct something, I'm going to construct it a certain way and I'm going to make all the pieces fit. But, sometimes, you know, we put pieces in there that fit…we put [it] in there because they fit our theories. So, I like to go back and see if there's any alternatives and just sort of see where it goes.”

*Pseudonym

Table H9

Kathy Interview Text Data*

Appropriation Code	Text
Bridging	"You know, I think if God intended for mountains to be made then He made the Earth to make mountains through pressure and all that. And so, I guess I see it as confirmation of what I believe, not a contradiction."
Integration	"I do wish that sometimes we could maybe… I know there are scientists that have a firm grip on a divine creator and the way the Earth is and I think what would be wrong with bringing those two things together. I think society is afraid to do that, and I think when we finally…just continue to keep proving those things over and over again, I think. I think they could be meshed."
Bridging	"I just think you have to be more open to how creative God was and that He's a lot more powerful than we give Him credit for and so I don't think there will be a conflict or contradiction."
Integration	But again, my mind is open to believe that if God decided to do it that way then okay I accept that.
Bridging	"Now, I guess the part where I have the conflict is leaving Him out. You know, if you leave out that, you know, where did all this stuff come from in the beginning, something had to…and we as human beings understand that most…well, I think, everything that complex has to have something that designs it and I just, you know, I think it's, like I said, it's going to affirm and confirm."

*Pseudonym

Table H10

Kim Interview Text Data*

Appropriation Code	Text
Differentiation	“You know, theories give me problems. I still teach them just from the reading, and you know, the info but I don't ever teach it as fact. I just say that this is another theory and I go through it because I don't see it, you know, it's not tangible.”
Bridging	“A lot of the science is itself just kind of strengthens my belief in God and you know, His creation and everything. I think that to be so huge I think that it just, you know, reinforces that God did this all. Dinosaurs, for example. I mean it talks in the Bible about the behemoth.”
Bridging	“I mean I just think it's all tied in in some way, you know, not to know exactly when or how and I think that like Biblical time like the seven days. We don't know how long a day may have been at that time. It may have been years. So, I think it all ties in. I just don't know how.”
Bridging	“Not that I would not believe God created everything but the processes that may have occurred.”

*Pseudonym

Table H11

Laura Interview Text Data*

Appropriation Code	Text
Differentiation	"We kind of do both. You know, we talk about that, talk about the Bible point of view and in certain terms. Then I just tell them it's a theory. I mean, really it's based on things that they think, you know, this is how it's happened. But, that's not necessarily, you know, true."
Differentiation	"From a teacher's point of view, yes [regard both Big Bang and Creation as confirmed theories]. Not really personally. But, I try not to bring my personal thoughts in to it even if they ask me. I just kind of move to something else."
Differentiation	"I don't really know. I know I have my beliefs and some of the things I've learned that I've heard all through elementary school growing up and I don't know it's just kind of like I have two different view points but they don't merge."
Differentiation	"I don't know. It's kind of like I believe…kind of believe in both and maybe I try to put it together but I know that certain things don't fit. But, still I believe in those things."

*Pseudonym

Table H12

Lois Interview Text Data*

Appropriation Code	Text
Differentiation	“I don’t buy into this whole millions and billions of year time frame and I would like to see how that falls into a more, I guess church based time frame. I’ve mentioned that in class and I have students that mention that….”
Differentiation	“I do. I do. [Regard Big Bang and Creation as separate ideas] And so this is you know….a certain group of people think that it is like this…and a certain group of people think it is like this…and you know you can have the conversation….well, which one do you think and why.”
Differentiation	“Basically, all I have said about that in my class, is that you know, this is two different theories that are presented and this is what one says and this is what the other says, and we have had a discussion.”

*Pseudonym

Table H13

Rena Interview Text Data*

Appropriation Code	Text
Bridging	"I think most of science just re-enforces my beliefs."
Bridging	"I think so. Just because they can explain or they think their theory of how the world was made, does not take anything away from the bible to me. It is just, well, that might be how it happened, but they can't do that. You know they can't re-create that. It is just affirming to me, it is just reaffirming that well, they understand more of how it happened, but it doesn't take away from who started it."
Integration	"I don't see a conflict. I think you can [mesh/integrate]. I remember in high school biology, you know our teacher, of creation told the big bang theory and he read from the bible.
Integration/Bridging	"Um….right. I mean. I do. That is the core that is that absolute truth to me. I do compare it. Like evolution. [she compares it to what she already knows] That has been, I mean of course we have evolved, we don't look the same as we did at the beginning…but, you know, yeah I do compare everything to that, I guess."
Integration/Bridging	"I know some people do have a problem with the age of the earth and I am just thinking, wow, if it was created in 7 days, his time table is not the same as ours and even if he did, I mean, he probably didn't start. He could create things with age, you know what I am saying, He didn't probably put a little seed tree or whatever, but created something with maturity. I don't…That is not a problem to me about how old something is."

*Pseudonym

Table H14

Sonya Interview Text Data*

Appropriation Code	Text
Integration	“It doesn't bother me at all. I enjoy listening to other things but I will think about it but I come back to what I know from me, from everything that I know and that's what I believe.”
Integration	“Yes, yes it is [what a person already knows and believes] and it is like I'll hear other things or learn about other things but I always test it through what I believe, what I already know, you know. I know that's what we have a saying, I know that I know that I know and I'll test it through that to see if it's something I want to think about or something I can add to my belief system or something that I just discard.”
Integration	“Well, as I said, I just listen, you know, I don’t want to ever tell anybody, ‘Oh, you wrong.’ I don’t want to listen to what someone else has to say so I listen but after I have run it through and I get my belief…They thought the world was flat; that was a theory. So, I teach that this is a theory and so when they say on movies and our text or whatever we’re reading billions or millions and millions of years, I just say that we replace that with many, many, you know. If you have trouble listening to that in your mind you can say many, many years ago.”

*Pseudonym

Table H15

Will Interview Text Data*

Appropriation Code	Text
Differentiation	“They don’t influence it at all. I don’t…I do my best to keep it separate.”
Differentiation	“…and you can separate both, and I try to explain it to kids [that] you can believe in the science and you can have both.”

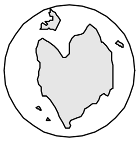
*Pseudonym

Appendix I: Geologic Time Questions from the GCI

1. Some scientists claim that they can determine when the Earth first formed as a planet. Which technique(s) do scientists use today to determine when the Earth first formed? **<u>Choose all that apply.</u>**

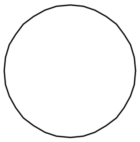
(A) Comparison of fossils found in rocks
(B) Comparison of different layers of rock
(C) Analysis of uranium and lead in rock
(D) Analysis of carbon in rock
(E) Scientists cannot calculate the age of the Earth

6. What did the Earth's surface look like when it first formed?



A

A. One large landmass surrounded by water

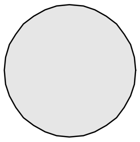


B

B. All water and no land

C

C. Similar to today



D

D. Mostly molten rock and no water

E

E. We have no way of knowing

3. If the single continent in #40 did exist, how could scientists estimate the time needed for the single continent to break apart and form the arrangement of continents we see today?

(A) Scientists do not yet have a valid method for estimating the time needed to break continents apart.
(B) Through comparison of fossils found in rocks
(C) Through analysis of carbon in rock
(D) Through analysis of uranium and lead in rock
(E) Through comparison of different layers found in rocks

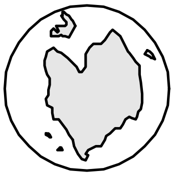
4. Which technique for determining when the Earth first formed as a planet is most accurate?

(A) Comparison of fossils found in rocks
(B) Comparison of different layers of rock
(C) Analysis of uranium and lead in rock
(D) Analysis of carbon in rock
(E) Scientists cannot calculate the age of the Earth

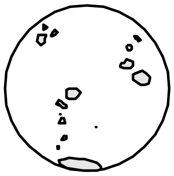
17. The figure below is a view of one-half of the Earth's surface as seen from space today. The gray areas represent land, and the white represents water. Which of the other figures do you think most closely represents this half of the Earth's surface when humans first appeared on Earth?

Circle one: **A** **B** **C** **D**

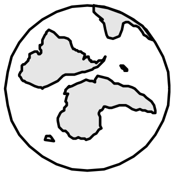
A



B



C



D

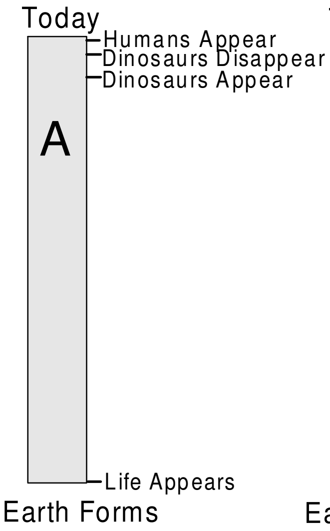
If you could travel back in time to when the Earth first formed as a planet:

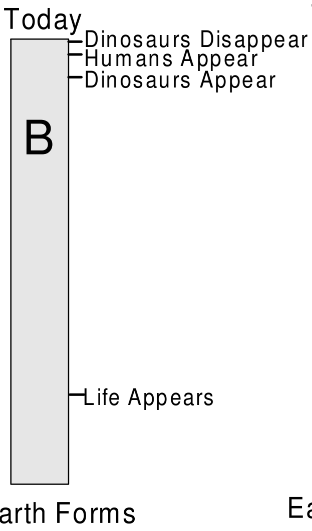
18. What type(s) of life do you think you might encounter?

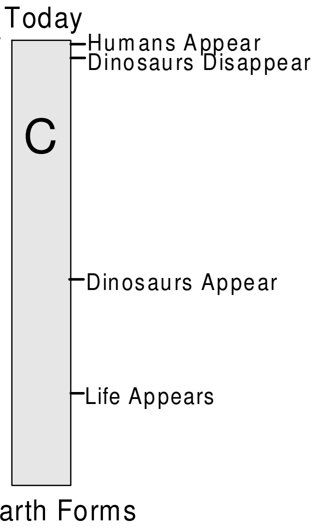
(A) There would be no life on Earth
(B) Simple, one-celled organisms
(C) Animal and plant life in water, but none on land
(D) All types of life in water and on land, except people
(E) All types of life in water and on land, including people

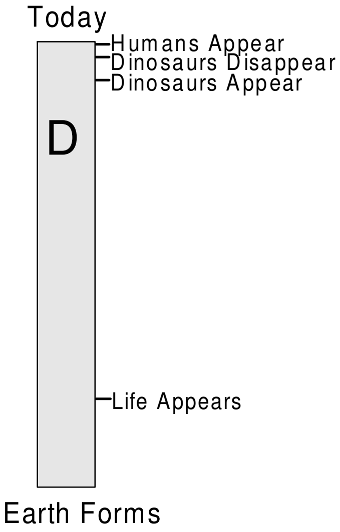
19. Which of the figures below do you think most closely represents changes in life on Earth over time?

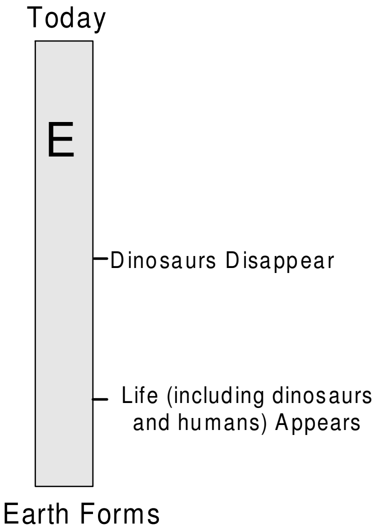
Choose one: **A** **B** **C** **D** **E**











23. Which of the following statements do you think best describes the relationship between people and dinosaurs?

(A) People and dinosaurs co-existed for about five thousand years
(B) People and dinosaurs co-existed for about five hundred thousand years
(C) Dinosaurs died out about five thousand years before people appeared on Earth
(D) Dinosaurs died out about five hundred thousand years before people appeared on Earth
(E) Dinosaurs died out about 50 million years before people appeared on Earth

24. If the single continent in #40 did exist, how long did it take for the single continent to break apart and form the arrangement of continents we see today?

(A) Hundreds of years
(B) Thousands of years
(C) Millions of years
(D) Billions of years
(E) It is impossible to tell how long the break up would have taken

25. A scientist collects all of the fossils ever discovered into one room. This room now contains:

(A) Fossils of a few of the plants and animals that ever lived
(B) Fossils of most of the plants and animals that ever lived
(C) Fossils of most of the types of plants and animals that ever lived
(D) Fossils of all of the plants and animals that ever lived
(E) Fossils of all of the types of plants and animals that ever lived

33. Scientists have discovered fossils of four-legged creatures called dinosaurs. How much time passed between the appearance and extinction of these creatures?

(A) Hundreds of years
(B) Thousands of years
(C) Millions of years
(D) Billions of years
(E) Some of these creatures still exist

Appendix J: Analysis of the Complete Geoscience Concept Inventory (GCI)

The average number of questions answered correctly for the cumulative pre-GCI was 20, the post-GCI equaled 22, and the post-post-GCI a 21. The number of correctly answered questions ranged from 6 to 30, 12 to 30, and 6 to 31 for the pre, post, and post-post-GCI respectively (Table A). Paired or repeated measures t-Tests between the three administrations of the GCI showed that the mean scores were significantly different between the pre and post administration, $t(14) = -2.814$, $p = .014$, $r^2 = 0.32$, but not between pre and post-post, and post and post-post (Table B). The effect size for the significant t-Test between pre and post was large for both r^2 (0.32) and Cohen's d (0.73). Even though there was only an increase in two questions answered correctly on average between the pre and post administrations, some of the teachers experienced substantial gains (Table A). For example, Cindy experienced a 100% increase in the number of questions answered correctly. In addition, 8 of the 15 teachers experienced a 20% or greater increase in the number of correctly answered questions.

The reduction of teachers' geology content knowledge over time may not be a unique phenomenon. This situation has been observed regarding other science content. Trundle, et al (2007b) observed the same phenomenon for moon-phase concepts among pre-service elementary teachers that attended a specially designed course and then were assessed again several months later. However, in this current study the teachers attended four follow-up sessions throughout the year subsequent to the ten-day sessions that were designed to refresh, support, and expand their geosciences content knowledge. In addition, the follow-up sessions provided pedagogical instruction related to the content focus for each day. In Trundle, et al's (2007b) study, the pre-service teachers did not receive any further instruction after their exposure to the content in the class. The authors noted that a certain degree of loss of content knowledge is to be expected.

Table A

Number of Questions Answered Correctly on the Geoscience Concept Inventory (GCI)

Teacher*	Pre - GCI	Post - GCI	Post-Post - GCI
Angela	21	24	18
Ben	23	21	22
Beth	8	12	6
Carrie	20	24	23
Cindy	6	12	13
David	23	21	21
Hallie	30	30	31
Jack	22	27	25
Kathy	21	27	-
Kim	26	24	22
Laura	12	15	16
Lois	19	17	21
Rena	22	27	25
Sonya	15	18	20
Will	28	30	30
Average	20	22	21

*Pseudonym

Table B

Paired Sample t-Test for Correctly Answered GCI Questions

Pair	Mean	Std. Deviation	t	df	Sig. (2-tailed)*
Pre-Program To Post Program	-2.200	3.028	-2.814	14	.014*
Pre-Program To Post-Post Program	-1.286	3.245	-1.483	13	.162
Post Program To Post-Post Program	.643	2.818	.845	13	.409

*$p < .05$

VITA

James Harold Roberson was born in Jacksonville, Florida on April 1, 1967. After his father retired from the Navy, his family settled in eastern middle Tennessee. He graduated from Cookeville High School in 1985. He graduated from Middle Tennessee State University with a bachelor's degree in biology with a minor in chemistry in 1991. He subsequently completed a master's degree in biology at Tennessee Technological University in 1994. While at TTU, James completed research involving the effects of heavy metals on testosterone production in cultured tissues.

James spent several years in industry working in research and development for Identity Group, Inc. He was involved in basic and applied research on polymeric open-celled foam structures. In addition, he would accept interim management roles for the company.

In 2002 James decided to leave industrial chemistry and return to academe. First, James completed his licensure to teach secondary science (biology and chemistry) in the State of Tennessee. He taught chemistry at White County High School from the 2003 to 2004 school year. In the summer of 2004, James accepted a full-time tenure track position to teach introductory biology and anatomy & physiology courses at the Livingston campus of Volunteer State Community College. Within a few semesters at Volunteer State, James added microbiology and fundamentals of chemistry to the list of courses he taught.

James left the position at Volunteer State in May of 2007 to pursue doctoral studies in the Department of Theory & Practice in Teacher Education at The University of Tennessee. He was supported by a research assistantship through the TENNMAPS Math and Science Partnership granted to Dr. Michael Clark and William Deane in the Department of Earth & Planetary Sciences.

In January of 2010, James returned to Volunteer State Community College in Livingston full-time. He has resumed teaching the same array of courses. In addition, James maintains the science laboratory for the Livingston campus.